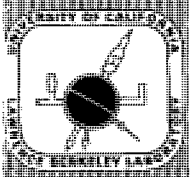
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Proceedings of the International Conference on Nuclear Physics

August 24-30, 1980 Berkeley, California

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Abstracts

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Volume 1
Abstracts

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PREFACE

This volume contains all of the abstracts received before June 20, 1980. Those received by the deadline of April 23, 1980 were considered by the program committee for oral or poster session presentation at the conference. The abstracts are grouped by conference topics, and a complete author/page number index is provided after the abstracts.



This logotype, designed for the
1980 ICNP, represents E. O. Lawrence's
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FEW-NUCLEON BINDING ENERGY CORRELATIONS

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The effect of strongly linear few-nucleon binding energy correlations under variation of the potential originally established by Tjon[1] in the four-nucleon case has been previously found by the authors[2] also in the three-nucleon case. A linear correlation $E_T = \text{const} \cdot E_d$ was found under variation of the potential coupling parameter starting either from nearly energy-dependent three-body form factors or from the range condition; i.e., the assumption of a long range of the potential compared with the range of the free propagator at $E = E_d$ which holds for realistic choices of parameters. Here we want to give the extensions:

i) The range condition causes weakly energy-dependent three-body form factors thus unifying our two approaches.

ii) In zero-order the range ratio γ was set 0 yielding $|E_T| = \frac{1}{\alpha^2} |E_d|$ with $\alpha = \text{const}$ in the order of magnitude 1. Taking into account a first-order correction $0 \neq \gamma \ll 1$, one finds

$$|E_T| = E_T^0 + E_T^1 \quad , \quad E_T^0 = \frac{1}{\alpha^2} |E_d|$$

$$|E_T^1 / E_T^0| = \gamma / 2\alpha \ll 1.$$

That means the greater the range of the potential, the smaller is E_T^1, the deviation from the zero-order result. This is confirmed by the comparison of separable Gauss and Yamaguchi two-body potentials. The Gauss form factor has an effective range β_{Gauss} determined from the falloff behavior in the region $|\vec{q}| < \sqrt{m|E_d|}$ and fulfills $\beta_{Gauss} > \beta_{Yamaguchi}$. Thus $E^1_{TGauss} < E^1_{TYamaguchi}$ which can be read off the d-t and t-α case).

iii) Our former results derived for separable rank one two-body potentials V can be generalized to any $V(\vec{q}', \vec{q})$ which varies little in the region $|\vec{q}'|, |\vec{q}| < \sqrt{m|E_d|}$ and falls off smoothly.

*NATO Fellow from Justus-Liebig-Universität, Giessen, West Germany.

†Research sponsored by the Division of Basic Energy Sciences, U.S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation.

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EFIMOV PATHOLOGY IN CLUSTER MODELS

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Some time ago, Efimov[1] discovered that if the pair interaction becomes sufficiently resonant, the number of bound states of a three-particle system increases without limit. As an application of the effect, the existence of the level in ^{12}C with excitation energy 7.65 MeV could be understood at least qualitatively in terms of a three-particle system with resonant pair interaction of the α particles in the s-state (the resonance is the ground state of ^{8}Be). In recent attempts[2] the possibility has been investigated to describe the vibration-rotation structure of molecular spectroscopy using Efimov's effect in the special limiting case with two heavy and one light particle. But all these considerations had been restricted to three-body systems, because in the general integral equations approach to few-body problems, there is no such pathology for $n \geq 4$, as emphasized by Amado and Greenwood[3]. In contrast to these investigations, we applied to the full four-boson integral equations a twofold separable approximation and arrived at effective two-body equations by introducing suitable unitary pole approximations[4] which, in particular, take into account two-body and three-body bound-state clusters by incorporating their wave functions. We have shown[5] that with the help of a carefully chosen position space cutoff parameter r_0, which enables us to vary the range of the effective potential in the three-particle subsystem, the number of four-body bound levels in the 0^+ state goes with $N \approx k \cdot \ell n(\varepsilon a)$ and $2/3\pi \leq k \leq 1/3$, when r_0 decreases to a particular value r_E for which the scattering length a of the two-body system and a third particle tends to infinity (ε is a momentum cutoff). Furthermore, there are indications that this effect survives for $n > 4$ if the complexity of the n-body equations is reduced by successive separable approximations of the subsystem amplitudes. So we are optimistic that also in a four-body bound-state cluster model the cutoff parameter-induced appearance of a family of 0^+ levels will turn out to be an appropriate tool in the analysis of empirical data, especially of nuclear reactions.

*NATO Fellow from Justus-Liebig-Universität, Giessen, West Germany.

†Research sponsored by the Division of Basic Energy Sciences, U.S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation.

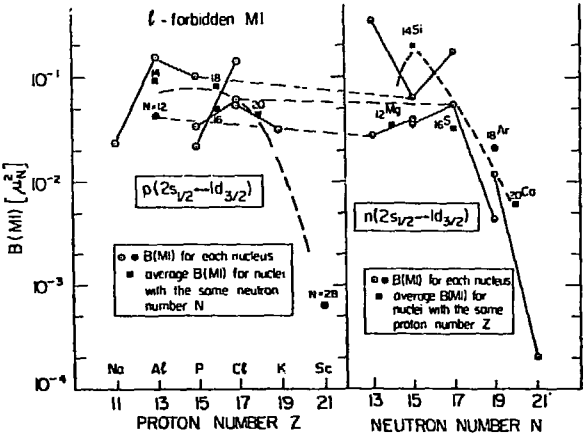
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CORE POLARIZATION FOR ℓ-FORBIDDEN M1 TRANSITIONS IN LIGHT NUCLEI

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The study of M1 transitions between shell model states with $\Delta l = 2$ in heavier mass regions [1]) reveals a pronounced dependence on shell effects with a strange behaviour in the vicinity of ^{208}Pb. Now, first results from a systematics in light nuclei are presented.

Approaching nucleon numbers Z, N = 20 a decrease of the B(M1) values is expected since the probability for first-order core polarization decreases approaching a LS-closed shell. However, the B(M1) strength in ^{39}K (one proton hole in the ^{40}Ca core), where first order core polarization is exactly forbidden appears surprisingly high, very similarly to that in ^{207}Tl (one proton hole in the ^{208}Pb core). Obviously, further studies in terms of core polarization and pion exchange are necessary to understand this systematics. Also, new experiments (e.g. in the unclarified case of ^{41}K) would be of interest.



Transitions in mirror nuclei turn out to have within the experimental errors the same B(M1) strength (^{25}Al and ^{25}Mg, ^{29}P and ^{29}Si, ^{33}Cl and ^{33}S; in the figure the corresponding points are connected). This fact might appear unusual as the odd proton is expected to polarize the core in a different way than the odd neutron does. Quantitative considerations using a δ-force show, however, that this behaviour can be nicely understood by the predominant isovector M1 polarization neglecting the much weaker isoscalar excitation.

*On leave from Institute of Nuclear Research, 1113 Sofia, Bulgaria.

†Supported in part by the National Science Foundation.

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REGULARITIES IN THE CHARGE DEPENDENCE OF NUCLEAR FORCES

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Coulomb effects in nuclei are believed to offer the possibility of separating the known Coulomb interaction from the ambiguities of the nuclear wavefunctions and thus to enable us to extract specific information regarding the nuclear wavefunction[1]). Considerable attention has been devoted therefore to the interpretation of charge dependent effects in nuclei.

Some charge dependence of nuclear forces arises from meson exchange forces. In heavier nuclei, an additional source of charge dependence exists. This part is connected with a mechanism which reflects general properties of the nuclear structure[2,3]). Qualitatively, it can be explained[4]) by the effective charge dependence of nuclear forces which arises from the coupling of the discrete states to the continuum. This effective charge dependence leads to a charge dependent energy shift not only of decaying states but also of bound states. Furthermore, it determines the widths of isospin forbidden decays.

The numerical calculations on the basis of the continuum shell model[5]) have shown[4]) that the charge-dependent effects in nuclei depend very sensitively on the channels and the position of their thresholds. Shell effects in the charge dependence appear via the distinguished parentage structure of the ground state of the nuclei just beyond the shell closures relative to the energetical lowest channel. The odd-even effect in the Coulomb displacement energy as well as the fact that the neutron decays of the lowest $T = 3/2$ levels of the $A = 4n+1$ light nuclei are always faster than the analogous proton decays are shown to be connected with the $A = 4$ regularities in the binding energy.

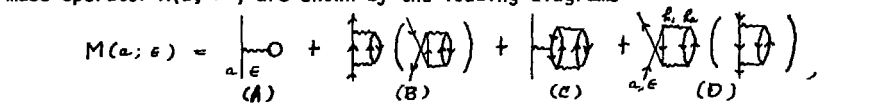
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SINGLE PARTICLE SPIN-ORBIT SPLITTING (I)
—Two-Body Force Contribution—

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The single-particle (sp) spin-orbit (so) splitting Δ_{so} in ^{16}O and ^{40}Ca is evaluated microscopically within the framework of the effective interaction theory along with the double-partitioning approach. Basic ingredients of the mass operator $M(a;\epsilon)$ are shown by the leading diagrams



$$T_a + M(a;\epsilon) = \epsilon \quad (SC)$$

In the Brueckner sp energy (A), the 2-body LS part of the G-matrix contributes to Δ_{so}. (B) is essentially the low-lying counterpart of (A). (C) and (D) are the starting-energy- and Pauli-rearrangement contribution, respectively. (D) increases Δ_{so}, while (B) and (C) reduce it. Self-consistency (SC) requirement gives another reduction of Δ_{so}. Negative contributions (B), (C) and (SC) to Δ_{so} cancel out the positive contribution (D), giving the net Δ_{so} even smaller than that from (A).[1]

In view of the importance and peculiar Antisym. LS nature of the Pauli-rearrangement (D)=$M_p(a;\epsilon)$, we restudy it by taking an intermediate particle spectrum more appropriate than the QTQ spectrum adopted previously. We take Green's operator $Q/(Q(T+U)Q)$ ($\omega = \varepsilon_k + \varepsilon_{k'} - \epsilon$), where Q excludes occupied HO sp states and U is taken to be a non-local sp potential constructed from the G-matrix force.[2] Taking essentially all intermediate particle states and using the G-matrix for the Reid-SC potential, we obtain the results in the table. The Δ_{so} obtained by solving the SC-equation are listed in the table below. Thus, the theoretical Δ_{so} obtained starting from the 2-body nuclear force is generally too small compared with the experiment. We investigate the 2-pion exchange 3-body force effect on Δ_{so} in another contribution(II).

^{16}O	ϵ=-16.0	$M_p(a;\epsilon)$	^{40}Ca	ϵ=-16.0
0p3/2	3.31 (4.28)		0d5/2	3.75 (5.35)
0p1/2	4.45 (5.90)		0d3/2	4.96 (7.08)
			1s1/2	4.26 (6.24)
	ϵ=-2.0			ϵ=-4.0
0d5/2	1.43		0f7/2	1.94
0d3/2	2.64		0f5/2	3.12
1s1/2	2.10		1p3/2	2.65
	(MeV)		1p1/2	3.03 (MeV)

HO size parameters b=1.76fm (^{16}O) and b=1.94fm (^{40}Ca). Numbers in () are for the simple HO Nh intermediate particle spectrum.

^{16}O	Cal	Exp	^{40}Ca	Cal	Exp
0p	3.2	6.16	0d	5.4	7.0
0d	4.2	5.08	0f	4.2	6.5
		(MeV)	1p	1.4	1.8

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SINGLE PARTICLE SPIN-ORBIT SPLITTING (II)
— Two-Pion Exchange Three-Body Force Effect —

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As is exhibited in our preceding contribution (I), it is quite likely that the 2-body force contribution is not large enough to reproduce the entire single-particle spin-orbit splitting especially for normally occupied states. We here report numerical estimates for the 2π-exchange 3-body force (TPETBF) contribution, Δ_{so}^{TBF}, by using the TPETBF of the form:[3]

$$V_{TBF}^{(2\pi)}(1,2,3) = W(1,2;3) + \text{cyclic},$$

$$W = W_{t,s}^{(3)}(a,c) + W_{t,p}^{(b)}(C_p) + W_{-,\sigma}^{(b)}(\mathcal{D}_p),$$

where $W_{t,s}^{(3)}$ denotes the π-N s-wave part, while $W_{t,p}^{(b)}$ and $W_{-,\sigma}^{(b)}$ p-wave parts; $C_p=-(1/2)(f/4\pi)^2 b/\mu^4$ (μ=0.7fm^{-1}) and $D_p=(f/4\pi)^2(d_3+d_4)/\mu^4$ in the notation of Ref. 1). We evaluate Δ_{so}^{TBF} directly by using harmonic oscillator wave functions, including the double-exchange (Dx) contribution in addition to the single-exchange (Sx) one; total Δ_{so}^{TBF} is broken down as

$$\Delta_{so}^{TBF} = \Delta_{so}^{TBF}(S_x) + \Delta_{so}^{TBF}(\mathcal{D}_x),$$

$$\Delta_{so}^{TBF}(S_x) = S_x^{(a)} \cdot a/\mu + S_x^{(c)} \cdot c/\mu^3 + S_x^{(p)} \cdot C_p,$$

$$\Delta_{so}^{TBF}(\mathcal{D}_x) = \mathcal{D}_x^{(a)} \cdot a/\mu + \mathcal{D}_x^{(c)} \cdot c/\mu^3 + \mathcal{D}_x^{(p)} \cdot C_p$$

In our calculation the form factor $H(q^2)=(\eta^2-\mu^2)/(\eta^2+q^2)$ and the short-range correlation function obtained from the Reid-SC potential are employed. The table lists the coefficients, $S_x^{(a)} \sim D_x^{(p)}$, for the cases of 0p-orbit in ^{16}O and 0d in ^{40}Ca evaluated with $\eta=6\mu$.

	$S_x^{(a)}$	$S_x^{(c)}$	$S_x^{(p)}$	$D_x^{(a)}$	$D_x^{(c)}$	$D_x^{(p)}$
0p(^{16}O)	-0.92	-0.80	2.76	-0.10	-0.19	0.55
0d(^{40}Ca)	-1.00	-0.82	3.42	0.04	0.06	0.31

It is seen that the p-wave contribution is really significant in agreement with the suggestion based on the Fermi-gas model.[2] By employing the TPETBF given by Coon et al.[1], a =1.13, c =1.05, Cp=1.13 and Dp=0.66, we have: Δ_{so}^{TBF}(0p; ^{16}O)=1.55MeV and Δ_{so}^{TBF}(0d; ^{40}Ca)=2.12MeV, while the TPETBF given by Kasahara et al.[3], a=c=0 and Cp=2Dp=0.45, leads to: Δ_{so}^{TBF}(0p; ^{16}O) =1.37MeV and Δ_{so}^{TBF}(0d; ^{40}Ca)=1.61MeV. These values are actually very sensitive to the choice of the cut-off mass η especially for the first type of TPETBF. Combining these values with those in (I), the net thoretical values are still not sufficient to reach the experimental Δ_{so}.

In conclusion, the TPETBF effect on Δ_{so} can be as important as the 2-body force effect. Thus, investigation of Δ_{so} provides a good testing ground for TBF.

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SHELL MODEL CALCULATIONS WITH A THREE-BODY INTERACTION

T. Inoue, Y. Akiyama, and T. Suzuki (Nihon University)

N. Onishi and A. Arima (Tokyo University)

The importance of the three-body interaction has been established in Hartree-Fock calculations. We have examined phenomenologically a possible effect of a three-body interaction in the shell model calculations of the sd-shell. We assumed the KUO interaction and the WILDENTHAL and PREEDOM interaction with a three-body term as the effective interaction.

The three-body term as assumed as

$$V_3 = 12333.\kappa.\delta(r_1-r_2).\delta(r_2-r_3)$$

where κ is varied phenomenologically.

The calculated energy levels of ^{21}Ne, as example, are shown in Fig. 1 and 2. High spin states, i.e., 7/2+, 9/2+ and 11/2+ come down very quickly as κ increases. A 1/2+ state behaves very interestingly. Table 1 shows the binding energy and the percentage probability of [41](81) component of the lowest 3/2+ state. We are thus shell model calculations are capable of fixing the strength of the three-body interaction. We are trying to find an effective interaction which contains two-body and three-body terms and satisfy the saturation condition.

Table 1

KUO + V_3				WILDENTHAL + V_3			
κ	B.E.	Probability [41]	(81)	κ	B.E.	Probability [41]	(81)
0	-28.51	90.7	77.4	0	-26.70	85.1	68.5
0.5	-24.34	86.4	74.7	0.5	-22.63	78.3	64.1
1.0	-20.75	80.8	65.5	1.0	-19.03	67.9	55.7
1.5	-18.09	78.1	49.3	1.5	-16.56	41.1	11.6

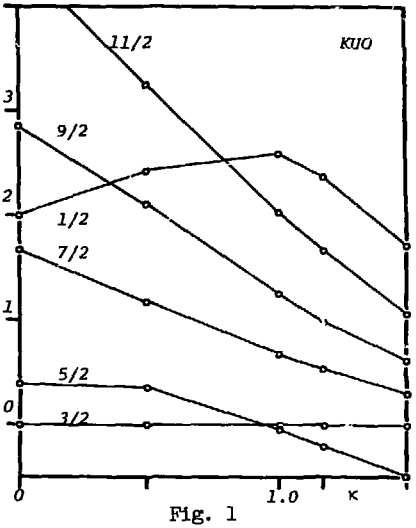


Fig. 1

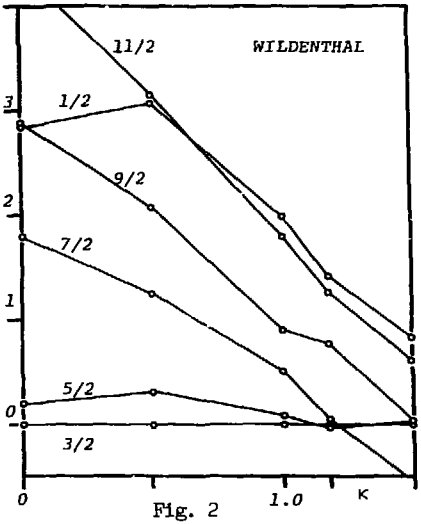


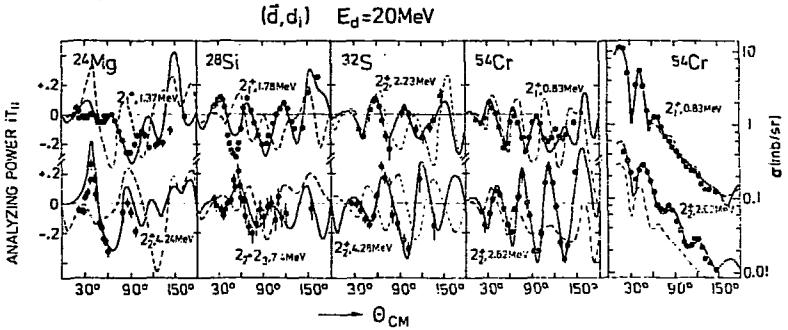
Fig. 2

MEASUREMENT OF QUADRUPOLEMOMENTS AND P_3-TERMS BY INELASTIC SCATTERING OF VECTOR POLARIZED DEUTERONS +)

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The high sensitivity of the scattering of polarized deuterons to interference terms in the scattering process has been used to study the detailed structure of excited states. Special attention has been paid to 2_1^+ and 2_2^+-states, which play a dominant role in the determination of the nuclear shape. The figure shows the analyzing powers for the first two 2^+-states in ^{24}Mg, ^{28}Si, ^{32}S and ^{54}Cr, for the latter also the cross sections as an example. In all four cases the angular distributions for the 2_2^+-states behave very differently from those of the 2_1^+-states exhibiting a different reaction mechanism and thus a different nuclear structure. The drawn full curves are the result of the simultaneous CC-analyses of cross sections and analyzing powers for the level system 0^+-2_1^+-2_2^+-4_1^+ and others specific for the individual nucleus. In all cases a global OM-set has been used for the description of the spherical part of the deuteron-nucleus interaction. In the analyses the data show extreme sensitivity to the phases of the interference terms in the scattering caused by quadrupole moments Q_{2^+} and P_3-terms; the latter of which describe for the 2_2^+-states the interference of the direct transition from the groundstate with the indirect one via the 2_1^+-state. The dashed lines in the figure show on the upper part the effect on the 2_1^+-scattering of changing the sign of Q_{2^+}, and on the lower part the effect on the 2_2^+-scattering of changing the $^{2}1$ phase of P_3. Both changes show pronounced effects in the analyzing powers of the corresponding states, leading to an unique determination of Q_{2^+} and P_3 for all four nuclei. While for Q_{2^+} our values agree with the $^{2}1$ ones from coulomb excitation, there ^{1} are no P_3-measurements else known for these nuclei. Additionally also the quadrupole moment of the 2_2^+-state shows significant effects in the angular distributions, its influence, however, is generally smaller than that of P_3.



Comparison to microscopic calculations[1] for the sd-shell nuclei gives agreement to our results for transition amplitudes and quadrupole moments in their absolute values and phases. Alternatively the results for all four nuclei can be interpreted equally well in the frame of collective models, either in the geometrical models or in the IBA. This points to the dominance of simple symmetries even in nuclei as light as the ones in the sd-shell.

+) supported in part by the Bundesministerium für Forschung und Technologie

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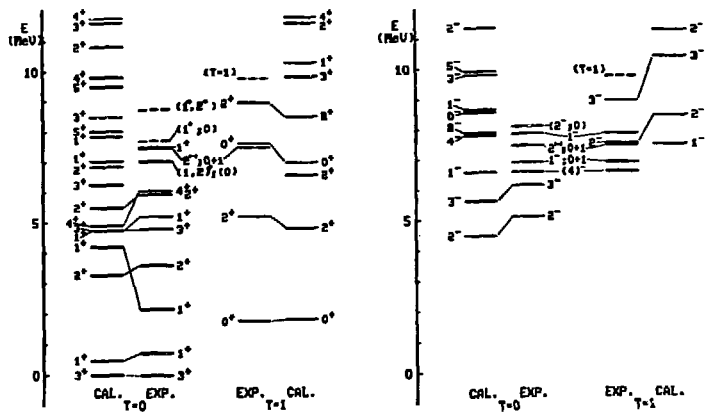
STRUCTURE OF ^{10}B NUCLEUS BY A MOLECULAR MODEL

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^{10}B nucleus which is in the middle of p-shell nuclei, is known to have anomalous properties in the simple spherical shell model and have been recently investigated by some extended methods of the model[1]. In this report we treat not six valence-nucleons around an α-core but two valence-nucleons around a two-α core microscopically on the basis of the study about ^{9}Be nucleus[2]. The two-α core has well-developed cluster structure, so that a $|\Omega|^{\pi}=1/2^{+}$ orbital comes down and degenerates to clusterized p-orbitals. The structure of ^{9}Be nucleus is well represented in terms of the above three molecular orbitals[2]. In the present calculations we exactly remove spurious states of the center-of-mass motion and use the following effective interaction; the modified Volkov potential with exchange mixtures b=h=0.1 and realistic effective spin-orbit and tensor potentials[3].

In the figure results are shown to well reproduce the experimental energy levels. Anomalous states, 1_3^+(T=0) state at 5.16 MeV, 0_2^+(T=1) state at 7.56 MeV and 2_3^+(T=1) state at 8.89 MeV are described as well-developed cluster states. 3_2^+(T=0) state at 4.77 MeV is found to be a mixed state of shell and cluster configurations, which is consistent with its large α-decay width. Negative-parity states show rotational-band like structure with a high degree of clustering in comparison with the ground state. Unfortunately we have not definite conclusions for states above 6 MeV because of insufficient experimental information. Electromagnetic properties are also well explained[3]. The present result gives a too-high excitation energy to 1_2^+(T=0) state at 2.15 MeV, which requires further investigation on the effective interaction in the truncated model space.



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Lepton-Hadron Relation and the NN and ΛN Potential.

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India.

Abstract

We have attempted here to derive the Nucleon-Nucleon potential on the basis of the structural aspects of hadrons. On the basis of a lepton-hadron relation as proposed in a recent paper, it is found that the constituent pions formed by the clustering of spin $\frac{1}{2}$ particles in the configuration of a nucleon demands the exchange of π, ω, ρ and f^0-mesons. 2π exchange is found to be less probable. Also in this scheme no adhoc mechanism or fictitious parameter is needed, nor the exchange of any hypothetical particle is required. The phase-shifts for $^3P_0$, $^3P_1$, $^3D_1$, $^3D_2$, $^1D_2$, $^3F_2$ and $^3F_3$ states are found to be in excellent agreement with experiments.(1) For S-states as well as for $^3P_2$ and $^1P_1$ states the potential for the core region is found to have a dominant role. In this region, a potential of the Gaussian form $V_{core} = V_o\, e^{-\beta r^2}$ is introduced and the phase-shifts for these states are found to be in very good agreement. This dynamical scheme is then extended to Λ-N case which includes the exchange of η, K, ω as well as K^*, K^{A1} and f^0 among the constituent pions.and a generalised Λ-N potential is then derived. The scattering length deduced from this is found to be in very good agreement with experiments. We then predict the Λ-N phase shifts at low energy for different states.

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SOME PROPERTIES OF BARYON-ANTIBARYON STATES ACCORDING TO SU(6)

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Usually one considers the behavior of a single $B\bar{B}$ state, for instance the $P\bar{P}$ state. Here we consider three baryons P, N, Λ and their antiparticles as a whole just in analogy with the quarks in a naive quark model. As the strong interactions between the baryons and antibaryons possess SU(3) symmetry, and the SU(3) forms SU(6) with the spin SU(2). The baryon-antibaryon combination has 36 different ways and $36 = 1 \oplus 35$, Now 35 can be decomposed into $8_1 \oplus (1_3 \oplus 8_3)$. Let a state of multiplicity μ, isotopic spin t, spin j and charge Q be written as $|\mu t/jQ$, then the S states of $B\bar{B}$ are;

$|1o\rangle oo$, $|8o\rangle oo$, $|81\rangle o+$, $|81\rangle oo$, $|81\rangle o-$, $|81/2\rangle o+$

$|81/2\rangle oo$, $|81\overrightarrow{/2}\rangle oo$, $|81/2\rangle o-$; $|1o\rangle 1o$, $|8o\rangle 1o$, $|81\rangle 1+$

$|81\rangle 1o$, $|81\rangle 1-$, $|81/2\rangle 1+$, $|81/2\rangle oo$, $|81\overrightarrow{/2}\rangle oo$, $|81/2\rangle o-$

Let the interaction Hamiltonian between a baryon and an antibaryon be [1]

$$H_1 = aj(j+1) + b\left[\delta(B\Lambda) + \delta(\bar{B}\bar{\Lambda})\right]$$

where the first term is to differentiate $j \neq o$ from $j=1$ state, while the second term is to differentiate hyperon from nucleon, then we have

$$4\langle 81/2|H_1|81/2\rangle_o = 3\langle 8o|H_1|8o\rangle_o + \langle 81|H_1|81\rangle_o$$

This illustrates the linear relationships between the different binding energies.

A $j=1$ state can make a transition to a state of $j=o$ acompanied by emission of a gamma ray photon, such as

$$|81\rangle 1o \rightarrow |81\rangle oo + \gamma$$

$|81\rangle 1o$ and $|81\rangle oo$ are both negative parity states. During the transition the parity does not change, hence it is a MI transition. Let the magnetic moment operator of $B\bar{B}$ be $\mu = (g_b s_b + g_{\bar{b}} s_{\bar{b}})\mu_o$, then for $|81\rangle 1\pm, o \rightarrow |81\rangle o\pm, o$ + gamma, we have

$$\langle 81_{1o}|u_3|81_{oo}\rangle = \langle 81_{1+}|u^+|81_{o+}\rangle = \langle 81_{1-}|u^-|81_{o-}\rangle$$

During such a transition a $|81\rangle 1o$ state transforms into a $|81\rangle oo$ state.

The B and $\bar{B}$ in $|1o\rangle oo$ or $|8o\rangle oo$ can be annihilated into two gamma photons, while the B and $\bar{B}$ in the state $|1o\rangle 1o$ can be annihilated only into one gamma photon.

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THE 3F3 DIPROTON IN THE FADDEEV πNN DYNAMICS

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In a series of works we have studied dibaryons arising in πNN and ππNN dynamics 1, 2). In ref.1) Heitler-London mechanism is proposed and in ref.2) a Faddeev approach is made to the 3F3 diproton. This report summarizes highlights of the results in ref.2) and a subsequent study about the πd decay of the 3F3 diproton.

In the energy range of laboratory energies EL = 0-1200 MeV we consider pp elastic scattering and one-pion-production in the IJP = 13- state. In the Faddeev AGS formalism we represent the processes by transition amplitudes between various πNN channels. The pp channel is represented by the πNN channel in which a πN subsystem is in the bound state equivalent to proton. This bound state and the spectator proton are correctly antisymmetrized. All particles are treated as being non-relativistic as is done in ref.3).

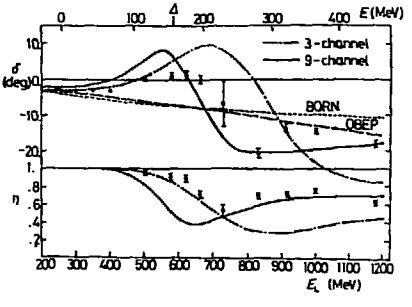
We select the following 10 channels as important.

Channel	1	2	3	4	5	6	7	8	9	10
Pair states	P11	P11	P33	P33	P33	P33	3P2	3P2	3P2	3S1
S	1	0	2	1	2	2	2	2	2	1
L	3	3	1	3	3	5	1	3	5	2

In this table S represents the sum of the spins of the spectator and the interacting pair and L does their relative orbital angular momentum.

Phase-shifts δ and absorption coefficients η of pp scattering are calculated both in the 3 channel model, which involves channels 1, 3 and 7 and thus is similar with the one in ref.1, and in the 9 channel model, which involves the 9 channels from channel 1 to 9. In both models the inelastic resonance pattern is reproduced. However, compared with the phase-shift analysis result 4), the resonance energy is 50 MeV higher in the 3 channel model and 50 MeV lower in the 9 channel model. The deficiency of the 9 channel model would be remedied by a relativistic treatment of the pion and by introducing the ρ-contribution and other ignored channel effects.

We calculate the effect of channel 10, the πd channel. We find that the effect to the 3F3 phase parameters is so small as changes the resonance energy to only a few MeV lower one. Further we find that the branching ratio of the 3F3 diproton to the πd channel is so small as 0.17% around the resonance energy of EL ≃ 600 MeV. The 3F3 diproton in our model is composed primarily by the NN subsystem of the P state and the p-wave pion with respect to the NN subsystem. Therefore the wave functions of the 3F3 diproton and the πd channel are almost orthogonal. This is the main reason why the branching ratio is so small.



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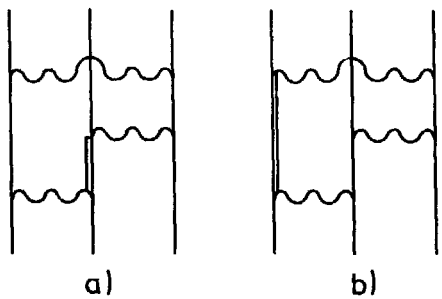
Δ(3,3) EXCITATIONS AND EFFECTIVE THREE-NUCLEON FORCES IN FINITE NUCLEI

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One of the central aims of nuclear structure theory is to derive the ground state properties of nuclear systems from a microscopic Hamiltonian which is adjusted to describe the two-nucleon data. If one uses e.g. the Brueckner-Hartree-Fock approximation to solve the many-body problem, it seems to be impossible to describe simultaneously the binding energy and radius of finite nuclei. Since for light nuclei, like e.g. ^{16}O, the contribution of higher-order terms in the many-body perturbation expansion seems to be small, this discrepancy leads to the conclusion that one has to go beyond the model of a nucleus being a system of inert nucleons which interact via NN potentials.

Several groups try to investigate the influence of intermediate excitations of the nucleons to the Δ(3,3) resonance on the effective interaction in nuclei. In a nuclear medium the attractive contributions of intermediate Δ(3,3) excitations are quenched because of Pauli and dispersion effects. This typically yields a repulsive effect for the binding energy of ^{16}O of about 1 MeV per nucleon[1]). The explicit treatment of isobar excitations, however, also leads to three-body terms as they are displayed in the figure[2]). These terms can be understood as components of a three-body correlation function, which should be calculated by solving a system of Bethe-Faddeev equations which consider pure nucleonic and nuclear plus isobar excitations on the same footing. Compared to a conventional many-body theory which would treat the diagrams displayed in the figure as contributions to a three-body force, the present approach has the following advantages: NN correlations can be considered in a selfconsistent way, exchange terms are conveniently included and the effects of isobar excitations on two- and three-body terms are studied systematically.



The calculation of the lowest order terms, explicitly displayed in the figure, leads to about 0.5 MeV per nucleon attraction for the binding energy of ^{16}O. This is smaller than the repulsive effect in the two-body terms mentioned above. It is of the same magnitude as the contribution from the pure nucleonic three-body correlations[3]).

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SINGLE K MESON AND $2\pi, \pi\rho$ EXCHANGES IN THE Λ-N INTERACTION

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The purpose of this paper is to study the Λ-N interaction by using the meson exchange theory. We have considered three processes:(1)Single k meson exchange, (2)Box diagrams of 2π and $\pi\rho$ exchanges with a nucleon in the intermediate states, and (3)Box diagrams of 2π and $\pi\rho$ exchanges with an isobar in the intermediate states(see Fig.1).

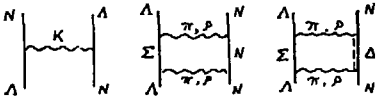


Fig.1.

For simplicity, two approximations have been taken in the calculation.[1] First, the initial nucleon N and hyperon Λ are considered to be at rest and their excitation energies compared with the pion energies in the intermediate states are neglected. Second, an average value is used for the energies of the intermediate states. Thus the 2π and $\pi\rho$ exchange potentials can be decomposed into two transition potentials, which could be written in simple and analytic expressions.

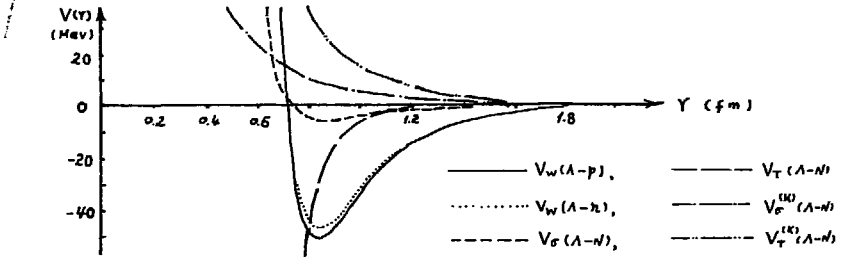


Fig.2.

The results are shown in Fig.2. It is seen that the Λ-N interaction is somewhat weaker than its N-N counterpart and the Λ-N singlet force is stronger than its triplet force. If the meson mass differences, the Σ mass differences, etc. are taken into account, then the charge symmetry breaking in the Λ-N interaction and a deeper Λ-p potential are obtained. All these results are coincide with experiments.

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SCATTERING AMPLITUDE WITH LARGE MOMENTUM TRANSFER CALCULATED FROM THE B-T EQUATION AND THE REPULSIVE CORE OF NUCLEAR FORCE

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The interior of the nuclear force can not be made clear by low energy data. Thus it is desirable to redefine the phenomenological nuclear force by a dynamic equation with relativistic kinematics and to determine this force by higher energy scattering data. In doing so, we choose the BT equation which was first proposed about 30 years ago[1] and can also be derived from some quasi-potential equations developed in recent years.[2]

For time independent solution, the BT equation in CM system looks like

$$\left(\sqrt{-\nabla^2+m_1^2} + \sqrt{-\nabla^2+m_2^2} + V \right) \psi = E\psi$$

Obviously, the V so defined is in accordance with that defined by Schrödinger equation when the energy is low.

Using eikonal wave Born expansion[3] we derive an analytic approximate amplitude for large angle($<90^\circ$) scattering:

$$\langle f|V|\psi\rangle = \langle f|V|\psi_i^e\rangle + \frac{4k^2k^2c^2}{E}\langle \psi_f^e - f \,|\, k_i' \,|\, \psi_i^e\rangle$$

$$-\frac{1}{\varepsilon E}\langle \psi_f^e|V^2|\psi_i^e\rangle + \text{high order terms}$$

here

$$k_i' = \left[(k + i\nabla_{//})^2 - \nabla_\perp^2\right]/2k$$

$$\psi_i^e = \exp\left[ik\delta_i - i\frac{E}{4k^2k^2c^2}\int_\infty^{\delta_i} V d\delta_i'\right], \quad \psi_f^e = \exp\left[ik\delta_f + i\frac{E}{4k^2k^2c^2}\int_{\delta_f}^{\infty} V^* d\delta_f'\right]$$

$\delta_i = \vec{r}\cdot\vec{n}_i$, $\vec{n}_f$ is the outgoing direction. With this amplitude, using p-p scattering data, we can discuss the behavior of V in higher energy. Let V= repulsive+ attractive+ imaginary part. We find that the contribution to $d\sigma/dt$ as $t \geq 2.5\,(\text{Gev}/c)^2$ arises dominantly from the repulsive core. For a small t, the contribution of the core is negligible. Thus, using large t data we are able to determine the strength and the range of the core. For example, assuming that the repulsive part is

$$V_{rep.} = V_1 e^{-r^2/\beta_1^2} + V_2 e^{-r^2/\beta_2^2}$$

for $\sqrt{S}$=6.15Gev we find that V_1 =340Mev, β_1 =0.43fm, V_2 =30Mev, β_2= 0.17fm. It is remarkable that the height of the core is not very large. It is even lower when $\sqrt{S}$ is larger. Because a hard repulsive core is not necessary in explaining the low energy data and fails in explaining the high energy data, there is no need to introduce this concept in the nuclear force.

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REDUCTION OF THE $\bar{N}N$ ANNIHILATION POTENTIAL DUE TO THE PRESENCE OF BOUND BARYONIUM STATES

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In two recent articles[1,2] is was pointed out that the presence of $\bar{N}N$ bound states $(\bar{N}N)_B$ - as possibly seen in a CERN γ-ray experiment[3] - could be responsible for the long range part of the annihilation potential needed to explain $\bar{N}N$ elastic, charge-exchange and inelastic scattering upto a $\bar{p}$ laboratory energy of about 450 MeV[4]. A quantitative estimate of this effect is now made using a coupled channels formalism for the two-body configurations $\bar{N}N$ and $(\bar{N}N)_B\pi$. For the case of $\bar{N}N(^{33}P_2)$ the effect of a $^{13}P_2(\bar{N}N)_B$ configuration bound by 183 MeV is to reduce the annihilation potential of ref.[4] from

$$\frac{-21 - i20}{1 + \exp(5r)} \text{ GeV} \quad \text{to} \quad \frac{-7.6 - i4.1}{1 + \exp(4.8r)} \text{ GeV}$$

At 1 fm the imaginary part of this new potential is now only 34 MeV compared with 134 MeV in ref.[4]. It remains to be seen whether or not this reduction is sufficient to give bound states with widths ($\simeq$ 20 MeV) comparable to those suggested by the CERN experiment.

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NON-ITERATIVE TWO-PION EXCHANGE AND ITS EFFECT IN NN-SCATTERING AND NUCLEAR MATTER

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Recent progress in our aim[1] of an explicit description of the 2π-exchange contribution to the NN-interaction is reported. Such a program is essential for a realistic treatment of the modifications of the NN-interaction in the medium (because of Pauli and dispersive effects), which play a decisive role in obtaining a consistent description of light and heavy nuclei.

Our general scheme is to start from a field-theoretic Hamiltonian (containing as interaction part a meson-nucleon vertex, not a nucleon-nucleon potential), which is treated in old-fashioned perturbation theory in order to have a consistent framework for the two- and the many-body problem.

In this paper we study the influence of non-iterative 2π-exchange diagrams, involving nucleon-nucleon as well as nucleon-isobar (Δ) states, on NN-scattering phase shifts and the binding energy of infinitely extended nuclear matter. The quenching of these diagrams in the medium is appreciable, though smaller than in the case of the corresponding iterative (box) diagrams[2]. By adding suitable one-boson exchange terms, a reasonable fit of phase shifts and deuteron data is obtained.

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QUARK FORCE AND NUCLEAR FORCE I. n-p SCATTERING

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We regard the nucleon as a three quark cluster, use $SU_3^{(a)} \times SU_2^{(\tau)} \times SU_2^{(\sigma)}$ color-flavor-spin wave function and Gaussian space wave function to describe a nucleon, and employ the di-cluster single channel resonanting group wave function to describe the di-nucleon system. Acording to the quark confinement and color saturation concepts, we suppose the quark force as follows.

$$V_{ij} = \vec{\lambda}_i \cdot \vec{\lambda}_j (a + b\,\vec{\sigma}_i \cdot \vec{\sigma}_j + c\,\vec{\tau}_i \cdot \vec{\tau}_j + d\,\vec{\sigma}_i \cdot \vec{\sigma}_j\,\vec{\tau}_i \cdot \vec{\tau}_j) V(r_{ij})$$

$$V(r_{ij}) = \begin{cases} V_0^{\mathrm{I}} + K r_{ij}^2 \\ V_0^{\mathrm{II}} + \frac{\alpha}{r_{ij}} + \beta r_{ij} \\ V_0^{\mathrm{III}} e^{-\nu r_{ij}^2} \end{cases} \qquad (1)$$

Here $\vec{\lambda}$ is the $SU_3^{(a)}$ Gell-Mann operators. Adapting the single channel resonanting group approximation [1], we have derived an equation which determines the nuclear force from quark force.

$$V_{nn}(r) = \frac{\hbar^2}{2\mu} \frac{1}{f_l^{(s)}(r)} \int_0^\infty K_l^{(s)}(r,r') f_l^{(s)}(r') dr' \qquad (2)$$

Here $2\mu = m$, m is nucleon mass. $f_l^{(s)}(r)$ is the solution of the following intergro-differential equation.

$$\left[\frac{d^2}{dr^2} + k^2 - \frac{l(l+1)}{r^2}\right] f_l^{(s)}(r) = \int_0^\infty K_l^{(s)}(r,r') f_l^{(s)}(r')\, dr' \qquad (3)$$

Where the concrete form of the integro-kernel $K_l^{(s)}(r,r')$ has the following character

$$K_l^{(s)}(r,r') \sim e^{-G_n(r^2+r'^2)} I_l(-K_n r r') \qquad (4)$$

Here $I_l(x)$ is Bessel function with imaginary argument. $K_n \sim G_n \sim r_N^{-2}$ (r_N is nucleon radius). Therefore our model derives the short range nonconfinement nuclear force from the quark force possessing confinement naturally. Futhermore we have calculated the n-p scattering cross sections in the energy range 0.1-450 MeV. Except the mixed parameters a,b,c,d, the other parameters of quark force(1) are determined from the ground state property of nucleon. Provided the form and mixed parameters of quark force (1) are selected adequately, the calculated cross sections are consistent with the experiments.

QUARK FORCE AND NUCLEAR FORCE II. COMPARING WITH PHENOMENOLOGICAL NUCLEAR FORCE

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We have proposed the form of the quark interaction in I. In this paper, we use the method of double well cluster model to compute the nuclear force by the adiabatic approximation as follows

$$V_{NN}(z) = \langle \Psi | H | \Psi \rangle - \langle \Psi | H | \Psi \rangle_{\infty}$$

for (S,T)=(1,1), (1,0), (0,1) (0,0). Here z is the distance between the double well. The parameters of the quark interaction in I(besides a,b,c and d) are determined by the elementary properties of a single nucleon. The results are shown in fig 1-4, and are compared with the central part of HJ potential, Reid soft potential, Yale potential and Lomon-Feshbach potential. There is only one binding in S=1, T=0 case.

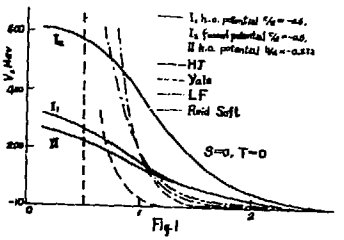


Fig.1

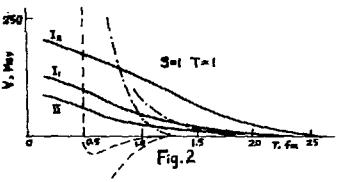


Fig.2

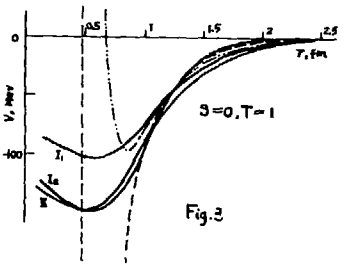


Fig.3

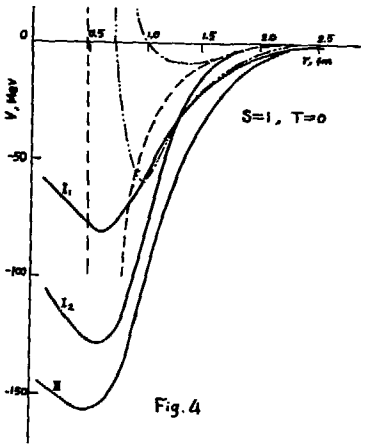


Fig.4

SHELL MODEL NUCLEAR STRUCTURE CALCULATIONS WITH THE PARIS N-N POTENTIAL*

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The Paris N-N potential[1], derived from a field theory of nuclear forces, is among the "best" N-N potentials available. A particularly interesting feature of this potential is its much weaker tensor force component compared to those of earlier phenomenological potentials. In this work we employ the Paris potential in nuclear many body calculations, within the framework of the nuclear shell model and the folded diagram theory of effective interactions. More specifically, we calculate the energy levels and some transition rates for several nuclei at the beginning of the sd shell, to see if we can obtain some sensible results.

We begin with a parametrized form of the theoretically derived potential and construct the two body G-matrix, $G=V+VQ(\omega-QTQ)^{-1}QG$. A momentum space matrix inversion method is used in solving the above G-matrix equation. As a test of this method, we calculate the N-N phase shifts, which are reproduced satisfactorily. We then solve the model space problem $PH_{eff}P\psi_\lambda=(E_\lambda-E_c)P\psi_\lambda$ with the model space P composed of sd shell valence particles outside a closed ^{16}O core. E_c is the ^{16}O ground state energy. The 1-body part of H_{eff} is taken from the experimental ^{17}O and ^{17}F states. The 2-body part V_{eff} is calculated using the $\hat{Q}$-box formulation of the folded diagram theory[2]. The $\hat{Q}$-box is calculated approximately, including only some low order valence-linked and irreducible G-matrix diagrams. We then calculate the folded diagram series $V_{eff}=\hat{Q}-\hat{Q}\int\hat{Q}+\hat{Q}\int\hat{Q}\int\hat{Q}-\ldots$ including terms with up to 4 foldings (denoted by $\int$). Representative matrix elements are compared with those of the Reid potential in Table 1. Note that V_{eff} is slightly non-Hermitian. Also, the folded diagram series for V_{eff} seems to converge satisfactorily. The Paris potential matrix elements yield ^{18}O and ^{18}F spectra which are closer to the experimental spectra than do the Reid potential matrix elements. However, there is still some underbinding. This can perhaps be corrected by including higher order core polarization processes in the basic $\hat{Q}$-box. Results about other s-d shell nuclei will be discussed.

Table 1.

Folded diagram series for $\langle aaJT|V_{eff}|bbJT\rangle$. F_n is term with n foldings.

	T	J	a	b	F_o	F_1	F_2	F_3	F_4	Sum	
Paris	1	0	$0d_{5/2}$	$0d_{5/2}$	-2.942	0.963	-0.327	0.072	-0.015	-2.249	[MeV]
Reid					-2.801	0.969	-0.311	0.047	0.007	-2.089	
			$0d_{5/2}$	$0d_{3/2}$	-4.201	0.881	0.072	0.012	-0.033	-3.270	
					-4.128	0.961	0.071	-0.009	-0.031	-3.136	
			$0d_{3/2}$	$0d_{5/2}$	-4.201	1.286	0.009	-0.022	-0.051	-2.977	
					-4.128	1.380	-0.008	-0.051	-0.041	-2.849	

*Supported in part by USDOE Contract No. DE-AC02-76ER 13001.

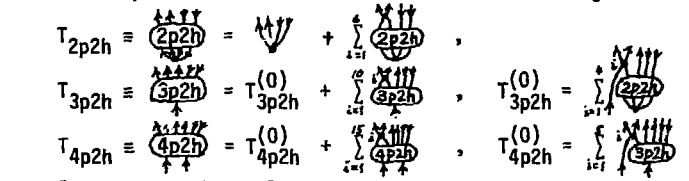
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MULTIPLE SCATTERING FORMALISM FOR THE 4P2H CONTRIBUTION TO V_{eff}

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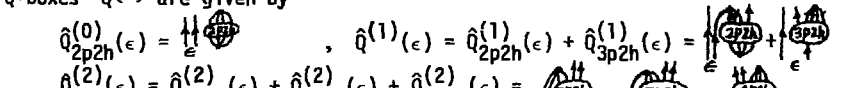
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The multiple scattering (m.s.) formalism used previously to evaluate low-lying 2p1h and 3p1h contribution to V_{eff} between valence nucleons[1] is generalized to include another important correlation, 4 particle-2 hole (4p2h), which results in a hierarchy of coupled m.s. eqs. for various correlation amplitudes. We treat here a case where only 2p2h, 3p2h and 4p2h correlations are taken into account and the $f_{7/2}$-$d_{3/2}$ 2-level model is employed to simulate A=42 systems. The hierarchy of m.s. eqs. for the 2p2h, 3p2h and 4p2h correlation amplitudes T is expressed diagrammatically in fig. 1 where a dot is a double-partitioned G-matrix and $T^{(0)}$ is the driving term for T.



(Fig. 1)

In terms of the amplitudes T, contributions to the 0-, 1- and 2-body Q-boxes[2] $\hat{Q}^{(n)}$ are given by



Thus we can evaluate the $\hat{Q}^{(n)}$-boxes separately and also can divide $\hat{Q}^{(n)}$ into parts characterized by really correlating p and h numbers ; $\hat{Q}^{(2)}_{2p2h}$ is a generalization of the standard 2nd order 4p2h diagram and $\hat{Q}^{(2)}_{4p2h}$ reflects the strong 4p correlation. Methods are available to evaluate connected folded diagram series to give the energy-independent V_{eff} by using the above Q-boxes. Conventional [2p+4p2h] shell-model calculations containing disconnected diagram contributions are equivalent in the present model to solving the equation for ϵ for each JT, $G_{2p} + \hat{Q}^{(0)}(\epsilon) + 2\hat{Q}^{(1)}(\epsilon) + \hat{Q}^{(2)}(\epsilon) = \epsilon$, but with the entering T_{2p2h} being evaluated at $\epsilon - G_{2p}$ in place of at ϵ.

Fig. 2 illustrates $\hat{Q}^{(n)}(\epsilon)$ and fig. 3 shows contributions of different $J_{4p}T_{4p}$ components to $Q^{(2)}_{4p2h}(JT=01)$. Used parameters are :

G_{2p} } empirically
G_{2p2h} determined,

p-h and h-h int. neglected,

$\epsilon_p - \epsilon_h = 8$ MeV.

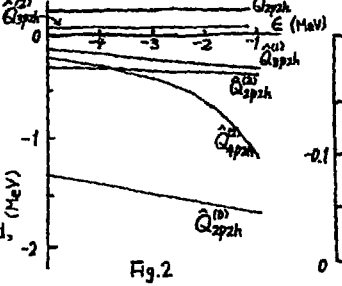


Fig.2

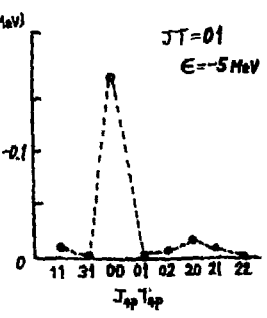


Fig.3

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GOLDSTONE DIAGRAMS IN AN ANGULAR MOMENTUM COUPLED REPRESENTATION*

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Many-body nuclear structure theory is usually formulated in terms of Goldstone (or Feynman) diagrams, as diagrams are a convenient tool for enumerating the various terms in the perturbation expansion of the effective interaction and other effective operators of interest (such as electromagnetic transition operators). Further, diagrams display in a very direct way the physical processes contributing to these quantities. An instructive example is provided by the so-called core-polarization diagram[1], which was found to contribute a long-range quadrupole-like component to the effective interaction between two valence nucleons.

As nuclear structure calculations are generally performed in an angular momentum coupled representation, the external lines of the diagrams considered must be coupled to a definite total angular momentum. In the past such diagrams have been evaluated by first writing down the diagrams in the m-scheme (i.e. uncoupled) representation and then transforming them to an angular momentum coupled representation. In general such transformations involve a large amount of angular momentum algebra and may thus become very tedious. There is also a significant probability of making errors.

In this note we report on a method which allows one to write down the angular momentum factors of such diagrams essentially by inspection. The method is rather general and can be used to evaluate any effective interaction and operator diagrams for both closed-shell nuclei (vacuum to vacuum linked diagrams) and open-shell nuclei (valence linked diagrams). Our basic strategy is to decompose a given diagram into a product of ladder diagrams with one or more rungs. The ladder diagrams may be of particle-particle, particle-hole or hole-hole type. Ladders are easily dealt with, as they factorize into products of vertices. In order to decompose a diagram into ladders, it is often useful to couple the diagram to a scalar and then use recoupling transformations. For this purpose it may be useful to recouple diagrams and matrix elements to cross-coupled form[2]. Thus, the celebrated core-polarization diagram may be viewed as a particle-hole ladder in the cross channel. Other useful techniques for obtaining the desired decomposition are to cut open internal lines and to cut off one-body insertions and operators. Phase rules associated with these operations are established. There are also phase factors associated with the angular momentum coupling of external particle and hole lines.

The procedure may be summarized as follows: First, we write down the phases, energy denominators and other numerical factors associated with the diagram in uncoupled form. Then, the factors and phases associated with the angular momentum structure are derived from the various operations performed to decompose the diagram into ladders, which are then easily evaluated.

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BARYON-BARYON INTERACTION IN A QUARK MODEL

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The short range part of the interaction between two non-strange baryons (NN, NΔ and ΔΔ) is studied in a non-relativistic quark model.[1,2] The quark-quark interaction consists of a confinement part and the one gluon exchange part (OGEP), and a baryon B(=N or Δ) is described by a cluster of three quarks with a Gaussian wave function ϕ_B. The two baryon system is treated by the resonating group method (RGM)[3], which assumes that the wave function for the total six quark system is given by

$$\Psi = \sum_{BB'} \mathcal{A}[\phi_B\phi_{B'}\chi_{BB'}],$$

where χ describes the relative motion between two clusters and $\mathcal{A}$ is the antisymmetrizing operator for quarks. With the total hamiltonian, H, the RGM equation can be written as

$$\langle\phi_B\phi_{B'}|(E-H)|\Psi\rangle = 0$$

which is a set of coupled integral equation for χ's. It is solved by a standard method in nuclear cluster model calculations.[4] The advantage of using RGM is that the relative motion between two clusters is treated in a fully quantum mechanical way. The results for the relative S states can be summarized as follows.

a) Interaction between two baryons is almost independent of the confinement term and is mainly due to the quark exchange effect (Pauli principle) and the spin-spin term in OGEP. It is strongly dependent on the spin (S) and isospin (T) of the system.
b) Attractive forces appear in (S,T) = (3,0), (1,0) and (0,1) ΔΔ states and, for the first two states, they are strong enough to give bound states which might correspond to the di-baryon resonances.[5]
c) The interaction is repulsive for the other spin-isospin states and the calculated phase shifts for the lowest threshold channels behave like those of hard core scatterings. In particular, (S,T) = (1,0) and (0,1) NN phase shifts give the hard core radii of 0.39 and 0.45 fm, respectively.
d) The qualitative behaviour of the observed NN phase shifts can be reproduced if the meson exchange effect is simulated by an additional local attractive potential.
e) The center of mass fluctuation of each cluster which is neglected in the adiabatic approaches[2,6] is found to be significant and the quantal treatment of the relative motion seems necessary for quantitative arguments.

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THE EFFECT OF DIFFERENT N-N INTERACTIONS ON THE CONVERGENCE PROPERTIES OF CORE POLARIZATION DIAGRAMS

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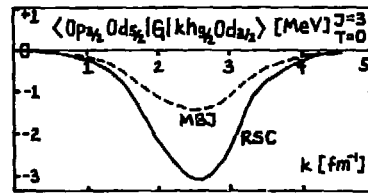
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The core polarization diagram G_{3p1h} has played a very important role in the development of microscopic effective interactions. Conventionally it was calculated with a restricted sum over the intermediate particle-hole oscillator states: $\varepsilon_p-\varepsilon_h=2\hbar\omega$. Vary, Sauer and Wong[1] questioned the validity of this approximation. They included p-h excitations up to $22\hbar\omega$ for A=18 nuclei and found a rather slow rate of convergence. Similar conclusions have also been reached recently by Kung, Kuo and Ratcliff.[2] Both calculations employed the Reid soft-core N-N potential (RSC).

In this work we demonstrate the delicate dependence of the above slow convergence behavior on the N-N potential used in the calculation. Taking a double partition approach[2] in which the high lying intermediate states are treated as plane waves while an oscillator basis is chosen for the low lying states, we have now carried out an extensive calculation of G_{3p1h} using a recent meson exchange Bonn-Juelich N-N potential (MBJ). We have obtained some rather interesting results: The contributions to G_{3p1h} from intermediate particle orbits above the p-f shell (k>10 in Table) are much smaller for MBJ than for RSC. This indicates fast convergence. In fact, our results strongly suggest that G_{3p1h} diagrams can well be approximated by including $\varepsilon_p-\varepsilon_h=2\hbar\omega$ excitations only.

		$\langle ab\|G_{3p1h}\|cd\rangle$	$2\hbar\omega$	k>10		
T=1	J=0	4 4 4 4	-.868	.476	RSC	(4 = $0d_{5/2}$)
			-1.198	.107	MBJ	
		5 5 5 5	-.306	.477		(5 = $0d_{3/2}$)
			-.564	.183		
		6 6 6 6	.153	.515		(6 = $1s_{1/2}$)
			-.160	.171		

The previous slow convergence of G_{3p1h} had been directly related to the strength of the N-N tensor force. The Bonn-Juelich potential, because of its stronger ρ-nucleon coupling constant, has a much weaker tensor force than the RSC interaction. Its effect is clearly demonstrated through the reduction of the strength of the reaction matrix G for large momenta, in matrix elements which are dominated by the tensor force (Figure). We therefore understand the origin of the better convergence behavior in the case of MBJ. Furthermore, the resulting effective interaction leads to improved agreement with the experimental spectrum of ^{18}O.



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[+]On leave from the State University of New York at Stony Brook and supported in part by the USDOE Contract No. DE-AC02-76ER 13001.
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RELATIONSHIP BETWEEN LOW-ENERGY PARAMETERS FOR CHARGED TWO-BODY SYSTEMS AND THE ACCURATE DETERMINATION OF THE GROUND STATE LEVEL OF THE ^{2}He NUCLEUS†

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The Coulomb-modified effective-range expansion technique, existing for almost half a century already, is very useful for the description of phenomena near zero energy.

On the one hand, given the position of a bound state, a decaying bound state, or a resonance at $E \equiv k^2 \equiv -\kappa^2$, where E is a complex-valued variable, one can obtain two relations between the Coulomb-modified low-energy scattering parameters, which can be written as real and maginary parts of Eq.(1), (ℓ=0),

$$\tfrac{1}{2} a_B \, \mathrm{sgn}(s) \; K_c(k^2) = H(\gamma), \qquad (1)$$

$$K_c(k^2) = -1/a_c + \tfrac{1}{2} r_c k^2 - P r_c^3 k^4 + \ldots, \quad H(\gamma) \equiv \psi(i\gamma) + (2i\gamma)^{-1} - \ln(-i\gamma \, \mathrm{sgn}(s)),$$

$\gamma \equiv -s/k$, $a_B = |s|$ = Bohr radius, ψ = digamma function.

Here s>0 (s<0) gives Coulomb attraction (repulsion). I have shown that (1) for Coulomb repulsion can be used to find the universal curve in the k plane on which all resonances lie caused by the trapping of the particles within the Coulomb barrier in the presence of an attractive short-range hermitian interaction V_s [1]. When the strength of V_s is varied the corresponding pole follows this curve to the origin, leading to extremely narrow resonances. A celebrated example here is the ^{8}Be ground state. At the origin the pole represents a zero-energy bound state. Upon increasing the strong coupling a bound state results. The shape of the curve near zero energy is completely Coulomb determined, i.e. it is independent of the details of V_s. For *any* V_s we will get a resonance which is extremely narrow before a bound state occurs, no matter how weak the repulsive Coulomb potential is, for a suitably chosen strength of V_s. If such a resonance or bound state occurs very close to E=0, the scattering parameters a_c, r_c, P,... behave in a very special way, determined essentially by the Coulomb interaction.

On the other hand, if a_c, r_c, P,..., have been determined accurately experimentally (1) can be exploited to find directly the precise position of levels. This has been done in Ref. 1 for the pp system, i.e. the ground state level of ^{2}He. A value E = -140-i 467 keV is obtained. This value is essentially error-free. This state has a special character. It is much closer to being a resonance than to being an antibound state! When I increase V_s^{pp} in strength by a few percent I obtain a proper resonance, a few more percent then gives a bound state.

The contour plot in Ref. 1, Figs. 1 and 2, can also be used for Coulomb attraction, combined with a real or absorptive short-range interaction V_s, with suitable reinterpretation and relabelling of the curves. This is of extreme interest for the theory of exotic atoms. Here the theory of complex-valued quantum defects can be profitably used to connect (complex) Coulomb level shifts and (complex) *Coulomb-modified* low-energy scattering parameters. I stress that the connection to the purely nuclear scattering parameters (Coulomb switched off) is less direct.

This work is part of the project "The Coulomb Potential in Quantum Mechanics and Related Topics".

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ROLE OF THE Δ-ISOBAR IN NUCLEAR INDEPENDENT PARTICLE MOTION

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The direct (not exchange) contribution of OPEP to the binding energy of nuclear matter is known to vanish because of cancellation involving spin and isospin. On the other hand, the two pion exchange potential (TPEP) is very important for the intermediate range attraction including both nuclear and isobaric intermediate states, which is known to be nearly S=T=0, i.e. as if it involved exchange of scalar σ-meson.[1] Similarly, three meson exchange processes involving mainly Δ-intermediate states are expected to be quite important and nearly independent of S and T, just like the analogous TPEP process.

In the present note we make use of the fact that the two and three pion exchanges form the first two in a series of ring diagrams which may be solved using the RPA. Previous calculations show that the short range repulsions contribute only about 1/4 of the density dependence required for saturation. With realistic interactions most of the saturation results from tensor forces. We can use closure to calculate the effective two body interaction.[1]

$$V^{(2)}(r) = V_\omega(r) - V_\sigma(r) = V_\omega(r) - V_\pi^2(r)/\Delta$$

where Δ is an average excitation energy (>>T_F), and V_ω denotes the short ranged repulsive ω interaction. The effective three body interaction resulting from 3 pion exchange is

$$V^{(3)}(r) = V_\pi(r_{12})V_\pi(r_{13})V_\pi(r_{23})/\Delta^2$$

which is repulsive. Calculations using gaussian form show that the effective density dependent two body interaction resulting from the three body terms (by summing over the third particle), has approximately the same range as the two body interaction. (On the other hand, for a strong short range repulsion, the density dependent part has a much shorter range.) A simple analytical approximation for the density dependent G matrix (neglecting exchange) is

$$G(\rho,r) = V_\omega(r) - (1 + c\rho)^{-1} V_\sigma(r)$$

The interaction between valence nucleons (which we denote here by F(r)) may be obtained using the Landau theory.

$$F(\rho,r) = \frac{1}{2}\frac{d^2}{d\rho^2}\left(\rho^2 G(\rho,r)\right) = V_\omega(r) - (1 + c\rho)^{-3} V_\sigma(r)$$

Thus F is even more strongly density dependent than G.

It appears, based on calculations using this model, that density dependence is relatively more important than the Pauli principle in establishing nuclear saturation and the approximate validity of the independent particle model. We can also derive a simple analytical expression for the equation of state of nuclear matter and for heavy ion potentials.

†This work was supported partially by NSF Contract No. PHY78-15811.

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THE PARIS POTENTIAL AND THE RECENT MEASUREMENTS IN NN SCATTERING

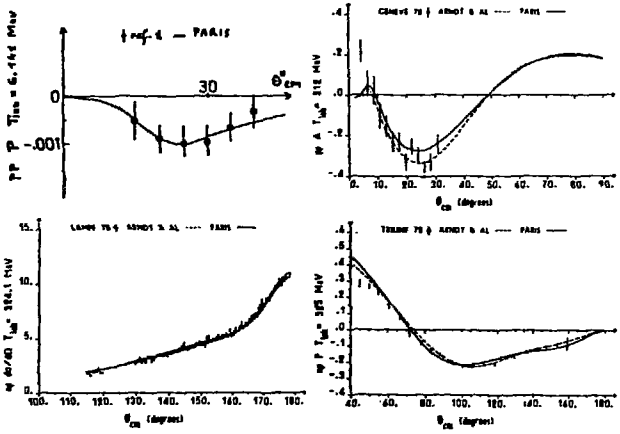
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New data (cross section, polarization and Wolfenstein parameters : A,D,R, etc.) on pp and np scattering have been recently published by different groups [1-5]. These include high precision or original measurements covering the energy region 6 MeV $\lesssim E_{lab} \lesssim$ 800 MeV.

We report here a direct comparison of these data with the values produced by the Paris NN potential [6] for energies $E_{lab} < 325$ MeV. The agreement between theory and experiment is very satisfactory both for low and medium energies. As examples, the pp polarization at 6.141 MeV [1], the pp A parameter at 312 MeV [2], the np backward cross section at 324 MeV [3] and the np polarization at 325 MeV [4] are shown in the figure below.

The total χ^2 for the world data set in the $E_{lab} \lesssim 325$ MeV region is also reported and compared with that given by the Reid potential.



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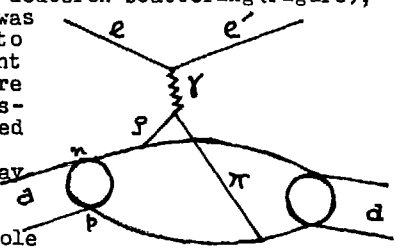
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MESON CURRENTS AND DEUTERON MAGNETIC MOMENT[+]

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The degree of sensitivity to the % D state[1] and other nucleon-nucleon interaction model dependent effects on meson exchange current (MEC) contribution to the deuteron magnetic moment have been examined. Adler's[2] $\rho\pi$ MEC correction to the magnetic form factor for electron deuteron scattering (Figure), which for zero momentum transfer was associated with MEC contribution to the deuteron static magnetic moment has been modified by employing more recent value of $\rho\pi\gamma$ coupling constant ($g^2_{\rho\pi\gamma}/4\pi = 1.24\times10^{-3}$), based on electromagnetic decay width (=0.035 MeV) for $\rho \to \gamma + \pi$ decay reported by Gobbi et al[3]. MEC corrections for deuteron magnetic moment corresponding to the two pole fit to the amplitude for nucleon form factor for various nucleon-nucleon potential models are shown in table. We conclude that $\rho\pi$ MEC contribution to the deuteron magnetic moment are much smaller than those estimated by Adler (0.0188 and 0.0180 for Yale and HJ potentials respectively) and that these contributions strongly depend on the form of the nucleon-nucleon potential in general and on the % of D state in particular.



POTENTIAL	$\Delta\mu_d$	P_d
Yale	0.00479	6.96
HAMADA-JOHNSON		
(HJ)	0.00429	6.93
HJ(M)	0.00424	7.01
REID-SOFT		
(RSC)	0.00361	6.47
RSC(M)	0.00333	5.84

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NEUTRON-NEUTRON EFFECTIVE RANGE FROM QUASIFREE SCATTERING IN $^2H(n,nn)p$ AT 25 MeV

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A neutron coincidence time of flight spectrum of the deuteron breakup by 25 MeV neutrons was measured to determine the effective range r_{nn} of the neutron-neutron interaction. The background could be reduced to a very low level due to a new conception for the shielding of the neutron source and the collimators of the szintillation counters. No additional coincidence with the recoil proton in the target was necessary. In this way we succeeded to record the spectrum for the exact kinematics of quasifree scattering which is the most suitable condition for measuring a reliable r_{nn}-value. The result depends sensitively on the absolut cross section of the process. Therefore efforts were made to measure carefully the efficiencies of the neutron detectors, the neutron flux and the dead time losses. About 2000 coincidence events were collected.

By fitting a theoretical spectrum calculated by means of the Ebenhöh-Bruinsma-Stuivenberg code to the experimental one the value

$$r_{nn} = (2.69 \pm 0.27) \text{ fm}$$

was evaluated. The energy resolutions and the geometry of the experimental setup as well as double scattering in the D_2O target were taken into account by a Monte Carlo simulation of the experiment. The used code includes S-waves only and charge dependence. The sensitivity of the result to inclusion of higher partial waves and tensor forces is small as was shown by comparison with calculations performed by Bruinsma and Doleschal. The quoted error gives only the experimental uncertainties.

The value of r_{nn} agrees within the errors with the effective ranges of the other nucleon-nucleon pairs. At the present accuracy of r_{nn} information on charge dependence can only be obtained from the scattering lengths. A substantial improvement of the result requires mainly further efforts in a more precise determination of the detector efficiences and the neutron flux.

EFFECTIVE INTERACTIONS FROM THE ENERGY DENSITY METHOD

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The energy density method can be used as a starting point to calculate excitation energies in nuclei. The Landau theory provides us with a way of constructing the effective interaction between elementary excitations directly from functionals. In the present work we compare the values of the Landau parameters derived from various functionals. The stability against spin and isospin excitations is very simply discussed in terms of F_0', G_0 and G_0', using the following expansion for the energy per particle in nuclear matter

$$\frac{E}{A} = E_0 + \beta\alpha^2 + \gamma s^2 + \delta u^2$$

where α, s and u are the isospin, spin and spin-isospin excesses respectively. The 3 coefficients β, γ and δ are given by

$$\beta = \frac{h^2 k_F^2}{6m^*}(1+F_0') \qquad \gamma = \frac{h^2 k_F^2}{6m^*}(1+G_0) \qquad \delta = \frac{h^2 k_F^2}{6m^*}(1+G_0') \ .$$

In addition, typical spectra in Pb-nuclei are calculated.

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BOSONIC VIEWPOINTS IN NUCLEAR STRUCTURE

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Through the advent of the quark structure of hadrons the conventional boson theory of nuclear forces has been seriously questioned; it thus appears worthwhile to summarize its successes and shortcomings: First of all, the 1-boson exchange of $\pi\eta\sigma\delta\omega\rho\phi$ leads to a natural and detailed interpretation of the experimental NN-scattering data.[1] It must, however, be stressed that the 2-pion exchange which was so far replaced by the exchange of an "unphysical" σ-boson (in other cases by dispersion relations) has to be calculated in all details: The corresponding higher diagrams (crossed pion lines and so-called box diagrams containing the Δ-resonance) lead, in fact, to a characteristic repulsive effect in the calculation of the properties of nuclear matter (influence of the Pauli principle in the additional intermediate states[2]). Explicit computations with the help of Brueckner's theory or the HNCA (both methods by now agree![3]) show that the direct insertion of an unchanged nuclear potential (satisfying the scattering data) leads to a definite disagreement (too high density) with experimental data. In addition, we have also checked through the introduction of bosonic variables into an enlarged state function of nuclear matter that the 2-boson exchange plays by far the most important role.[4] (A complete treatment of this exchange calls, in addition, for the explicit introduction of the π-π-interaction). As a second point the question arises whether boson theory is still suited for an interpretation of the well-known properties of the nucleon-antinucleon ($N\bar{N}$)--system. Here, the vector bosons, which so far generated the repulsive core in the NN-system (it is responsible for the saturation properties of nuclear matter as well as for the suppression of higher exchange terms), lead through their G-parity to a short-range attractive potential and hence to a new kind of strongly bound states and resonances.[5] Recent calculations, in particular a boson theoretical determination of the widths of these levels, showed, strangely enough, that relatively reasonable results could be obtained for the density of bound states and the energies and widths of the low lying resonances. It might be that the centrifugal barrier is reducing the effect of higher exchange terms which could by now be of great importance. On the other hand, it was realized that these results depend in a crucial way on the form factors (cut-off masses) which had to be introduced from the outset at the various boson-nucleon vertices. It would, of course, be desirable if these masses (for which characteristic values were obtained) could be determined from a quark theoretical viewpoint. The diameter of the well-known MIT--bag is in this respect by far too large and will lead to a complete change of this conventional theoretical description.

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THE BOUND STATE SOLUTION OF THE P-$\bar{P}$ SYSTEM WITH COMPLEX SQUARE POTENTIAL AND THE ANALYSIS FOR THE $\bar{P}$-NUCLEUS SYSTEM

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In the recent years, the narrow width resonances and the bound state structures have been discovered near the $\bar{p}$-p threshold[1]. The purposes of this paper are: 1) To explain the narrow width structures and 2) To discuss the possibility for the existence of the antiproton-nucleus bound states.

A. The bound state solution of the $\bar{p}$-p system with complex square potential

Using a complex square potential with finite depth to describe the complicated annihilation effect, we have solved this equation exactly for s, p, d waves, and have discussed the relations between the parameters and the real and imaginary parts of the eigenvalues. The energy levels raise as the depth parameter of the imaginary part k increases (while other parameters are fixed), but the widths are not always widened with it. After arriving at a limiting value, the widths becomes narrower with the increasing of k. We conclude that

1) In a reasonable region of the parameters, there exists eight narrow bound state structures with the width from a few Mev to several tens of Mev below threshold energy.

2) The perturbation method can not be applied to calculate the widths of the levels for a complex square potential when the depth of its virtual part is much larger than that of the real part.

3) In order to exhibit stronger absorption effect in the complex potential model, it is necessary not only to increase the depth of the imaginary potential, but also to increase the range of the potential.

B. The possibility for the existence of the bound antiproton-nucleus system

The possibility for the existence of the narrow width structure in the $\bar{p}$-nucleus system is discussed qualitatively by using the complex shell model theory. Qualitative analysis indicates that the repulsive coherent states might exist in the $\bar{p}$-nucleus system. The argument is that the sign of the width calculated from the residual interaction for these states is opposite to that calculated from the average field. The physical picture is very similar to the GDR in low energy nuclear physics. These structures are very salient in the antiproton-one nucleon hole nucleus system. Probably, it is useful to use these nuclei as targets to look for the bound antiproton-nucleus system.

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THREE-BODY FORCE IN BOUND TRINUCLEON SYSTEM WITH EXPLICIT Δ(1236) COMPONENTS†

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Efforts have been made[1] to calculate the properties of the trinucleon bound state in the framework of Faddeev equations, which, in addition to the dominant pure nucleonic configurations, also include the NNΔ wave-function components. One of the advantages of this approach is that the effect of the three-body force due to the excitation of one nucleon into Δ on the trinucleon binding energy can be studied in a natural fashion. However, the retardation effects of the exchanged mesons as shown diagrammatically in Fig. 1(a) with Δ in the intermediate states are left out in the above procedure.

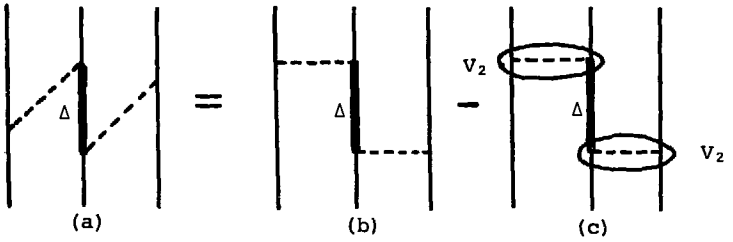


Fig. 1

The diagram of Fig. 1(a) can best be studied by noting that it is equal to the difference between Fig. 1(b) and Fig. 1(c), where Fig. 1(b) is a Feynman graph and the blob in Fig. 1(c) represents a transition potential V_2 for generating a NΔ configuration from two nucleons through one-pion exchange. Fig.1(b) has been investigated before[2] and the problem reduces to calculating the potential V_3 corresponding to Fig. 1(c) which can be done by using V_2 as derived in Ref. 3.

The contribution of V_3 to the binding energy of triton is being evaluated with a realistic wavefunction and the numerical results will be presented.

† Supported by the National Science Council of ROC.

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MULTIQUARK STATES IN NUCLEI[†]

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In the quark model of particle structure, nucleons are made up of more fundamental fermions called quarks. Since nucleons are known experimentally to have rather large sizes, interesting new multiquark states might be expected when nucleons overlap strongly either in nuclei or in nuclear reactions. Such multiquark hadronic states have been predicted both in the MIT bag model[1] and in potential models[2] to have masses higher than those of their constituent hadrons. A typical multiquark state exists partly in confined or closed colored channels and partly in unconfined or open hadronic channels. However, when theoretical models for these multiquark states are examined, they are found to have imposed constraints or boundary conditions even in the open channels. What then might be the physical significance of the calculated multiquark states which are confined by "perhaps artificial confining boundary conditions"[3]?

We argue that the boundary condition imposed in the open channels selects a discrete subset of scattering states in the continuum. These states will be called nodal states (NS), because the channel wave function in an open channel is supposed to vanish at the boundary. To the extent that the strong-interaction dynamics resides inside the boundary, the calculated masses of multiquark states give the energies of these NS. In other words, multiquark states are the internal parts of NS.

Nodal states are not resonances, but they are related to them. Their relation is studied with the help of an infinite square well coupled to a finite square potential. We find that to each NS whose internal normalization has significant contribution from the closed channel, there is associated a prominent resonance nearby in energy. We also find NS-resonance pairs in the entrance channel. Other NS-resonance pairs are expected from null states caused by the Pauli exclusion principle on scattering composites of identical fermions. In addition, "accidental" NS are expected in the entrance channel with no associated resonances at finite distances from the real momentum axis. We also find that sharp resonances and their NS tend to disappear from the elastic channel with energy average or strong inelasticities.

We make detailed nodal analyses of S-wave hadron-hadron phase shifts, of the type first proposed by Jaffe and Low.[3] We find a satisfactory agreement between observed and calculated NS expected of two- and four-quark nonexotic mesons. In dinucleon and exotic meson channels, the observed NS do not appear to be multiquark states. The possibility of finding additional structure in the $pp\,^1S_0$ phase shift due to an expected multiquark state is discussed. Finally we suggest that future resonance analyses should also be made in a manner consistent with the number and locations of NS implied by the phase shifts used.

[†]This work was supported partially by NSF Contract No. PHY78-15811.

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HIGH MOMENTUM BEHAVIOUR OF DEUTERON FORM FACTOR USING FULLY ANTISYMMETRIZED QUARK CLUSTERS

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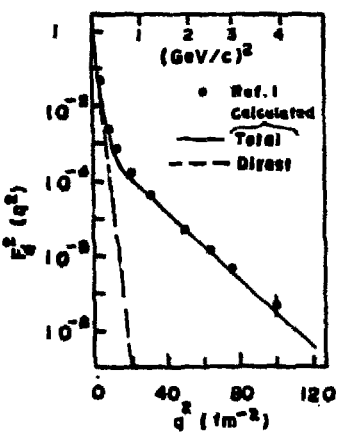
In the conventional nuclear dynamics high momentum components are not expected to arise due to nucleon-nucleon (N-N) interaction. The high momentum components observed in the elastic[1] and inelastic form factors of the deuteron as well as other nuclei[2] should therefore arise due to the internal structure of the nucleons. Previous attempts using dimensional counting in the framework of a scale-invariant quark model have qualitatively accounted for these high momentum components[3]. In this work we describe the deuteron by a fully antisymmetrized (in colour, spin and space) six quark wave function in the cluster model. Gaussian functions were used for both the 3 quark internal and relative (N-N) spatial wave function. The elastic form factor is then a sum of direct and exchange terms:

$$F_{total}(q^2) = F_{direct}(q^2) + F^{single}_{exchange}(q^2) + F^{double}_{exchange}(q^2)$$

The behaviour of the direct term depends only on the size of the deuteron while the exchange terms are more sensitive to the internal structure of the nucleon.

The contributions of the single and double quark exchange terms to the overlap integral are found to be equal. The two exchange terms add to increase the overlap in the triplet (S=1) state while they cancel each other in the singlet (S=0) state of the deuteron. Therefore the effective N-N interaction in our picture is stronger in the triplet state than in the singlet state.

As seen in the figure the calculations are in good agreement with experiment[3] for the elastic form factor of the deuteron only when the contributions from exchange terms are considered. Extension of this picture to N-N behaviour in other nuclei is also expected to explain the observed high momentum components without incorporating them in the N-N interaction.



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A COMPARATIVE STUDY OF PAIRING AND QUADRUPOLE COMPONENTS OF EFFECTIVE INTERACTIONS

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Schematic interactions such as pairing and quadrupole have played an important role in development of nuclear models. However, for most practical calculations one uses highly complex realistic or effective interactions. It would be of great interest to obtain a quantitative measure of pairing and quadrupole strength in a given effective interaction, and to compare pairing and quadrupole contents of many such interactions. The only available technique for doing so is the spectral distribution methods of French. We have examined a large number of effective interactions in ds and fp shells by constructing for each an empirical interaction (a linear combination of pairing and quadrupole operators) such that its correlation coefficient with the parent effective interaction is maximum, and the spectral widths for the two are identical. The correlation coefficients are calculated using traces of products of Hamiltonian operators in scalar as well as scalar-isospin spaces of m particles. Thus the varying nature of the interaction with the number of particles and isospin is clearly demonstrated. The calculations show that different effective interactions differ substantially in their pairing contents. The effects of core excitation and subsequent renormalisation of the interaction is also brought out.

Several different ways of parameterising the empirical interaction are considered, e.g. $H_{1,2} = SPE + a_{1,2} Q + b_{1,2} P$ where SPE denote the usual shell model single particle energies, Q and P define standard quadrupole and pairing operators, and suffixes 1 and 2 denote calculation of the correlation coefficient by taking averages over all the states with fixed particle number m or over all the states with fixed particle number m as well as T. The following table gives some representative values, for $(ds)^8$, where c_1 and c_2 are correlation coefficients, a_2 and b_2 are calcu-

	a_1	b_1	c_1	a_2	b_2	c_2
KUO-G	-0.070	0.142	0.753	-0.061	0.249	0.760
K + 12 FP	-0.106	0.135	0.779	-0.093	0.245	0.795
PW	-0.134	0.205	0.741	-0.120	0.355	0.754

lated for T=0, KUO-G denotes the G-matrix elements calculated by Kuo and Brown, K + 12 FP is defined by Halbert et al. and PW denotes the Preedom-Wildenthal interaction.

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SPHERICAL ORBIT OCCUPANCIES AND STRUCTURE OF EFFECTIVE INTERACTIONS FOR Z=30-40 NUCLEI

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In recent years, vast amount of data is getting accumulated for the nuclei with Z=30-40. So far little attention is paid to understand the structure of these nuclei from a microscopic stand point. As a part of our programme 'on the study of the structure of these nuclei', we calculated the spherical orbit occupancies in order to learn about the importance of $1g_{9/2}$ orbit. Norms of various IR parts (in scalar and scalar-T) of effective interactions are studied and also the variation in the strength (with particle number and isospin) of pairing and Q.Q operators, when the effective interaction is expressed as a linear combination of these two operators, is studied. Configuration proton-neutron spectral averages are used[1] to extract out the occupancies of $p_{3/2}$, $f_{5/2}$, $p_{1/2}$ and $g_{9/2}$ orbits (see table).

Nucleus	Protons		Neutrons	
	$f_{5/2}$	$g_{9/2}$	$f_{5/2}$	$g_{9/2}$
^{66}Ge	0.12 (0.05)*	0.02 (0.00)	0.60 (0.65)	0.16 (0.08)
^{70}Ge	0.13 (0.002)	0.03 (0.00)	2.62 (3.20)	1.57 (0.89)
^{72}Se	0.46 (0.29)	0.12 (0.06)	2.43 (2.83)	1.70 (1.21)
^{76}Se	0.97 (0.37)	0.10 (0.05)	4.08 (4.70)	4.12 (3.31)
^{76}Kr	1.79 (1.64)	0.57 (0.43)	3.43 (3.92)	2.71 (2.09)
^{80}Kr	2.68 (1.84)	0.45 (0.34)	4.70 (5.19)	5.63 (4.82)
^{82}Sr	3.76 (3.23)	1.21 (0.88)	4.81 (5.15)	5.61 (4.87)

We used Kuo's[2] Bare and renormalized interactions with ^{56}Ni as a core and the single particle energies (ESPE) are taken from ^{57}Ni spectrum. The present study clearly demonstrate that $g_{9/2}$ orbit is quite important for Z or N>34. Renormalization has the influence of enhancing $f_{5/2}$ orbit occupancy for protons and $g_{9/2}$ orbit occupancy for neutrons. A study of the induced single particle energies (ISPE) reveals that upon renormalization, ISPE get anticorrelated with ESPE and the v=1 part of the interaction gets reduced by 50% (goes from 65% to 30% of the total H). A complete study of occupancies and the structure of various effective interactions for Z=30-40 nuclei vis-a-vis the experimental results will be reported elsewhere.

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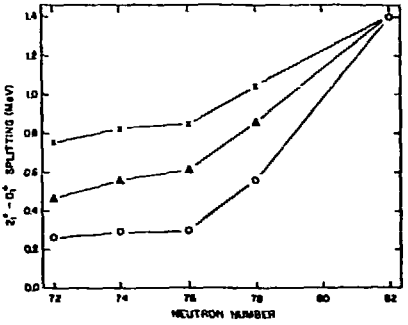
RENORMALIZATION OF THE IBA HAMILTONIAN FOR THE EFFECTS OF THE g-BOSON[+]

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In a recent letter, Otsuka, et al.[1]) discuss the necessity of renormalizing the single-boson energy ε used in their phenomenological IBA Hamiltonian when fitting low-lying energy levels in the Ba isotopes. We find[2]) that this renormalization can be explained in part by including the effects of a "g-boson" through the use of second-order Rayleigh-Schroedinger perturbation theory. The perturbation is taken to be the quadrupole-quadrupole, proton-neutron interaction $-\kappa Q_\pi \cdot Q_\nu$, where we have used a two-body quadrupole operator because we consider interacting pairs of fermions. Pairs of protons and neutrons, each in a single j-shell, are separately coupled to good angular momentum J_π and J_ν and the resulting proton and neutron states are then coupled to total angular momentum J. The intermediate states have either $J_\pi = 4$ or $J_\nu = 4$ (proton g-boson or neutron g-boson). It is found that the correction term consists of monopole-monopole, quadrupole-quadrupole and hexadecapole-hexadecapole terms. Only the monopole-monopole correction is considered here.

The energy denominator for each contributing second-order diagram is evaluated using the first 2^+ and 4^+ levels of ^{134}Te (protons) and ^{130}Sn (neutrons). The parameter κ is chosen using the single-particle values of Kisslinger and Sorensen[3]) because no two-body Q·Q parameters are available. The radial integrals in the calculation of the matrix elements of $Q_\pi \cdot Q_\nu$ were evaluated using harmonic-oscillator wavefunctions.



The resulting perturbative monopole-monopole correction is given by:

$$v_2(L=0) = -\kappa^2 A^{-4/3}[6\times10^{-6}(\hat{n}_\pi \hat{n}_{d_\nu} + \hat{n}_{d_\pi} \hat{n}_\nu) + 2\times10^{-5}\, \hat{n}_{d_\pi} \hat{n}_{d_\nu}]$$

where $\hat{n}_\pi(\hat{n}_\nu)$ is the number operator for proton (neutron) bosons and $\hat{n}_{d_\pi}(\hat{n}_{d_\nu})$ is the number operator for proton (neutron) d-bosons and where for the Ba isotopes $\kappa = 116A^{-2/3}$MeV. This correction was used to calculate the $2_1^+ - 0_1^+$ splitting for ^{128}Ba to ^{138}Ba; the results are shown in the figure above. The open circles are the results of Otsuka, et al.[1]), the triangles are the present calculation assuming a constant single-boson energy ε (the closed-shell value) in the IBA Hamiltonian renormalized in second-order by the effects of the g-boson, and the crosses are the splittings found using the same constant ε in the IBA Hamiltonian but with no correction due to the g-boson. The figure shows that while part of the renormalization is due to changes with neutron number in the matrix elements (crosses), the effects of the g-boson further renormalize the closed shell value of ε and these effects have the proper trend with neutron number.

[+]This work was supported in part by the NSF, Grant No. PHY-7902654.

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NUCLEAR STRUCTURE EFFECTS ON PARITY VIOLATIONS IN LIGHT NUCLEI

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The weak interaction between quarks produces a parity violating interaction between mesons and nucleons which in turn gives rise to parity mixing in nuclear levels. There has been a great deal of experimental effort to measure the effects of this parity mixing in light nuclei via γ-ray circular polarization, γ-ray asymmetry and parity forbidden α capture widths[1]. In this work we use microscopic models for the nuclear many-body wave functions in order to relate the various measured quantities to the strengths of the two-nucleon parity violating matrix elements. The new features of our work are (1) that the parity violating matrix elements between two states $\langle\psi_F|H_{pv}|\psi_i\rangle$ are calculated exactly using two-body transition densities (as opposed to an approximation in which H_{pv} is treated as an effective one-body operator) and hence (2) it is straightforward to investigate the sensitivity to nuclear structure problems such as model-space truncation and the related core-polarization contribution, spurious centre-of-mass motion and uncertainties in the effective (strong) interaction. In addition we calculate the E1 electromagnetic transition rates between the low-lying opposite parity states; these E1 matrix elements are very sensitive to the nuclear structure problems mentioned above.

The calculation of the two-body transition densities has been facilitated by the development of a new shell-model code at Oxford by N.S. Godwin and W.D.M. Rae[2]. In this code a linearly independent (but non-orthogonal) basis with definite (J,T) value is constructed by (J,T) projection from a suitably chosen random subset of the m-scheme states. Thus, matrix elements can be conveniently calculated between the m-scheme states in occupation number formalism but the dimension of the Hamiltonian matrix is just the number of states with a definite (J,T) value.

Our initial calculation has concentrated on the effects due to charged pion exchange which contribute to the $\Delta T=1$ matrix elements. The pion-nucleon weak interaction is particularly sensitive to the weak neutral currents between quarks[1]. Of particular interest are $\Delta T=1$ transitions in ^{6}Li, ^{10}B, ^{18}F, ^{19}F, ^{20}Ne and ^{21}Ne. We also plan to include other $\Delta T=0,1$ and 2 weak interactions on a phenomenological level.

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$K^\pi = 0^-$ BAND AND POSSIBLE OCTUPOLE DEFORMATION IN THE MASS REGION $220 \leq A \leq 235$[†]

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The low-lying $K^\pi = 0^-$ band is a most notable feature of even nuclides in the mass region $220 \leq A \leq 235$; occuring at an excitation energy of only 216 kev in the nuclide ^{224}Ra. Apart from rotational states, the 1^- member of this band is the lowest lying excited state to be found in even nuclides. In order to develop an understanding of nuclear structure in this mass region, and to explore the possibility of permanent octupole deformation, it is necessary to treat the interactions giving rise to this band in a non-perturbative way.

To study this region, we use the Hamiltonian

$$H = \sum_K \varepsilon_K N_K - \sum_{\lambda=1,3} \sum_{i,j} G_i^\lambda G_j^\lambda a_i^\dagger a_{-i}^\dagger a_{-j} a_j$$

$$- \sum_{\lambda=2,3} V_\lambda \sum_{i,j} \langle i | r^\lambda Y_\lambda^0 | j \rangle a_i^\dagger a_j \sum_{k,\ell} \langle k | r^\lambda Y_\lambda^0 | \ell \rangle a_k^\dagger a_\ell \quad (1)$$

where the symbols have their conventional meanings. Our pairing interaction is a somewhat more realistic version of monopole plus quadrupole pairing; the quadrupole and octupole interactions are of the multipole-multipole form.

The solutions[1] that we obtain for this Hamiltonian are of a generalized product form, in which pairing and particle-hole excitations are treated in a completely equivalent way; these solutions conserve particle number and parity. We are able to treat odd nuclides as well as even nuclides; high seniority states, and groups of up to five doubly degenerate levels in each of the product terms.

The code that we have developed is being applied to analyze the known levels in the odd and even mass isotopes of Ra, Th and U, to obtain a consistent set of single particle energies and interaction strengths. We apply the output of this analysis to study the lighter isotopes in this mass region. We shall point out the nuclides in this region that are most likely to display permanent octupole deformations, and the parity doublets that are the signature of this mode for $K \neq 0$ states.

[†]This work was performed under the auspices of the Division of Nuclear Physics of the U. S. Department of Energy.

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EFFECTIVE HAMILTONIAN IN THE PROTON-NEUTRON INTERACTING BOSON MODEL

T. Otsuka

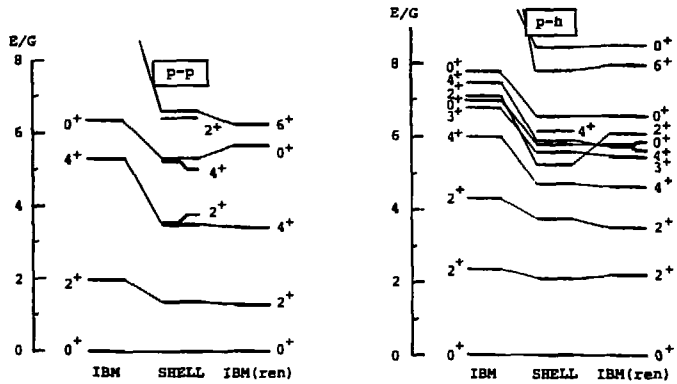
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The effective Hamiltonian of the proton-neutron interacting boson model (P-N IBM)[1]) is derived microscopically, and the P-N IBM is tested by comparing spectra produced by the derived Hamiltonian with those obtained by the shell model diagonalizations.

The nucleon configuration space is assumed for simplicity to consist of degenerate $g_{7/2}$, $d_{5/2}$, $d_{3/2}$, $s_{1/2}$ single particle orbits. The same space is taken for both of protons and neutrons. The proton-proton and neutron-neutron interactions are the surface delta interaction with strength G. The proton-neutron interaction is of the same type (strength 0.3·G) with the quadrupole-quadrupole part enhancement by factor 1.5. Results of the shell model calculations are shown in the figures (SHELL). Four particles are taken for both of protons and neutrons in the left figure ("p-p"), while four proton particles and four neutron holes are taken in the right figure ("p-h").

Collective nucleon pairs of 0^+, 2^+, 4^+, 6^+ are uniquely defined in the present cases[2]), and the 0^+ and 2^+ pairs correspond respectively to the S- and D-pairs introduced in the Otsuka-Arima-Iachello method (OAI) of the microscopic foundation of the P-N IBM[3]). By applying the OAI method to the present two cases, the P-N IBM Hamiltonians are obtained, and spectra produced by the Hamiltonians are shown in the figures (IBM).

Discrepancies between the shell model and the P-N IBM results are noticed in the figures. Effects of states which can not be constructed only by the S- and D-pairs are neglected in these P-N IBM calculations, and this causes the discrepancies. In order to take into account the effects, matrix elements of S-D states are renormalized by the Feshbach method[4]), and parameters in the P-N IBM Hamiltonian are calculated from the renormalized S-D matrix elements by the OAI method. Agreement with the shell model results is appreciably improved as shown in the figures (IBM(ren)). Note that the P-N IBM Hamiltonian still consists of one- and two-body terms. The P-N IBM seems to be a good approximation, if the renormalization effects are properly included.



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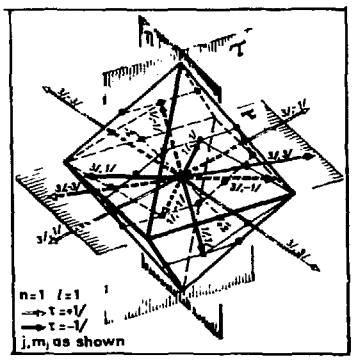
THE SYMMETRY OF ANGULAR MOMENTUM IMPOSES LIMITATIONS ON THE INDEPENDENT PARTICLE MODEL†

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It has been found[1,2] that the quantization of orbital, spin, and total angular momenta, in fields of central symmetry, corresponds to symmetries of regular or quasi-regular polyhedra, which inherently include this symmetry. For example, axes through the vertices of an octahedron correspond exactly to the orbital angular momentum $\ell=1$ (taken as a constant of motion; $m_\ell=0,\pm1$), while axes through the vertices of a dodecahedron correspond to $\ell=2$ ($m_\ell=0,\pm1,\pm2$) etc., with respect to a common quantization axis[1]. Also, axes through the middles of edges of a cuboctahedron correspond to the quantization of direction of the spin 1/2 (when spin is taken as a constant of motion, e.g. in s-states). When total angular momentum $\bar{j}$ is a constant of motion (and of course, in the general case, neither $\bar{\ell}$ nor $\bar{s}$ necessarily have as directions those previously described), the quantization of direction for $\bar{j}$ ($m_j=\pm1/2,\pm3/2,\ldots$) again corresponds to the geometry of the same polyhedra.

It has been proved that the "law of addition" of angular momenta is exactly valid for the $\bar{j}$ determined above. Thus, an assignment of a pair of values j,m_j, to each $\bar{j}$ can be made with confidence. In addition (since an even number of neutrons or protons or both always couple their $\bar{j}$ to a total $\bar{J}=0$, while an odd number of neutrons or protons or both always couple their $\bar{j}$ to $\bar{J}\neq0$), a distinction between $\bar{j}$ for protons ($\tau=-1/2$) and $\bar{j}$ for neutrons ($\tau=1/2$) is made. The case of p-states is presented in the figure, where each arrow is specified with a set of five quantum numbers (n,ℓ,j,m_j, and τ). Arrows with different τ are connected via reflections through each of the two τ-planes, while arrows with different n are connected via reflections through the n-plane of symmetry and are omitted.



It is very interesting to notice that p1/2-states lie on the n-plane and thus their reflections do not give any new $\bar{j}$, thus only 1p1/2-states may have an IPM motion. That is, when the ^{2}p1/2-states show up, these states have a dependent motion with the 1p1/2 states and consequently collective phenomena emerge. Also, p3/2-states may have an IPM motion only when $n\leq2$. For $n=3$ (well deformed region) neither 3p1/2-nor 3p3/2-states have an IPM motion. The same is true for all ℓ values and $n\geq3$ (superheavy region). Also, lack of independent $\bar{j}$, and thus dependent particle motion, exists in many areas of the chart of the nuclides. Thus, the symmetry of angular momenta, in fields with central symmetry, imposes limitations on the IPM which may cause changes in the shape (e.g. deformation) and the mode or excitation (e.g. rotational bands) of the corresponding nuclei. Of course, these limitations may not be the only source of such collective phenomena.

†Work supported in part by the Public Benefit Foundation ALEXANDER S. ONASSIS

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VALIDITY OF PPQ INTERACTION AND THE DYNAMIC DEFORMATION THEORY FOR B(E2) VALUES IN $^{146-150}$Nd

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The transitional nuclei near A=150 and A=190 provide a challenge for a consistent nuclear theory. The dynamic deformation theory of Kumar -Baranger (KB) based on pairing-plus-quadrupole interaction approximation[1] which provided an understanding of the shape transitions in Pt-Os-W region and ^{152}Sm has been used to study its validity in the weakly deformed nuclei. By taking into account the delicate balance between the pairing and quadrupole forces existing in the soft core nuclei we have shown that even for the N=88 transitional nuclei ^{152}Gd and ^{150}Sm, the PPQ model treated in the dynamic approach of KB explains the B(E2) values and branching ratios for interband transitions[2]. The $^{146-150}$Nd nuclei exhibiting a sharp variation in the E_4/E_2 ratio at N= 86-90, are studied to further test the validity of the PPQ model interaction and to elucidate the structure of these nuclei.

The calculated potential energy surfaces exhibit axially prolate symmetry and show a variation in β_0 from 0.24 to 0.20 and in V_{def} from 2.4 V to 0.5 V at N=90-88, with a spherical minimum at N=86 isotope. The calculated energy levels of $I \leq 4$ in the three lowest bands are reproduced fairly well. The B(E2; $0 \rightarrow 2$) for 2_1, 2_2 and 2_3 states and $Q(2^+)$ compare well with coulomb excitation data. The larger B(E2; $2_3 \rightarrow 0$)/B(E2; $2_3 \rightarrow 2$) ratio compared to B(E2; $2_2 \rightarrow 0$)/B(E2; $2_2 \rightarrow 2$) for the three isotopes, with the least difference in ^{146}Nd, and the variation with N is reproduced (Table 1)

Transition I_i $I_f/I_{f'}$	^{150}Nd EX	^{150}Nd TH	^{148}Nd EX	^{148}Nd TH	^{146}Nd EX	^{146}Nd TH
B(E2) ratios						
2_2 0/2	0.11	0.02	0.034(8)	0.07	0.11(3)	0.07
2_3 0/2	0.42	0.4	0.60(12)	0.60	0.15(2)	0.14
B(E2) e^2b^2						
0 2	2.72(4)	2.70	1.36(3)	1.72	0.76(2)	1.09
0 2_2	0.012(1)	0.005	0.020(2)	0.033	0.073(6)	0.053
0 2_3	0.076(5)	0.11	0.084(5)	0.065		0.014
$Q(2^+)$ eb	-1.69(37)	-1.50	-1.36(30)	-1.21	-0.72(20)	-0.91
$K^\pi = 0^+$ component in %						
2_2		94		64		51
2_3		6		38		50

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NEW SEMIEMPIRICAL MOMENT METHOD FOR CALCULATING AN EFFECTIVE NUCLEAR INTERACTION

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Past numerical calculations have demonstrated that the density of states for a finite space shell model is very near Gaussian in shape, and as a consequence, easily reproduced by a low moment expansion. Within the validity of the shell model we expect that the lower edge of the Gaussian to reproduce the experimental state densities up to some energy determined by truncation of the basis. Using the two moments of H as parameters we have recently shown that the Gaussian gives an excellent fit to the state densities for nuclei in the sdf region. To use these empirical moments to determine constraints on the Hamiltonian we turn to Ginocchio's moment reduction formula which has the form $\langle H^p \rangle = \sum_i f_i(n,Z,N) D_i(V,\varepsilon)$ where the f_i are known statistical factors completely determined from the neutron number (n), proton number (Z) and number of single particle states (N). The "basic sums" $D_i(V,\varepsilon)$ depend only upon the one and two body matrix elements of H. For example, the first moment of H is given by

$$\langle H \rangle = \frac{n}{N} \sum \varepsilon_i(n) + \frac{Z}{N} \sum \varepsilon_i(p) - \frac{1}{2} \frac{n(n-1)}{N(N-1)} \sum V_{ijij}(nn)$$
$$- \frac{1}{2} \frac{Z(Z-1)}{N(N-1)} \sum V_{ijij}(pp) - 2 \frac{nZ}{NN} \sum V_{ijij}(np)$$

The ε_i represents the single particle energies. We determine the "basic sums" by using them as parameters to fit the empirical moments of H for several nuclei. These basic sums represent empirical constaints on H. We then assume for V a sum of standard forms $V = V_1 F_1(r) + V_2 F_2(r)\, \vec{\sigma}\cdot\vec{\sigma} + \ldots$ and use the basic sums to determine the potential strengths V_i. This procedure represents a new method for using empirical information to determine a "global" effective interaction for the shell model region in question.

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MULTI-STEP SHELL MODEL METHOD

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A method to solve the shell-model equations within a basis that contains correlated pairs of particles was recently presented [1]. This method was found to be very suitable to make drastic truncations of the basis at low spin. In this contribution we extended the method given in [1] to analyse four-and six-particle systems outside closed-shell cores. The basic idea here is to use the two-particle spectrum components as building blocks to describe the four-particle system. Once the four-particle spectrum is obtained, we use this spectrum and that of the two-particle system as building blocks to describe the six-particle system. The formalism turns out to be very simple. We applied it to analyse the (p,t) reactions [2] leading to low-spin states in ^{204}Pb and ^{206}Pb and to calculate the high-spin states in ^{204}Pb. A complete calculation in the low-spin region would be impossible. There would be, for instance, several hundred 2^+ states in ^{204}Pb and several thousand in ^{202}Pb. Still, we expect that the lowest states in both nuclei, i.e. states close to the yrast line, are contained in a rather small subspace of the total space spanned by the corresponding correlated basis (which also spans the shell-model space).

We took the two-particle energies and wave-functions from the calculation by J. Blomqvist [3] which, including six single-particle levels, fits well most of the experimental data in ^{206}Pb. The calculated quantities in ^{204}Pb agree well with the experimental data. For ^{202}Pb the agreement is not as good but still reasonable [2]. In the table we give the calculated ^{204}Pb high-spin states.

State	21^-	20^-	20^+	19^-	$17^{(-)}$	17^-
Exp. [4]	—	—	—	6.098	6.073	5.664
Theor.	8.781	8.672	7.707	6.095	6.074	5.669
State	16^+	16^+	15^+	14^+	12^+	
Exp. [4]	5.348	4.887	4.302	4.135	3.516	
Theor.	5.239	4.849	4.306	4.075	3.436	

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A PRACTICAL APPROXIMATION TO SENIORITY SHELL MODEL

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The well known dimensionality problem of the Hamiltonian matrices in the shell model (SM) necessitates the need to develop approximate methods which should be tractable and at the same time should retain all the basics of the shell model. The Broken Pair Approximation (BPA) developed[1]) as a useful approximation to SM and an improvement over the projected quasiparticle method, genuinely meets these requirements. The BPA configuration space includes for an even number of identical valence nucleons all the seniority (ν) two components while it contains all configurations with $\nu \leq 4$ except $\nu = 4$ proton components and $\nu = 4$ neutron components for the non-identical (even-even) valence nucleons. Various expressions of the physical quantities like the matrix elements (m.e.) of the Hamiltonian, transition rates etc. are expressed in a simple, coherent form involving overlaps of the BPA basis states, and are ideal for numerical computation. The validity of BPA has been demonstrated[1]) for identical (even isotopes of Ca, Ni and N=50 even A nuclei) as well as for non-identical (even Zr isotopes) through an excellent agreement obtained between the BPA results and the corresponding SM results. The BPA calculations have also been performed for even isotopes of Zr, Mo and Ru nuclei using Sussex interaction m.e. and for even isotopes of Ca, Ti, Cr and Fe with Tabakin, Kuo-Brown and modified Kuo-Brown sets of interaction m.e. The results in the Zr-region are exceptionally good while those in the 2p-1f region are satisfactory. Some problems regarding the proper choice of the effective interaction m.e. in the 2p-1f region still remain. Some BPA calculations in the truncated valence space have been performed using renormalized sets of realistic interaction m.e. both in the Zr and 2p-1f regions, for the sake of comparison with the corresponding SM and the BPA results obtained with the phenomenological sets of interaction m.e. These renormalized sets of realistic interaction m.e. are calculated using projection method to incorporate the effects of the truncation of the valence configuration space. The agreement between the results in the full and in the truncated valence spaces is particularly impressive.

The main conclusions of the present investigation are : (i) The BPA has been found to be a valid and useful approximation to seniority SM and can be applied with confidence to other nuclear regions (ii) The Sussex interaction m.e. are able to reproduce reasonably well the observed nuclear properties in the framework of BPA (iii) Though the results in the 2p-1f region are reasonable, however, the problem of choosing the correct set of interaction m.e. still remains (iv) The projection method successfully incorporates the effects of the truncation of the valence space through the renormalization of interaction m.e.

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BAGS, DELTAS AND NUCLEAR MATTER

A.W. Thomas and S. Théberge

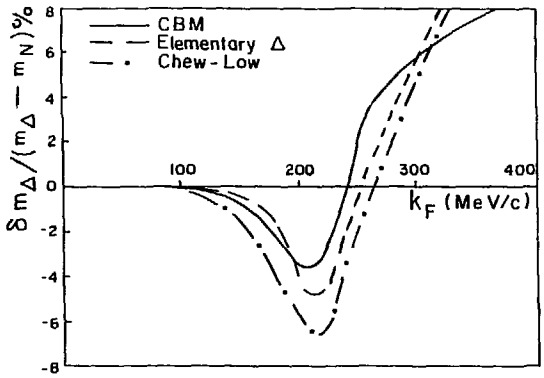
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Recently we have been led by considerations of chiral invariance in the MIT bag model[1,2], to a very natural inclusion of the pion as an elementary field coupled at the surface. The pion-nucleon system is then described by a Hamiltonian which contains $NN\pi$ and $\Delta N\pi$ couplings (with N and Δ bag states). The model specifies both the $\Delta N\pi$ and $NN\pi$ coupling constants and vertex functions. The latter are simply $[j_0(kR) + j_2(kR)]$, with R = 0.72 fm the bag radius which correctly reproduces the (3,3) resonance pion-nucleon scattering.

In such a model it is immediately clear that the self-energy of the P_{33} resonance in infinite nuclear matter will be altered from its free value, in a density dependent way, by the Pauli exclusion principle[3,4]. The figure shows the dramatic density dependence of the shift in the (3,3) resonance position in a number of models[4].



Since the intermediate range N-N attraction is known to arise partially through $N\Delta$ and $\Delta\Delta$ intermediate states, the effect of the mass increase shown in the figure will be a new saturation mechanism in nuclear matter. In ref. [4]) we constructed an approximate representation of this correction potential and showed that it moved the saturation point for nuclear matter significantly to the left of the Coester band towards the experimental point. Indeed for the Holinde-Machleidt (Δ,550) the Reid saturation point moves from (-17.3 MeV, 1.52 fm^{-1}) to (-15.6 MeV, 1.41 fm^{-1}).

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A CHIRAL SYMMETRY APPROACH TO THE NEUTRAL PION CONDENSATE AND THE ALTERNATING-LAYER-SPIN [ALS] STRUCTURE

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It has been shown, in the framework of the conventional OPE-Hamiltonian, that in the neutral pion condensed phase the nucleon system turns into a one-dimensionally localized state with a special spin order — the [ALS] state — where the spin direction changes alternately layer by layer.[1),2)] Recently Dautry and Nyman have shown another possibility of nucleonic structure in the neutral pion condensate by using the σ-model Lagrangian.[3)]

In the present paper we develop a chiral symmetry approach to the problem of the neutral pion condensate in pure neutron matter (z=0) by using the σ-model. By introducing "polar variables" $(\rho, \vec{\theta})$ s.t. $\sigma+i\vec{\tau}\vec{\pi}=\rho e^{i\vec{\tau}\vec{\theta}}$ into the σ-model Lagrangian, our approach acquires a close connection with the previous work[2)] and we can successfully discuss in detail two models mentioned above. After functionally minimizing the energy density with respect to each field variable, we obtain the following coupled field equations in the mean-field approximation:

$$[E_i + i\vec{\alpha}\vec{\nabla} - \beta M - f/m_\pi \vec{\sigma}\vec{\nabla}\theta_c]\psi_i = 0 \quad , \qquad (1\text{-a})$$

$$-\Delta\theta_c + \delta\mathcal{H}_{SB}^{(i)}/\delta\theta_c = f/m_\pi \vec{\nabla}\langle\psi^+\vec{\sigma}\psi\rangle_{gr.st.} \quad , \qquad (1\text{-b})$$

where $\delta\mathcal{H}_{SB}^{(1)}/\delta\theta_c = f_\pi m_\pi^2 \sin(\theta_c/f_\pi)$ and $\delta\mathcal{H}_{SB}^{(2)}/\delta\theta_c = \tilde{f}_\pi m_\pi^2 \sin(\theta_c/\tilde{f}_\pi)$ with $\tilde{f}_\pi = f_\pi/2$. Eqs.(1-a) and (1-b) are substantial ones in our approach and the physical features of the condensed phase are essentially revealed by solving these coupled equations self-consistently. We can see that the [ALS] structure is also derived naturally, from the viewpoint of the σ-model, as one of the sets of solutions in good approximation. On the other hand, the Dautry-Nyman model may lose its validity near the threshold and in lower densities.

We present some numerical results for each model (Fig. 1). The graphic behaviour clearly shows the different features between two models. Here we remark only one important point. For the [ALS] model, nonlinearity of the pion field never acts essential roles, i.e., the dependency on the type of symmetry breaking ($\mathcal{H}_{SB}^{(1)}$ or $\mathcal{H}_{SB}^{(2)}$) is almost absent. On the other hand, the Dautry-Nyman model is very sensitive to the selection of symmetry breaking. Furthermore we can see that the Dautry-Nyman model is never realized in the conventional OPE-Hamiltonian where nonlinearities are absent.

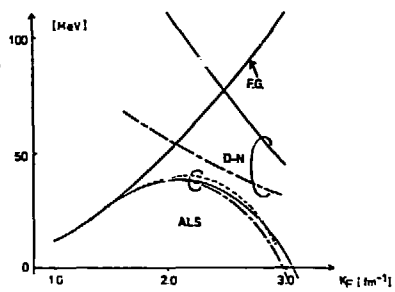


Fig.1. Density dependence of the ground-state energy per nucleon for the [ALS] model and for the Dautry-Nyman model taken from ref. 3). Solid curves and dashed-dotted curves correspond to two types of symmetry breaking, $\mathcal{H}_{SB}^{(1)}$ and $\mathcal{H}_{SB}^{(2)}$, respectively. Previous result[2)] is also shown for comparison (dashed curve).

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A STUDY OF NEUTRAL PION CONDENSATION AND ALS STRUCTURE WITH OBEP MODEL

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It has been shown that in the π^0-condensed state the baryons form the one-dimensionally localized structure with a special spin (-isospin) order called Alternating-Layer-Spin (ALS) structure.[1),2)]

Here, we propose an OBE (One-Boson-Exchange) approach for the purpose of obtaining the equation of state realistically and examining the role of the heavier mesons and then give preliminary results.

We construct an "effective interaction" for baryons from OBEP with the effective correlation function $g(r)=1-\exp(-\Lambda r)$ which simulate the one obtained from G-matrix calculations. For a given parameter Λ, a few coupling constants and mass of the "σ" meson which have the ambiguity even in the various OBEP's currently used are chosen in the following way. First, we calculate the ground state energy of the normal phase with direct and exchange energies. The remained parameters are determined by fitting the density dependence of the energy of the system to the existing G-matrix calculations. The coupling constants of the mesons to N-Δ and Δ-Δ are given by using the quark model. Then we calculate the energy of the ALS phase with thus determined "effective interaction", we present here two sets of parameters which equally reproduce an existing G-matrix calculation[3)] (mass in MeV).

Case	$\Lambda(m_\pi)$	f_π^2	m_π	f_ρ^2	m_ρ	f_η^2	m_η	g_σ^2	m_σ	g_ω^2	m_ω
[I]	6	1.01	140	24	770	7.5	550	57	447	251	780
[II]	6	1.01	140	34	770	11	550	57	466	232	780

The ground state energies of the ALS phase are shown in Fig. 1. We can see that the phase transition occurs at $\rho_0 \sim 2\rho_0$ (ρ_0; normal nuclear matter density). There is a characteristic difference between two cases: one ([I]) exhibits the first order phase transition and the other the second one. There is, however, a common feature that pressure $P=\rho^2\partial(E/N)/\partial\rho$ is positive and the condensed state can exist stably at least in the relatively high density region.

In Fig. 2, we show the contribution from each meson to the energy of the condensed or ALS phase in the case [I] of Table 1. The contribution the from "σ" and ω meson almost cancels each other and η meson never plays an important role. On the contrary, ρ meson, which acts against the phase transition plays a crucial role for the stability of the condensed phase. The details of the results will be reported elsewhere.

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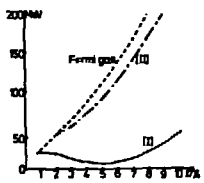


Fig. 1

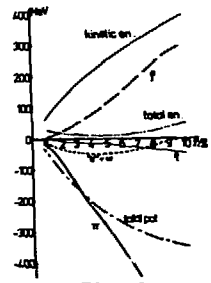


Fig. 2

INELASTIC PROTON SCATTERING ON CARBON AT 80 MEV

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In order to test theoretical predictions on precritical phenomena in nuclei [1], we performed measurements of inelastic proton scattering on carbon nuclei.

The incident particles were accelerated to an energy of 80 MeV by the isochronous cyclotron of Louvain-la-Neuve. The beam was momentum-analyzed before reaching a carbon target of 0.8 mgr/cm^2. A semiconductor-detector telescope identified the reaction products. It was made of a 2 mm-thick silicon surface barrier detector (ΔE) and one or two thick high purity germanium detector(s) (E). The latter were cooled to 77° K with a cryostat attached to a plateau rotating around the target. Typical beam intensities used ranged from 1 to 400 nA, depending on the detector angle. Great care was taken to maintain deadtime of the acquisition system below a few percent though a continuous monitoring of deadtime losses was available.

In the first stages of the experiment we used a telescope with a moderate resolution since the aim was to measure differential cross sections on easily separated levels of ^{12}C (ground state and excited states at 4.43 MeV, 7.65 MeV, 9.63 MeV and 12.7 MeV).

In a second step, the E-detector was a single Ge-detector sufficiently thick to stop 80 MeV protons. The overall resolution was greatly improved and we present differential cross sections of inelastic proton scattering from the excited states at 12.7 MeV ($J = 1^+$, $T = 0$) and 15.1 MeV ($J = 1^+$, $T = 1$). The angular range covered corresponds to a momentum transfer of 1 to 3 pion masses.

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NUCLEAR MEDIUM CORRECTIONS FOR THE Δ-ISOBAR

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It has become clear from recent investigations of medium energy reactions at energies around the 33-resonance, that for their quantitative understanding Δ-isobar degrees of freedom have to be included explicitly in a generalized many-body system[1]. Such a framework seems appropriate to treat medium corrections, which crucially influence the Δ-propagation in nuclei, in detail on a microscopic level.

For an approximate solution of the generalized many-body problem we proceed in three steps:

- we formulate the ΔN interaction in strong analogy to the NN interaction in the meson-exchange picture. Employing effective Lagrangians with coupling constants derived from the quark model the one-boson and two-boson exchange contributions are formulated; the resulting nonlocal, nonstatic and in general complex transition potentials reflect the coupling of the ΔN system to the elastic, the quasielastic and the true two-nucleon absorption channel;
- with this ΔN interaction as input a simplified Hartree-Fock approach for a single isobar being excited in a closed shell nucleus, is formulated. We investigate the structure of the low-lying Δ-states in an effective (complex-) single particle potential and draw connections both to the isobar-doorway approach[1] and to a recent effective shell model approach by Danos and Williams[2];
- allowing for the scattering of a pion on a correlated ΔN pair we investigate finite range and nonlocal corrections for the $\vec{\nabla}\rho(r)\vec{\nabla}$ term in the π-nucleus optical potential and compare - in a local approximation - its energy dependence with findings from Lin and Shakin obtained from a systematic fit of π-nucleus scattering data[3].

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JASTROW-TYPE CALCULATIONS FOR "NUCLEAR MATTER" WITH CORRELATION FUNCTIONS OBTAINED BY MEANS OF A DIFFERENTIAL EQUATION

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In this paper we report on low order calculations of the energy of "nuclear matter" which make use of correlation functions f(r) obtained by means of its well known differential equation, derived by functional variation of the constrained two-body energy functional with the healing condition $\rho\int(1-f(r))^2D(r)\,dr$ = constant (ρ is the density of nuclear matter and D(r) the radial distribution function of a free Fermi system). The potentials used are the test potentials IY and OMY-6. The energy is calculated by including the three body terms in its FIY-cluster expansion.

In this approach difficulty arises in the determination of the corresponding Lagrangian multiplier because of the unspecified value of the healing integral. We have chosen to determine the related to the Lagrangian multiplier λ parameter $\beta(\beta^2=m/\hbar^2\lambda)$ by minimizing the ratio $\left|\frac{E^{(3)}}{E^{(2)}}\right|$ of the third to the second term of the FIY expansion of the energy, in a way analogous to the one used previously in the case of a Λ-particle in nuclear matter[1]. From the two minima found for the ratio $\left|\frac{E^{(3)}}{E^{(2)}}\right|$ in the range of β values considered the choice of the second minimum(which is the less deep) appears more appropriate in order to achieve better convergence. With this choice for β the results obtained at equilibrium for both potentials for the Fermi wave number k_F, the energy per particle $E(E^{(1,2,3)})$, the healing integral H and the normalization integral in first order IN are:

IY : $k_F = 1.34$ fm^{-1}, E = - 3.6 MeV, H = . 174, IN = . 83

OMY-6 : $k_F = 1.52$ fm^{-1}, E = -10.0 MeV, H = . 241, IN = . 85

It is seen that the energy values lie above the ones found by other approaches , like those of ref.2 and 3. The choice of β corresponding to the second minimum appears therefore to lead to quite constrained correlation functions and we are currently investigating whether improvements can be made.

We thank Prof. M.E. Grypeos for useful discussions and constant interest in this work.

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INSTABILITY IN RELATIVISTIC NUCLEAR MATTER

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The nuclear matter consisting of equal number of neutrons and protons interacting with neutral scalar mesons and vector mesons is discussed. Such a nuclear matter is the simplest one that satisfies the nuclear saturation[1].

It is generally assumed that nucleons moves freely as the Fermi gas in nuclear matter. With such an assumption the system has the minimum binding energy at the normal density. But at the normal density the Fermi gas state is not stable against the density fluctuation.

To show this we evaluate the dimesic function $\varepsilon(k)$. The detailed form of $\varepsilon(k)$ is given in ref.2). The condition determining the collective modes is given by $\varepsilon(k)=0$. Thus we study the existence of the solution of eq.(2) with zero energy of the collective mode, which means the system considered is unstable against the above collective mode. In consequence there exists the solution in the wide range of the nucleon density including the normal density.

In this region the Fermi gas state is unstable and scalar meson condensation occurs. Non-relativistically the equidistant multi-layer structure (EMULS) is proposed to give lower binding energy than the Fermi gas state[3].

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DISADVANTAGE OF PION CONDENSATION

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Instability of the Fermi gas state in nuclear matter has been investigated by many authors. Specially instability of the system with nucleons and pions is known as the pion condensation[1]. The critical density of the pion condensation was estimated non-relativistically, and they concluded that the critical density was near the normal nucleon density. Thus it is suggested that there may exist precritical phenomena even in finite nuclei[2].

It is, however, shown that the critical density is much higher than the normal density by relativistic calculations for pion propagator[3]. This disadvantage of the pion condensation is mainly due to the contributions of intermediate anti-nucleon states. Such contributions are usually neglected in order to explain low energy experiments.

For this purpose contributions of scalar mesons are introduced to cancel the contributions of anti-nucleons. One of such models is the σ-model, and in this model the pion condensation is represented as a chiral rotation[4].

But the introduction of scalar mesons leads us to the scalar meson condensation[5]. It must occur at much lower density than the critical density of the pion condensation. That is, this suggests that pion condensation must be discussed in the basis of the scalar meson condensation instead of the Fermi gas. And we should seach for phenomena on the basis of the scalar meson condensation instead of the precritical phenomena of the pion condensation.

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"JASTROW-TYPE CALCULATIONS FOR "NUCLEAR MATTER" WITH CORRELATION FUNCTIONS OBTAINED BY MEANS OF A DIFFERENTIAL EQUATION"

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In this paper we report on low order calculations of the energy of "nuclear matter"which make use of correlation functions f(r) obtained by means of a differential equation. This is derived by functional variation of the constrained two-body energy functional. The constraint employed is the well known healing condition $\rho \int (1-f(r))^2 D(r) d\vec{r}$ = constant (ρ is the density of nuclear matter and D(r) the radial distribution function of a free Fermi system). The potentials used are the test potentials IY and OMY-6. The energy is calculated by including the three body terms in its FIY-cluster expansion.

The use of the healing condition as constraint in low-order calculations seems quite justified, since the healing integral is expected to give a rather good measure of the convergence of the cluster expansion. However one is facing the difficulty of determination of the corresponding Lagrangian multiplier because of the unspecified value of the healing integral. We have chosen to determine the related to the Lagrangian multiplier λ parameter β ($\beta = m/h^2 \lambda$) by minimizing the ratio $\left|\frac{E^{(3)}}{E^{(2)}}\right|$ of the third to the second term of the FIY expansion of the energy as it has been previously done in the case of Λ matter[1]. From the two minima found for the ratio $\left|\frac{E^{(3)}}{E^{(2)}}\right|$ in the range of β values considered to achieve better convergence we have selected the less deep one. The results obtained at equilibrium for both potentials for the Fermi wave number k_F, the energy per particle E ($E=E^{(1,2,3)}$) the healing integral H and the normalization integral in first order IN are given below:

IY : $k_F = 1.34$ fm^{-1} E=-3.6 MeV, H=.174, IN=.830

OMY : $k_F = 1.52$ fm^{-1} E=-10.0 MeV, H=.241, IN=.848

It is evident that results are satisfactory with respect to convergence. However the values of the energy lie above the ones obtained by Owen et al[2] with an f(r) derived suitably by means of a differential equation. They also lie above those obtained by low order calculations with analytic forms for f(r)[3]. The above suggest that our procedure is probably too constrained and we are therefore currently investigating possible ways of improvement.

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NUCLEAR MATRIX ELEMENT $g_s[\sigma \times Y_2]_1$ FOR THE SINGLE QUAST PARTICLE $1g\frac{7}{2} \rightarrow 2d\frac{5}{2}$ TRANSITION STUDIED BY THE PENETRATION EFFECT OF THE CONVERSION ELECTRON

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The parity change ($\Delta\pi$=yes) matrix elements $g_{\tau s\lambda}\tau^{\tau}[\sigma \times Y_\lambda]_J$ with λ=odd have been found to be uniformely reduced from systematic studies of M2γ, M4γ and first forbidden unique β transitions[1]. This suggests the reduction effect of the spin-isospin core polarization for the $\Delta\pi$=yes spin modes. This work deals with nuclear matrix elements without the parity change ($\Delta\pi$=no). The M1 $g_s[\sigma]$ and M3 $g_s[\sigma \times Y_2]_3$ moments are known to be reduced[2]. The γ matrix element $[\sigma \times Y_2]_J$ is very difficult to measure. We show in the present work an acculate investigation of the nuclear matrix element $[\sigma \times Y_2]_1$ through the penetration effect of the conversion electron corresponding to the ℓ-forbidden M1 transition. The 272 KeV single quasi-proton 1g7/2 → 2d5/2 transition in the semimagic ^{143}Pm was studied. Because the M1 γ is very much ℓ-forbidden, the $[\sigma \times Y_2]_1$ term comes out mainly in the conversion electron. The 272 KeV 1g7/2 state was excited by the ^{141}Pr (α,2nγ) reaction. The conversion electron was measured accurately by means of the TESS (triple focussing electron spectrum separator), and the γ-rays were measured simultaneously by a 55 cc Ge(Li) detector (Fig. 1). The efficiencies of the TESS and the γ-detector were calibrated by reffering to the rotational E2 transitions as shown in Fig. 2. Here we used the calculated E2 conversion coefficients. The conversion coefficient for the 272 KeV transition was measured as $(9.41 \pm 0.28) \cdot 10^{-2}$. Using the previously measured[3] M_γ=0.113μ_N, $Me=(g_s^p/\sqrt{6}) \cdot (r/R)^2 \cdot [\sigma \times Y_2]_1 = (0.93 \pm 0.26)\mu_N$. This leads to the reduction factor $g_s^{eff}/g_s^{free} \approx 0.62 \pm 0.17$ over the single quasi-particle value corrected for the small Q-Q force effect. This is of the same order as the M1 and M3 moments.

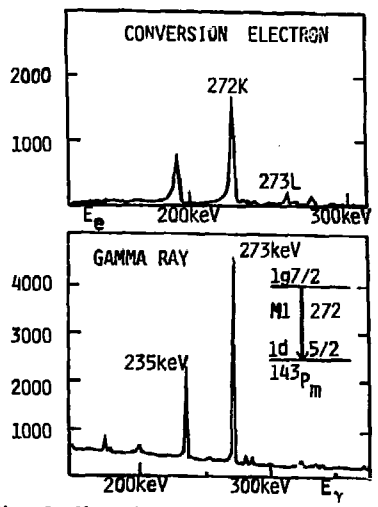


Fig. 1 Momentum spectrum of the conversion electrons and the γ rays from the ^{141}Pr(α,2nγ)^{143}Pm reaction.

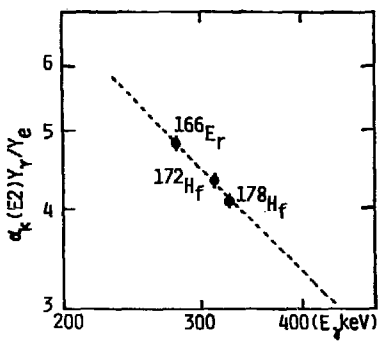


Fig. 2 The ratios of γ-yields to electron yield for E2 transitions and the relative γ-ray efficiency.

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FERMI LIQUID APPROACH TO THE ALPHA DECAY

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Feshbach's revolution in the nuclear reaction theory and recent development of the heavy ion physics have given a new impact for understanding the α-decay phenomenon. A new research direction has been created, namely the study of the effective interaction acting as an α-transition operator. The proposed models [1] for such a quantity, however, do not consider the α-decay process as a strong collective process in which large transferred momenta are involved, but rather they assume that the nucleus is a Fermi gas object. As a result the theoretical α-widths are constantly lower than the experimental ones.

Starting from Migdal's [2] quantum liquid treatment of the atomic nucleus we have proposed [3] a new α-transition operator satisfying the above-mentioned conditions and describing the α-clusterization in nuclei

$$T_\alpha = \kappa \, (\vec{e}_n \nabla) \, \rho(\vec{R}) \, \delta(\vec{\xi}_1) \, \delta(\vec{\xi}_2) \, \delta(\vec{\xi}_3) \quad .$$

Here κ is a universal constant, e_n is the unit normal to the nuclear surface, $\nabla\rho$ is the gradient of the mother nucleus density and ξ_i are the internal Jacobi co-ordinates of the four nucleons participating in the α-particle formation. This T_α is a model for the irreducible amplitude of the α-particle formation in the four particle channel. Using this operator we have calculated some favoured and unfavoured α-decay widths taking $\kappa = 1.044.10^7$ MeV fm^{13}. The nuclear states involved in the favoured transitions have the structure given by the BCS model, while for those involved in the unfavoured transitions we have used the two-particle RPA model. The s.p. basis was chosen to be the Saxon-Woods one. The relative motion part of the α-channel state is determined by a double-folded [4] Yukawa interaction potential. Due to the particular expression of our T_α operator we believe that the antisymmetry corrections to the α-widths should not be large.

Final conclusions can be drawn from some preliminary calculated widths. The ratios ($R = \Gamma_{exp}/\Gamma_{theor}$) of experimental to theoretical α-widths of favoured (g.s. → g.s.) α-decay of Ra and Rn isotopes are: 0.56 for ^{208}Ra, 1.00 for ^{210}Ra, 1.56 for ^{212}Ra, 2.95 for ^{214}Ra, 0.31 for ^{202}Rn, 1.6 for ^{206}Rn and 1.56 for ^{210}Rn. For unfavoured $^{210}Bi \rightarrow {}^{206}Tl$ α-decay we obtained:

$R(1^-,\text{g.s.} \rightarrow 1^-,0.304 \text{ MeV}) = 1.54$; $R(1^-,\text{g.s.} \rightarrow 2^-,0.266 \text{ MeV}) = 1.26$
$R(9^-,0.205 \text{ MeV} \rightarrow 1^-,0.304 \text{ MeV}) = 7.1$; $R(9^-,0.205 \text{ MeV} \rightarrow 2^-,0.266 \text{ MeV}) = 0.2$.

These results show an encouraging agreement with the experiment. Calculations in the actinide region are in process.

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CLUSTER MODEL FOR ALPHA-DECAY

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A model for alpha-decay is proposed. Alpha-particle, as such does not exist inside a nucleus. It exists in the form of an alpha-cluster. Such clusters exist at the nuclear surface region. The energy of an alpha-cluster is of the order of 20-24 MeV. In our model, alpha-cluster is formed out of an alpha-particle which is subjected to a strong perturbing force. It is the alpha-cluster that decays by tunnelling process. Once the alpha-cluster is out of the perturbing force, it becomes an alpha-particle. On this basis, we should expect a strong correlation between the cluster energy and the decay rate. Such correlation exists.

The total Hamiltonian of the system is

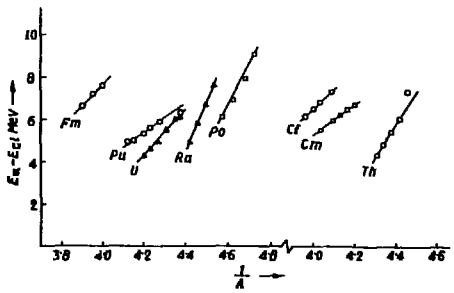
$$H = H_{\alpha} + H_{per} \qquad (1)$$

where H_{α} is the Hamiltonian of a free alpha-particle. Since clusters exist at the nuclear surface, we are interested in the form of H_{per} at the surface region. We have approximated H_{per} by a δ-type potential.

$$H_{per} = G\,\delta(r - R_0) \qquad (2)$$

where G stands for the strength of the perturbing force. The perturbing energy E_p is proportional to the radial integral R_{nl}. R_{nl} can be correlated to the nuclear parameter by taking the wave function of free alpha-particle as harmonic oscillator type[1]. R_{nl} is proportional to $(mw/\hbar)^{3/2}$

If we assume that the expectation value of the potential energy is one-half the oscillator energy, we get A^{-1} dependence of R_{nl}. Experimental values of $E_p = (E_{\alpha} - E_{\ell})$ shows such dependence as shown in the figure.



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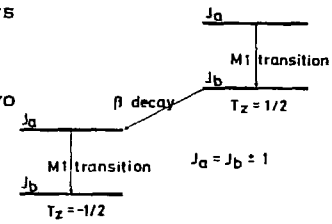
PRECISION β-DECAY BRANCHING RATIOS OF POSITRON EMITTERS, ^{21}Na ^{25}Al, ^{29}P and ^{33}Cl

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Precise ft values for β-decay branches of the mirror nuclei were determined in order to analyze the magnetic dipole transitions and the analogue β-decays for the case shown in the figure. The branching ratios were measured from the energy spectrum of the γ-rays following the β-decay branches and the 511keV-positron-annihilation γ-rays. The (p,γ) reactions were used to produce the β-emitters. The resonance charactor was useful because of the low back ground activities. It was possible to estimate the effects of the small back ground by an off-resonance experiment. The pulsed beam method was used for the production. The energy spectrum was measured by a 48cc Ge(Li) detector during the off-beam periods. The targets were completely covered by an Al plate of 10mmt, right after the production, to confine β^+ close to the targets and to symmetrize the positron distribution. The difference of the effective solid angles of the detector for the γ-rays and for the 511keV γ-ray was minimized to about 2±1 %. The relative efficiencies of the Ge(Li) detector were calibrated using the γ-ray sources, ^{22}Na, ^{56}Co, ^{108m}Ag and ^{152}Eu, with the same arrangement and detection system.

Present results of branching ratios are shown in the table together with the refined ft values. The matrix elements $\langle J_a J_a \tfrac{1}{2}\tfrac{1}{2} | \Sigma \tau_3 \sigma_+ | J_b J_b \tfrac{1}{2}\tfrac{1}{2} \rangle$ and $\langle J_a J_a \tfrac{1}{2}\tfrac{1}{2} | \Sigma \tau_3 \ell_+ | J_b J_b \tfrac{1}{2}\tfrac{1}{2} \rangle$ are calculated from the ft and the relevant $B_\pm$(M1) using the one body operator, and assuming the charge symmetry of the nuclear force and the negligible asymmetry due to Coulomb force[1].
The matrix elements show similar behaviors as the values obtained from ft for $J_b \Rightarrow J_b$ and the mirror magnetic moments[2] change with A.



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^{Z}A	$J_b \rightarrow J_a$	branching ratio(%)#	partial $t_{1/2}$(s)#	ft (s)	$\langle \tau_3 \sigma_+ \rangle$	$\langle \tau_3 \ell_+ \rangle$
^{21}Na	3/2 5/2	5.3(1)	428(10)	$3.83(9)\cdot10^4$	0.264(4)	1.03(3)
^{25}Al	5/2 7/2	0.78(2)	915(30)	$2.35(7)\cdot10^4$	0.357(7)	1.08(7)
^{29}P	1/2 3/2	1.32(4)	315(9)	$6.2(2)\cdot10^4$	0.180(3)	0.66(3)
	1/2 3/2	0.41(3)	1000(70)	$1.6(1)\cdot10^4$	0.35(1)	1.36(10)
^{33}Cl	3/2 1/2	0.45(3)	563(33)	$4.9(3)\cdot10^5$	0.090(2)	0.18(4)
	3/2 5/2	0.45(3)	560(40)	$9.6(7)\cdot10^4$	0.166(6)	0.65(6)
	3/2 5/2	0.37(2)	685(40)	$1.8(1)\cdot10^4$	0.38(1)	1.60(10)

#Present results.

DIRAC HARTREE APPROXIMATION AND THE NUCLEON-NUCLEUS OPTICAL POTENTIAL†

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A nucleon-nucleus optical potential for use at low and intermediate energies is discussed from the point of view of the relativistic Hartree approximation[1-6]. A number of interesting features arise from the relativistic treatment such as the natural occurrence of cross terms between the nuclear and Coulomb potentials and a large spin orbit potential.

The Dirac equation used is written

$$\{c\,\bar{\alpha}\cdot\bar{p}+\beta[mc^2+U_s(r)]+[U_o(r)+V_c(r)]\}\,\psi(\bar{r}) = E\,\psi(\bar{r}),$$

where $U_s(r)$ is a Lorentz scalar potential and $U_o(r)$ is the time-like component of a Lorentz four-vector potential. The Coulomb potential $V_c(r)$ is present for charged projectiles. The above equation is solved to obtain nucleon-nucleus elastic cross sections and analyzing powers for a number of different spin zero, isospin zero targets for a range of energies. The results of these calculations are compared with experiment and with the results of other analyses.

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SOLITON-POTENTIALS

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Recently it has been proposed to treat the nonlinear classical Korteweg-de Vries equation (KdVE),

$$u_t(x,t) - 6\cdot u\cdot u_x + \beta\cdot u_{xxx} = 0; \quad u_x =: \partial u/\partial x; \tag{1}$$

as a means of studying the nuclear potential. In here we first provide some soliton-pedagogy and discuss then the main arguments in favour of such a use of the KdVE and its soliton solutions:

(i) Starting from the Hamiltonian

$$H = -\beta\cdot\sum_i \frac{\partial^2}{\partial x_i^2} - 2\sqrt{2\cdot V_o}\sum_{i<j}\delta(x_i-x_j);\ \beta =: \hbar^2/2m; \tag{2}$$

the solutions of the corresponding TDHF equation are given by

$$f(x) = -(2V_o)^{1/4}\cdot \mathrm{sech}\left[\sqrt{V_o/2\beta}\cdot x\right], \tag{3}$$

which in turn leads to

$$u_1(x,0) = -\sqrt{2V_o}\, f^2 = -V_o\cdot \mathrm{sech}^2\left[\sqrt{V_o/2\beta}\cdot x\right], \tag{4}$$

i.e. the one-soliton solution of the KdV for t=0. Thus the TDHF-equation may be cast into the form

$$-\beta\cdot f_{xx} - (E-u_1(x,o))\cdot f = 0. \tag{5}$$

(ii) Historically, the KdVE itself could not be solved completely until it was discovered that its solutions u(x,t) are via

$$-\beta\cdot\psi_{xx} - (E-u(x,t))\cdot\psi = 0 \tag{6}$$

related to a Schrödinger problem. Solving Eq. (6) this transformation (leading to the inverse scattering method) allowed for the complete solution of Eq. (1).

(iii) The confinement problem consists basically in the task of solving two coupled nonlinear differential equations,

$$D_\psi(g,V)\cdot\psi = 0 \quad \text{and} \quad D_V(g,\psi)\cdot V = 0;\ \ g = \text{const}; \tag{7}$$

with prescribed boundary conditions. The most elementary requirements are only fulfilled by soliton supporting nonlinear evolution equations for ψ and V, resp.. They are that the appropriate solutions should vanish for large distances and that they be singular for a vanishing coupling constant g.

After these preliminaries one- and more-soliton solutions of the KdVE are applied to nuclear physics. It will be shown that the results support the underlying philosophy. The implications of the approach are discussed.

PAULI PRINCIPLE, OPTICAL POTENTIAL AND EFFECTIVE INTERACTIONS FOR TWO-FRAGMENT NUCLEAR SCATTERING AND REACTIONS[†]

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The introduction of the full complexities of the Pauli principle (PP) into nuclear reaction theory involves the simultaneous consideration of all channels which are physically equivalent by virtue of particle identity. Because of this and the difficulties in dealing with many-particle multichannel scattering equations the PP has never been adequately incorporated into either the microscopic theory of the optical potential (OP) or into the many variants of the coupled-reaction channel (CRC) formalism. We have shown how the PP can be taken into account in a consistent and practical manner both in the theory of the OP and in a generalized CRC formalism (GCRCF).

The idea central to our development is the recognition of the constraints imposed upon the off-shell behavior of the transition operators $T_{\alpha,\beta}$ for rearrangement scattering into physically equivalent two-fragment channels α and β imposed by the usual reality properties of the OP and the GCRCF effective potentials (EP). We require that the antisymmetrized OP possess no elastic unitarity cuts corresponding to the any of the physically equivalent channels. This is a special case of the demand in the GCRCF that the EP be free of unitarity cuts in all the coupled channels. We show that the off-shell unitarity relations for $T_{\alpha,\beta}$ imply that the simplest off-shell extension which satisfies our constraints is that proposed by Alt et al.[1]). With this form for $T_{\alpha,\beta}$ and using modern methods for constructing permutation symmetric scattering integral equations we develop a complete and consistent theory of the OP and the GCRCF with the PP included in a practical manner.

Several sets of dynamical equations for the OP and the EP which are appropriate to different physical circumstances are found. These equations are well-defined connected-kernel scattering integral equations which permit the systematic calculation of corrections to low-order approximations.

As applications we have considered low-density-type approximations to the OP. We show how the usual multiple-scattering prescriptions (e.g. Takeda-Watson) as well as the resonating-group method emerge in a systematic fashion and that the PP corrections to these approximations can be calculated without any substantial increase in computational difficulty. We have also obtained similar results in the GCRCF.

It should be stressed that our overall approach is essentially formalism independent. As an illustration of this independence we have found the correct counterparts of the usual Lippmann-Schwinger equation for the OP and we have investigated the generalization of the canonical Feshbach formalism with the complete inclusion of the PP.

[†]This work was supported in part by the National Science Foundation under Grant No. PHY 78-26595.

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HAVE ALPHA TRANSFERS ANYTHING TO DO WITH THE PAIRING FORCE?

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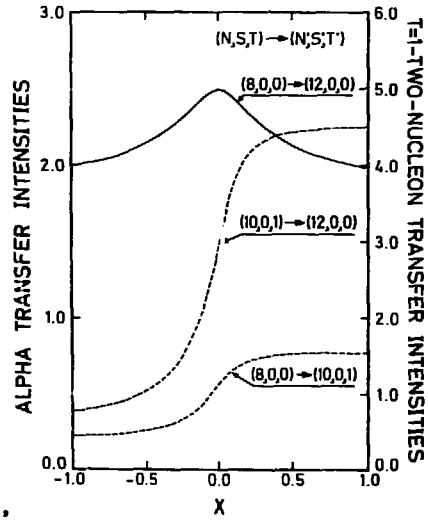
We investigate the assumption that α-transfer enhancements are mostly linked to the isovector pairing interaction. We consider systems of even number of nucleons moving in several ℓ-shells of total degeneracy Ω. We add, in the residual hamiltonian, a "deuteron" type of interaction to the usual T=1 pairing force,

$$H=-(1+x)(P^{+}.P)-(1-x)(D^{+}.D)$$

with

$$P^{+}_{\nu}=\{a^{+}a^{+}\}^{L=0,S=0,T=1}_{0\ ,\ 0\ ,\ \nu} \qquad \text{and} \qquad D^{+}_{\mu}=\{a^{+}a^{+}\}^{L=0,S=1,T=0}_{0\ ,\ \mu\ ,\ 0}$$

These operators, together with the number operator, the spin and isospin, and $W_{\mu,\nu}=\{a^{+}a\}^{0,1,1}_{0,\mu,\nu}$ are associated to the generators of the O_8 group[1]. We use this algebra to build the matrix elements of H. We consider a seniority-zero basis corresponding to the O_8 irreducible representation $(\Omega,0,0,0)$ and good N, S and T. In the pure pairing limit(x=1) we obtain isospin "rotational"bands following the T(T+1) law and the spin degree of freedom shows an almost "vibrational" behaviour. The rôles of S and T are interchanged when x is replaced by -x. Each of the two channels present in H induce a kind of correlation that interferes destructively with the other. For x=0, H corresponds to the Casimir operator of SU_4.



In the figure we show, for Ω=6, the square of the matrix element for a four(α-like)nucleon transfer together with two (T=1)two-nucleon transfers. These correspond to the two particle matrix elements in which the α-transfer shown would be factorized if only the pairing degree of freedom were present. They are seen to increase making full use of the correlations built by the pairing component of H. The maximum for x=0 is related to the fact that the α-transfer operator preserves the SU_4 symmetry.

We can conclude from our study and that of ref.[2]) that the α-transfer may present enhancements even when the pairing interaction is small and, thus, support the interpretation that it is, to a large extent, insensible to the two body correlations operant in nuclei.

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MEASUREMENT OF ANALYZING POWERS IN QUASI-ELASTIC SCATTERING†

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In a recently completed $^{40}Ca(\vec{p},2p)$ experiment using a 200 MeV polarized proton beam, cross sections and analyzing powers were measured as a function of energy sharing between the outgoing protons. Scattering from $1d_{\frac{3}{2}}$, $2s_{\frac{1}{2}}$, and $1d_{\frac{5}{2}}$ hole states was observed. We have compared the data with DWIA calculations[1]) which included the effects of spin-orbit terms in the optical potentials and utilized a half off-shell (Mcngan) prescription for pp scattering. The observed analyzing power for scattering from the $2s_{\frac{1}{2}}$ state is shown in Figure 1 as a function of the two body cms scattering angle, together with the results of DWIA calculations both with (solid line) and without (dotted line) spin-orbit terms in the optical potentials. In the latter case the predicted analyzing power is essentially given by the free p-p analyzing power (A) obtained from phase shifts. The observed analyzing powers for the $1d_{\frac{5}{2}}$ (x) and $1d_{\frac{3}{2}}$ (0) states are shown in Figure 2 as a function of the energy difference between the two outgoing protons, for the case where both outgoing protons are produced at 30° to the beam. Also shown are the DWIA predictions, which in this case are mostly sensitive to the correlation term (C_{NN}) in the nucleon-nucleon interaction. These results may be interpreted as supporting the assumption, implicit in DWIA, that the nucleon-nucleon interaction, and in particular the values of A and C_{NN}, are not significantly altered when the interaction takes place inside the nucleus.

FIGURE 1

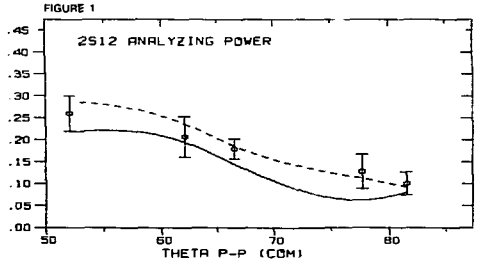
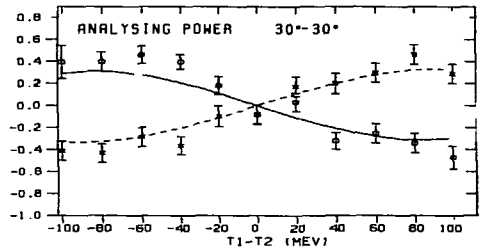


FIGURE 2



†This work was supported by NSERC, Canada, and the US National Science Foundation.

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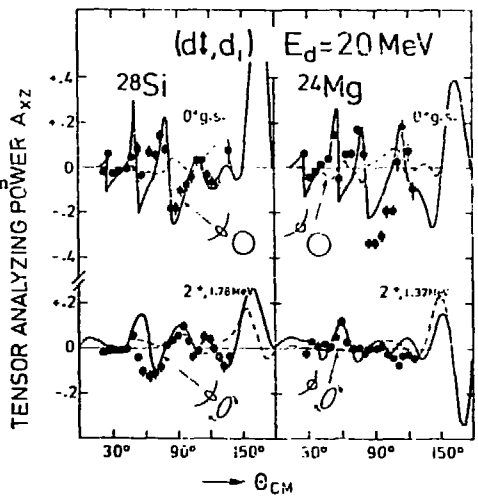
EVIDENCE FOR NUCLEAR QUADRUPOLE-QUADRUPOLE INTERACTION IN THE INELASTIC SCATTERING OF TENSOR POLARIZED DEUTERONS+)

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With aligned (tensor polarized) deuterons we have measured at 20 MeV the elastic and inelastic scattering on the two extremely deformed nuclei ^{28}Si (oblate, β_2=-.38) and ^{24}Mg (prolate, β_2=+.45). The figure shows the results for the observable A_{xz}, which exhibits the largest effect from the alignment of the deuteron quadrupole moment. While the elastic scattering data behave similar for ^{28}Si and ^{24}Mg, differ the inelastic data considerably in their angular distributions.

The drawn lines show CC-calculations with (full) and without (dashed) tensor interaction. The tensor potential is taken to be purely imaginary corresponding in its parameters to the conception of folding. This is in accordance with ref. 1 and also with our results from a systematic search on nuclei across the periodic table. The other parameters of the calculation are fixed by the analyses of the vector polarized measurements[2] resulting thus in a quasi parameter free calculation for A_{xz}.



The dashed lines simulate the scattering of a spherical deuteron, i.e. without tensor interaction. The analyzing powers for both scattering states in both nuclei are calculated hereby to be small and mostly out of phase with the data. The inclusion of the tensor potential in the elastic scattering leads to a phase correct, nearly quantitative reproduction of the data. The pronounced difference between dashed and full lines demonstrates the strong influence of the deuteron quadrupole moment on A_{xz}. In the elastic scattering to the 2^+_1-state also the deformed target nucleus is aligned in addition to the projectile. The inclusion of the deuteron quadrupole moment and the quadrupole-quadrupole interaction by means of a deformed tensor potential[3] leads to a description for the 2^+_1-scattering (full lines), which reproduces the characteristic features of the data. The difference between full and dashed lines in the inelastic scattering acounts for the significant contribution of the quadrupole-quadrupole interaction in the scattering of two deformed and aligned nuclei.

+) supported in part by the Bundesministerium für Forschung und Technologie

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MEASUREMENT OF PARITY VIOLATION IN PP-SCATTERING AT 45 MeV

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Parity violation in proton-proton scattering has been studied by measuring the longitudinal analyzing power $A_L = (\sigma^+ - \sigma^-)/(\sigma^+ + \sigma^-)$, where $\sigma^\pm$ are the (total) scattering cross sections for a longitudinally polarized beam of positive and negative helicity.

The polarized protons are produced in an atomic-beam type polarized-ion source and accelerated in the SIN injector cyclotron. RF-transitions, which act on the neutral atomic beam, are used to switch the polarization between $\pm$ 0.83 every 30 msec. Protons scattered in a 100 atm H_2 target by 25^0-55^0 enter a cylindrical ionisation chamber filled with 1 atm H_2 which is coaxial with the beam axis. To obtain $\sigma^\pm$, the currents from the ionisation chamber and a Faraday cup are integrated during 20 msec. Individual 20 msec measurements are separated by 10 msec dead time, during which specially designed on-line digital beam monitors[1] move through the beam thus providing a continuous record of the intensity- and the polarization-distributions.

The following instrumental effects, which could produce systematic errors, have to be considered:

(1) Transverse polarization components in the beam
(2) Beam intensity modulations correlated with spin reversal
(3) Beam position and emittance modulations correlated with spin reversal
(4) Asymmetry from the (parity violating) β-decay of activated nuclei
(5) Influence of the regular analyzing power in double scattering
(6) Spurious electronic effects

The result[2] obtained in a one week measurement is: $A_L = (-3.2 \pm 1.1) \cdot 10^{-7}$. The measurements are continuing and we hope to present at the conference a result with a further reduction of the uncertainties.

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N-BODY SCATTERING EQUATIONS FOR NUCLEAR REACTION THEORY

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Recently the effect of virtual particle exchange in nuclear reaction mechanisms has been studied by Greben and Levin[1] and has been found important. These effects are incorporated in an N-body scattering equation formalism of Faddeev-Yakubovski, Alt-Grassberger-Sandhas, or Kouri-Levin-Tobocman. These equations, however, have a complicated structure in the kernels, as they incorporate all the Green's functions of the N-1, N-2, .., two-body subsystems.

We want to present here N-body scattering equations which have a simpler structure of kernels, and which could then be used as a starting point for nuclear reaction theory. The kernels of our equations contain just the bound state part of the subsystem Green's functions, which requires only the knowledge of N-1, N-2, .., two-body bound states and binding energies. Let us define: σ describes a subsystem, b is an overall quantum number, ϕ^b_σ is a bound state wave function, E^b_σ is the correlated binding energy, $\vec{p}$ stands for all the Jacobi momenta, G_0 is the free Green's function, V is the potential, V_σ is the interaction of particles in cluster σ, $V_\sigma = V - V_\sigma$, $ES^b_\sigma = \{\vec{P}_{os} | E - E^b_\sigma - P^2_{os} = 0\}$ is a subsystem energy shell, $\tilde{\omega}^b_\sigma(p)$ is a function taking the value 1 if $p \in ES^b_\sigma$, 0 if $|\vec{p} - \vec{p}_{os}| > \frac{1}{3}$ distance of ES^b_σ to the closest shell $ES^{b'}_{\sigma'}$ with $\sigma \subsetneq \sigma'$ or $\sigma' \subsetneq \sigma$, and an arbitrary interpolation in between.

$$I^b_\sigma = \int d\vec{p}\, |\vec{p},\phi^b\rangle_\sigma \langle\vec{p},\phi^b|\,, \qquad \langle\vec{p}',\phi^{b'}| \frac{1}{P^b_\sigma(z)} |\vec{p},\phi^b\rangle_\sigma = \frac{\delta(\vec{p}' - \vec{p})\delta_{b'b}}{z - E^b_\sigma - p^2}\,,$$

$$\langle\vec{p}',\phi^{b'}| \omega^b_\sigma |\vec{p},\phi^b\rangle_\sigma = \delta(\vec{p}' - \vec{p})\delta_{b'b}\, \tilde{\omega}^b_\sigma(p)\,, \qquad O^b_\sigma = \omega^b_\sigma I^b_\sigma$$

The scattering equations read where σ,b of the incoming channel is kept fixed

$$I^{b'}_{\sigma'}(1 - \omega^{b'}_{\sigma'} G_0(z) V_{\sigma'}) \frac{1}{P^{b'}_{\sigma'}(z)} I^{b'}_{\sigma'} |R^{b'}\rangle_{\sigma'} = O^{b'}_{\sigma'}\Big(G_0(z)\bar{V}_\sigma |\vec{p}_{os},\phi^b\rangle_\sigma + G_0(z) V G_0(z) |R\rangle_0 +$$

$$G_0(z)\bar{V}_{\sigma'} \frac{1}{P^{b'}_{\sigma'}(z)} |R^{b'}\rangle_{\sigma'} + G_0(z) V \sum_{\sigma'' b''} \bar{\delta}_{(\sigma' b', \sigma'' b'')} \frac{1}{P^{b''}_{\sigma''}(z)} |R^{b''}\rangle_{\sigma''}\Big)$$

$$|R\rangle_0 = G_0^{-1}(z)\Big(1 - \sum_{\sigma' b'} O^{b'}_{\sigma'}\Big)\Big(G_0(z)\bar{V}_\sigma |\vec{p}_{os},\phi^b\rangle_\sigma + G_0(z) V G_0(z) |R\rangle_0 + G_0(z) V \sum_{\sigma'' b''} \frac{1}{P^{b''}_{\sigma''}(z)} |R^{b''}\rangle_{\sigma''}\Big)$$

One can show[2,3] that the on-shell scalar products with $|R^b\rangle_\sigma$ and $|R\rangle_0$ give the physical transition amplitudes and the equations remain unique going into the real axis.

*NATO Fellow from Justus-Liebig-Universität, Giessen, West Germany.
†Research sponsored by the Division of Basic Energy Sciences, U.S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation.

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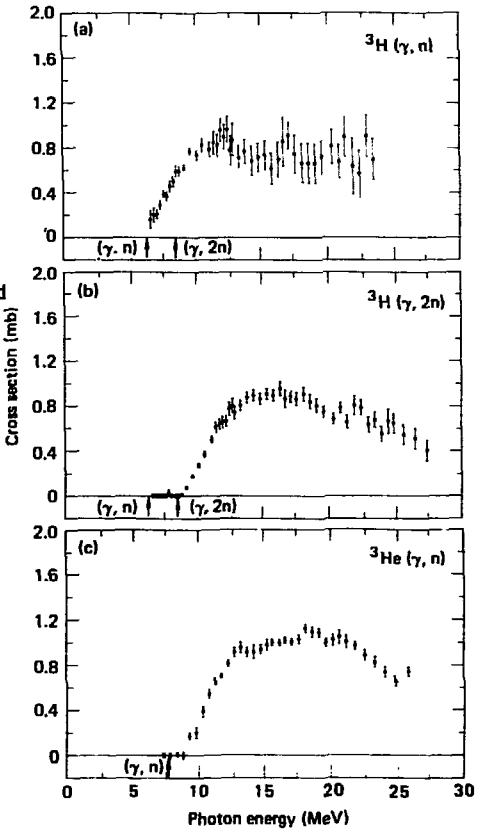
PHOTODISINTEGRATION OF THREE-BODY NUCLEI*

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We have measured the photoneutron cross sections for ^3H and ^3He from threshold to ∿25 MeV with monoenergetic photons from the annihilation in flight of fast positrons at the LLL Electron-Positron Linear Accelerator facility. These reactions include the two-body breakup of ^3H and the three-body breakup of both ^3H and ^3He; these measurements for ^3H are the first to span the energy region across the peaks of the cross sections. An efficient 4π BF_3-tube-and-paraffin neutron detector and high-pressure gaseous samples of several moles each (the activity of the ^3H sample was ∿200,000 Ci) were employed in these measurements. Measurements on ^{16}O and ^2H also were performed to verify the absolute cross-section scale.

The results of the measurements are shown in the figure. Comparison of these results with each other and with results for the two-body breakup cross section for ^3He from the literature shows that: (a) the two-body breakup cross sections for ^3H and ^3He have nearly the same shape, but the one for ^3H lies somewhat higher; (b) the three-body breakup cross section for ^3He lies somewhat higher and is broader in the peak region and rises less sharply from threshold than the one for ^3H; and (c) these measured differences between the cross sections for the breakup modes largely compensate in their sum, so that the total photon absorption cross sections for ^3H and ^3He are nearly the same in both size and shape at energies near and above their peaks.



*Work performed under the auspices of the U.S. Dept. of Energy by Lawrence Livermore Laboratory under contract number W-7405-ENG-48.

A 3-BODY APPROACH TO RESONANCE BEHAVIOUR IN N-N SCATTERING

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Recently there has been significant progress in the description of the coupled processes π-d $\rightarrow$ πd, π + NN $\leftrightarrow$ NN and NN $\rightarrow$ NN especially regarding the inclusion of the two nucleons in a symmetrical fashion[1,2]. The resulting Faddeev-like equations give promise of being able to describe NN scattering above the pion production threshold while still maintaining two and three body unitarity. Indeed reasonable fits have been obtained to the singlet channel phase shifts in a calculation that does not include ρ-exchange[3]. Moreover in this model it may be possible to obtain resonance behaviour in the NN channel by coupling to the NΔ channel. To this effect we have solved the Afnan-Blankleider equations[1] for the case $J^{\pi} = 2^{+}$ with the input consisting of the πNN vertex together with the deuteron and the P33 two body interactions only. We have used relativistic kinematics for the pion and non-relativistic kinematics for the nucleons. The resulting $^1D_2$ phase shifts (Fig. 1) display strong resonance behaviour and in this sense they agree with the results of Silbar and Kloet[4]. There are two better indications of a resonance. The first is the speed curve, which in our case (Fig. 2) is indicative of a resonance pole at 2200-i100 MeV. The second, and perhaps stronger criterion, is the trajectory of eigenvalues belonging to the kernel of our integral equations which in this calculation does not come close to the unit circle near the real axis, thereby giving no indication of a pole in the N-N t-matrix. Thus at this stage, it seems that our observed resonance behaviour is really a manifestation of the NΔ channel which for the case $J^{\pi} = 2^{+}$ has the Δ and N in relative s-state; and is not due to a resonance pole. However one would really need to carry out a search for this pole before any definite conclusion could be made. Finally we note that in a similar calculation[5] using totally non-relativistic kinematics there is strong indication of a real resonance pole. Thus the presence of a pole seems to be dependent on the off-shell behaviour of the two-body input or perhaps even on the type of kinematics used[5]!

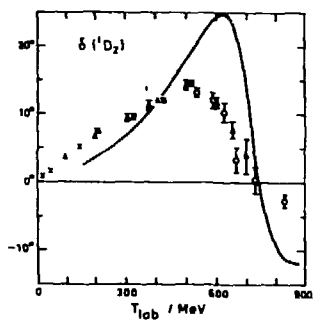


Fig. 1

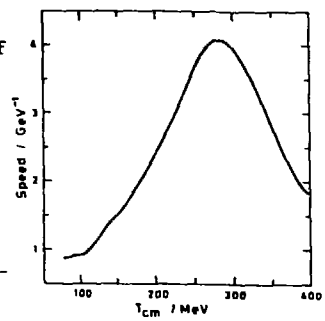


Fig. 2

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DEUTRON WAVE FUNCTION AT SMALL DISTANCES DEFINED FROM MEASUREMENTS OF THE d→p FRAGMENTATION SPECTRUM AT 8.9 Gev/c AT A ZERO EMISSION ANGLE OF PROTON-SPECTATORS

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The deutron fragmentation spectrum on $_3C$ and CH_2 targets with proton emission at angles of $0 \pm 2 \cdot 10^{-3}$ rad has been studied by means of a magnetic spectrometer (with proportional chambers, Cherenkov and time-of-flight counters) in a beam of 8.9 Gev/c deutrons at the Dubna synchrophasotron. The high momentum component of the proton spectrum has been measured up to the kinematical limit.

The data obtained are compared to theoretical calculations based on different deutron wave functions (with and without contribution from possible multiquark states in the deutron). It is shown that a hard part of the proton spectrum is essentially critical to the choice of deutron wave function and variations of 6Q-state contributions. The estimate of the production cross section of the lowest dinucleon resonances has been also obtained.

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ALPHA-PARTICLE SCATTERING ON C, Al AND Cu NUCLEI AT 17.9 Gev/c

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Using the one-arm spectrometer "ALPHA" with proportional chambers, the absolute differential cross sections have been measured of the sum of elastic and quasi-elastic (without meson production) scattering of 17.9 Gev/c α particles on C, Al and Cu nuclei.

The measurements have been performed in the range of 4-momentum transfers $0.008 < |t| < 0.18$ $(Gev/c)^2$.

The experimental data are compared to our calculations of $d\sigma/dt(t)$ in the framework of eikonal approximation of multiple scattering theory.

There were three variants in our calculations which corresponded to three versions:

a) approximation of rigid α particle,
b) optical approximation developed in papers [1,2],
c) swarm model [3].

The results of the calculation according to version c) lead to the best agreement with experiment.

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FORWARD DEEP INELASTIC SCATTERING dC→dX AT 8.9 Gev/c

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Measurements have been performed in a deutron beam of the Dubna synchrophasotron by means of the spectrometer (with proportional chambers, Cherenkov and time-of-flight counters) used to measure the spectrum of d→p fragmentation. The momentum spectrum of the deutrons emitted at zero angle ($\theta < 2 \cdot 10^{-3}$ rad)in deep inelastic collisions has been studied. The deutron wave function extracted from the data on d→p fragmentation at zero angle and e-d scattering [1]) has been used for description of the dC→dX cross section.

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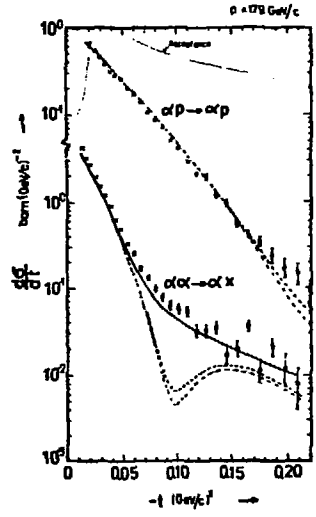
SCATTERING OF 17.9 Gev/c ALPHA-PARTICLES FROM HYDROGEN AND HELIUM NUCLEI

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Due to a search for the effects of high-excited intermediate states of baryon systems, studies of the scattering of relativistic nuclei on nuclei can be actual [1]. Experimental data and results of calculations of the differential cross section of elastic αp and of the sum of elastic and quasi-elastic $\alpha\alpha$ scattering at P_α= 17.9 Gev/c in an interval of $0.01<|t|<0.22$ $(Gev/c)^2$ are reported. The results are a part of the program on an investigation of the collisions of relativistic nuclei with nuclei [2] at the Dubna synchrophasotron.

Data on αp scattering are not in a good agreement with those calculated with the help of the Glauber model (see the fig.). Deviations $(d\sigma/dt)_{exp}$ from that calculated for $\alpha\alpha$ (solid curve) are about 15% within the diffraction cone and achieve about 25% in the vicinity of the expected (see the dotted and chain-dotted lines) elastic scattering diffraction minimum. The disagreement between the experiment and theory may probably occur due to the effects [3] of rescattering intermediate isobar states N* which are not taken into account in the conventional Glauber model. The parametrization $d\sigma/dt \sim \exp(bt)$ at small $|t|$ allowed one to find the parameters of αp and $\alpha\alpha$ reactions.



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OXYGEN INDUCED DEUTERON BREAKUP

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I. Koersner and B. Sundqvist

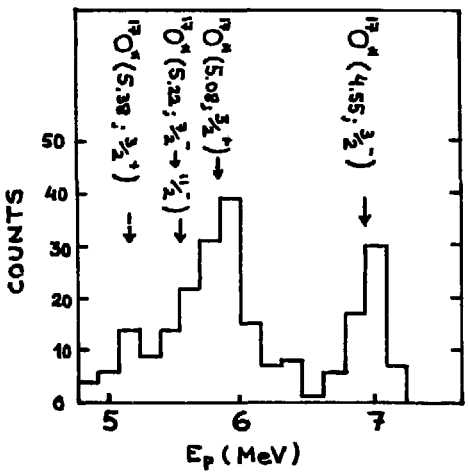
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An experimental study of the oxygen induced deuteron breakup reaction has been started. A three-body treatment of the α-d system in the frame-work of Faddev type calculations has turned out to be successful, in particular the description of the α-d breakup reaction at 15 MeV α-energy (1). The treatment of the Coulomb force, however, remains a fundamental difficulty. Therefore, we have considered it of interest to study the ^{16}O-d system in the same spirit.

A beam of 42 MeV ^{16}O from the Uppsala EN tandem accelerator was used to induce deuteron breakup reactions in a target of deuterated polyethylene. Protons and oxygen nuclei from the breakup reactions were observed in a kinematically complete experiment. The protons were detected with a Si(Sb) detector at 21° scattering angle and the oxygen ions were uniquely identified in a heavy ion detector system (2) at 4°. The time of flight of the heavy ion was measured between two carbon foil detectors with a time resolution of 250 ps. The energy loss and residual energy were measured with an ionization chamber and a Si(Sb) detector, respectively. A particular feature of the telescope was the thin entrance window of 15 μg/cm^2. In the figure a projected proton energy spectrum is shown.

The dominant features of the spectrum are peaks due to final state interactions in the ^{16}O-n system corresponding to excited states of ^{17}O.

Preparations are being made to perform three-body calculations with the Doleschall code in order to study the validity of a three-body picture of this reaction.



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Precision Measurement of Proton-Proton Scattering Above 1.0 MeV

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Cross-section measurements at 1.43, 1.86, 2.43, and 3.04 MeV have been completed as part of a continuing program to measure precise proton-proton scattering cross-sections in the energy range 0.35 - 5.0 MeV. This current phase of the program was undertaken to reproduce and check the results of others (Knecht et al.[1]) whose results have come under discussion by a number of authors (see Sher et al.[2]). Final results of our work at the above energies will be presented as well as a comparison with the work of Knecht et al.[1].

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CONTRIBUTIONS OF MESON EXCHANGE CURRENTS TO ELASTIC PHOTON SCATTERING OFF DEUTERIUM

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The presence of an exchange part in the NN-interaction does not only require an additional two-body exchange current but also an additional two-photon amplitude in order to fulfil gauge invariance requirements for the total nuclear two-photon amplitude. This exchange amplitude is of two-body nature and associated with a two-photon process like photon scattering during the exchange of a meson mediating the nuclear force (see fig. 1). Recently it has been suggested[1] that this exchange amplitude gives a rather large contribution to nuclear photon scattering at higher energies, say around $E_\gamma \approx 100$ MeV. This prediction, however, has been based on extrapolations of the low energy limit of the two-photon exchange amplitude, which is determined by gauge invariance, to higher energies. To avoid such questionable extrapolations we have evaluated explicitly this exchange amplitude for the one-pion exchange potential[2,3] and have calculated its contribution to the elastic forward scattering amplitude for deuterium. The result is shown in fig. 2 together with the resonance amplitude. One can see that the exchange contribution is rather small and, thus, it seems that the previous estimates have overestimated its influence quite considerably.

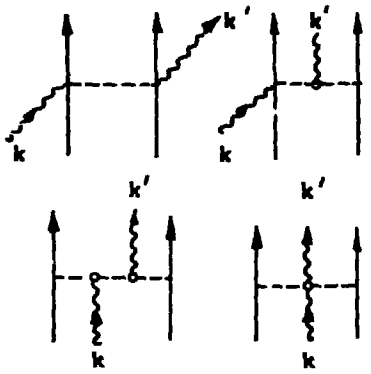


Fig. 1

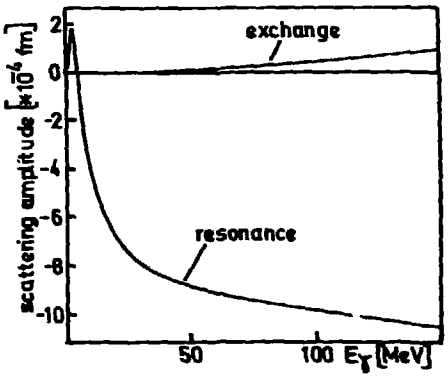


Fig. 2

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MEASUREMENT OF THE ASYMMETRY FACTOR IN D(γ,np) REACTION INDUCED BY MONOCHROMATIC, LINEARLY POLARIZED GAMMA RAYS.

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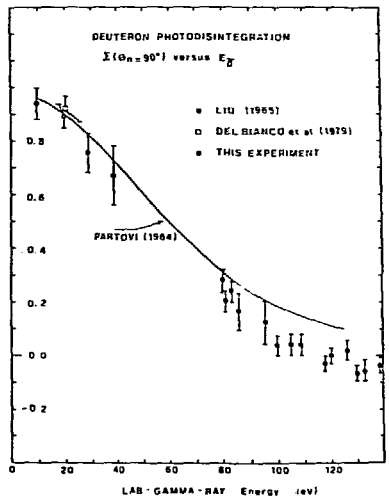
Old experimental data of Liu[1] in the energy interval 75 ÷ 230 MeV on the deuteron photodisintegration had pointed out a discrepancy with Partovi[2] theoretical calculation. More recent experiments performed at lower energies have shown not clear, contradictory results about the suitability of Partovi's theory to give account of the experimental results.

The differential cross section for the deuteron photodisintegration induced by linearly polarized γ-rays can be written in the form:

$$d\sigma/d\Omega = I_o(\theta)\ [1 + P\,\Sigma(\theta)\cos 2\phi]$$

where θ and ϕ are the angles that one of the ejected nucleons makes with the direction of the momentum and with the electric field of incident photon, respectively, I_o is the value of the cross section for unpolarized γ-ray beam, P represents the degree of linear polarization of the photon beam and Σ is the asymmetry factor deduced from measurements of the differential cross section at ϕ=0° and ϕ=90°.

Using the monochromatic and polarized ($P \approx 1$) γ-ray beam of the LADON[3] facility in Frascati National Laboratory we have measured the asymmetry factor at ϑ=90° in the energy interval E_γ=10 ÷ 40 MeV. In Figure, the measured values of Σ (90°) as a function of γ-ray energy have been plotted as well as the theoretical results of Partovi. Within the experimental accuracy the measured values are consistent with Partovi's theory.



(*) On leave of absence from the Montreal University.

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PHOTODISINTEGRATION OF QUASI-FREE TWO-NUCLEON SYSTEM INSIDE Be NUCLEUS

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In order to study the nucleon-nucleon correlation inside nucleus, momentum spectra of protons in the reaction of γ + Be → p + anything in the incident energy range from 180 MeV to 420 MeV were measured by a magnetic spectrometer located at the angle of 25° in the laboratory system. Tagged photons were used as an incident beam.

The momentum spectra obtained at various incident energies are shown in Figure 1, where we see two Gaussian type peaks. For the peak at lower momentum, the location and its change as a function of incident energy as well as the value of the integrated cross sections over this peak indicate that the protons in this peak come mainly from the recoil protor in the pion production from the quasi-free nucleons inside Be nucleus. For the peak at higher momentum, it is noted that this peak disappers as shown in Figure 2 when we require the scintillation hodoscopes which surrounded the target in order to detect charged particles accompanyed by the spectrometer protons. In this Figure, ●s are the events in the reaction of γ + Be → p + anything and ○s are the events in the reaction of γ + Be → p + (charged particle) + anything. This fact together with the peak location and its change as a function of energy indicate that the protons in this peak area come mainly from the photodis-

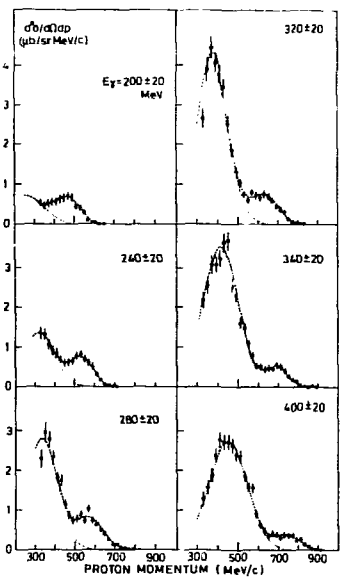
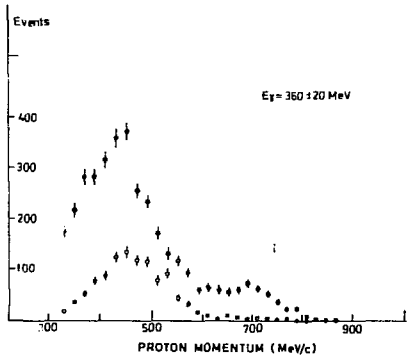


Fig. 1



. Fig. 2

integration of quasi-free deuteron-like proton-neutron system inside Be nucleus. The integrated cross sections are about 13 times larger than the existing cross sections of the photodisintegration of free deuterons.

COMPARISONS OF M8 TRANSITIONS TO $(g_{9/2}f_{7/2}^{-1})_{8^-}$ STATES IN ^{54}Fe, ^{58}Ni, AND ^{60}Ni[†]

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As part of a program to determine the systematics of the $(g_{9/2}f_{7/2}^{-1})$ particle-hole spectroscopic strength for states with spin parity 8^-, we have made electron scattering measurements on ^{60}Ni at the Bates-MIT Electron Linear Accelerator Facility. Data were taken at incident electron energies of 150, 170, 185, 205, 245, and 275 MeV at $\theta = 140°$ and 193 MeV at $\theta = 180°$. Several high multipole transitions were observed to levels of excitation up to 18 MeV excitation. In particular, levels at 7.55, 8.45, 12.36, 12.53, 13.96, 14.87, 15.33, and 16.13 MeV are strong candidates for $J^\pi = 8^-$ assignments. The M8 strength is fragmented and spread over both T_0 and T_0+1 levels as previously observed in ^{58}Ni.[1] The total M8 strength summed over the above levels is approximately the same as in ^{58}Ni, which is about one-third of the extreme single particle shell model predictions. The ^{60}Ni results will be discussed together with previously reported results on ^{58}Ni[1] and ^{54}Fe[2] focussing on the relative differences in their isospin structure and comparison with model calculations.

Most of the individual 8^- levels do not contain much of the $(g_{9/2}f_{7/2}^{-1})$ configuration, and probably consist mostly of multi particle-multi hole type configurations. However, for one-body inelastic excitations, [e.g., (e,e') (p,p')(π,π')] only the stretched $(g_{9/2}f_{7/2})_{8^-}$ element of the density matrix contributes to the scattering amplitude regardless of the complicated nature of the wave function as long as we can neglect $\geq 3\hbar\omega$ particle-hole configurations. This simplifies the calculations of the scattering amplitude in that some terms are either zero or are negligible. A discussion on how the spectroscopic factors deduced from (e,e') can be used in the interpretation of (p,p') measurements to deduce information on the nuclear force will also be presented.[3]

[†]Work supported by the U.S. Department of Energy.

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ELECTRON-DEUTERON SCATTERING AND THE DEUTERON WAVE FUNCTION

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We have recently shown that the measurement of the e-d tensor polarization T_{20} in addition to the deuteron electric form factor A out to momentum transfers $q = 4.5$ fm^{-1} would not allow us to distinguish between a P_D varying from 4.5 to 7.5, mainly due to the uncertainty in G_{En}, the neutron electric form factor[1]. Haftel et al[2] concluded that T_{21} could distinguish between several competing NN potentials V_{NN}, especially their P_D. Their results however indicate that T_{21} is not very sensitive to P_D for realistic V_{NN}. It only discriminates against unrealistic separable V_{NN}. As in ref. 1 we adopt a more stringent criterion for the usefulness of proposed measurements of T_{21} etc. One should demonstrate that T_{21} discriminates between *all* physically reasonable deuteron wave functions with different P_D, as can be generated by means of strictly finite and short range unitary transformations from one of the realistic V_{NN} (in our case the SSC potential). For our transformed wave functions, I1-I6, $4.54 \leq P_D \leq 7.55$[1].

In terms of this more stringent criterion we have shown that

a) $T_{21}(q)$ for $q \lesssim 4$ fm^{-1} cannot fix the P_D of the deuteron (see Fig. 1 - R_{av} specifies G_{En}[3]).

b) Our family of deuteron wave functions indicates that $T_{21}(q)$ for $q \gtrsim 4$ fm^{-1} could discriminate between some competing V_{NN} (see Fig. 1). However it is difficult to draw firm conclusions about using T_{21} to fix P_D as the variation in T_{21} in this region is mainly the result of a wide variation in the magnetic form factor B for the different deuteron wave functions (which is also the case for other realistic V_{NN}[4]). A narrowing of the range of variation especially in B, by plotting T_{21}/G_M and in A by taking the uncertainty in G_{En} into account, reduces the sensitivity of T_{21} to P_D considerably (see Fig. 2).

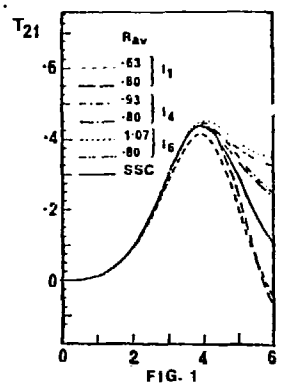


FIG. 1

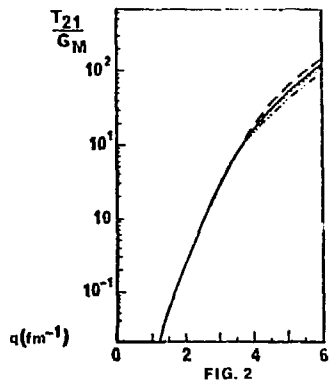


FIG. 2

c) It appears to be essential to improve and extend the data on A and especially B, as proposed by Arnold et al[4], and also on G_{En}. Some details of the deuteron are more clearly visible in B than in A. For interactions which fit such improved pseudodata on B and A the measurement of T_{20} and T_{21} does not appear to improve our ability to determine the properties of the deuteron very much, unless they are carried out at high accuracy and for $q \gtrsim 4$ fm^{-1}.

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IMPLICATIONS OF THE 1/E DEPENDENCE OF THE $^{7}Li(p,n)^{7}Be$ TOTAL REACTION† CROSS SECTION IN THE ENERGY RANGE $25 \leq E \leq 200$ MeV

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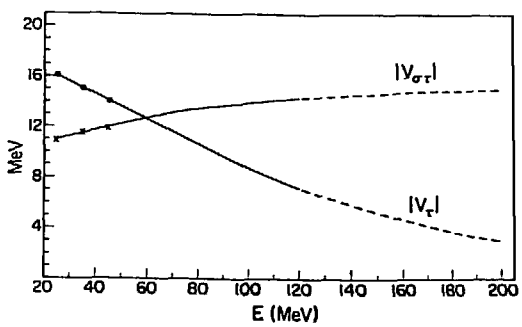
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The measured[1,2] excitation function, $\sigma(E)$, of the $^{7}Li(p,n)^{7}Be$ total reaction cross section is observed to vary inversely with the incident proton energy, E, from 25 to 200 MeV. A theoretical analysis, assuming the PWIA, an energy independent, very short range interaction, using harmonic oscillator wave functions and neglecting exchange effects, yields such an 1/E dependence for the summed inelastic scattering differential cross section to a particular state. This result implies that $\sigma(E) = 725.3\ (1/E) - 0.295$ with σ in millibarns, E in MeV and a determination coefficient of 0.998. It, further, implies that $(V_{\pi}^{2} + 2.36\ V_{\sigma\pi}^{2})$ is independent of incident proton energy. Using recently reported determinations[3] of V_{τ} and $V_{\sigma\tau}$ at 24.8, 35 and 45 MeV $(V_{\tau}^{2} + 2.36\ V_{\sigma\tau}^{2}) = 537\ MeV^{2}$ is obtained. Figure 1 is a plot of $|V_{\tau}|$ and $|V_{\sigma\tau}|$ versus E. The solid curves were calculated using this relation and experimental values,[3,4] of $(V_{\sigma\tau}/V_{\tau})^{2}$ at 24.8, 35, 45, 80 and 120 MeV. Dotted curves are based on a reasonable extrapolation of the observed energy dependence[4] of $(V_{\sigma\tau}/V_{\tau})^{2}$.

†Work supported in part by the National Science Foundation.

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SIMULTANEOUS MICROSCOPIC ANALYSIS OF MEDIUM ENERGY $p^3H \to p^3H$, $p^3He \to p^3He$ AND $p^3H \to n^3He$ REACTIONS

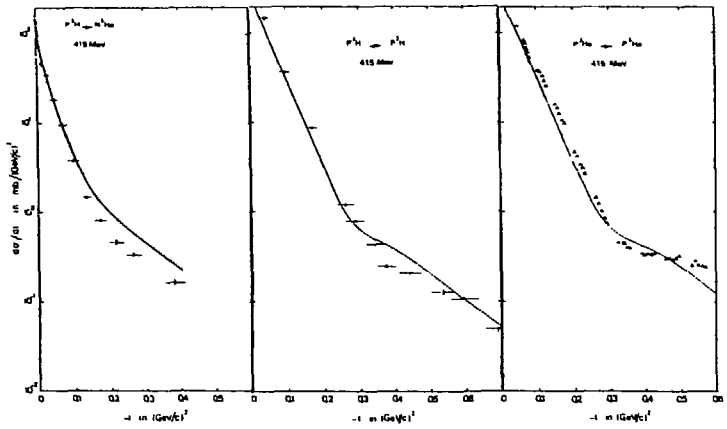
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The differential cross-sections of the elastic p^3H and p^3He scatterings and of the charge exchange reaction $p^3H \to n^3He$ are now available at 415 MeV and 600 MeV[1].

Expressing the nucleon-nucleus amplitudes through a spin-isospin dependent Glauber model in terms of the nucleon-nucleon phase shifts[2], we are able to describe simultaneously and satisfactorily the three differential cross-sections at both energies.

The figure below shows fits of the 415 MeV experimental data. The spin-isospin dependent N-N amplitudes at all orders of the scattering expansion, are constructed with the recent phase shifts of Bystricky et al[2]. The Chew kinematical approximation is used to account for the off-shell N-N interaction. At both energies, the best results were obtained using the theoretical wave function of Fabre de la Ripelle[3] for $p^3H \to n^3He$ and the phenomenological wave function of Samaranayake and Wilk[4] for the elastic angular distributions. The results displayed here are those obtained with this last wave function.

The 600 MeV results, not shown here, are also well described by the model although they are more sensitive to the phase shifts set.



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MEAN FREE PATH OF PROTONS INSIDE THE NUCLEUS AT E_p = 800 MeV DETERMINED FROM TWO-PROTON CORRELATIONS IN pA COLLISIONS†

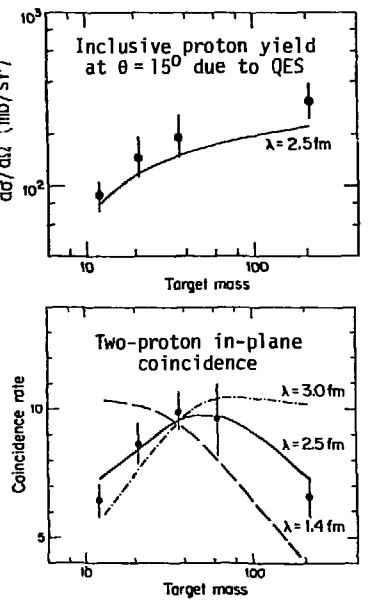
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Inclusive proton spectra and two-proton correlations have been measured in collisions of 800 MeV protons on C, NaF, KCl, Cu, and Pb targets. A magnetic spectrometer was used to measure the inclusive spectra at laboratory angles from 10^0 to 60^0 for proton momenta between 0.5 and 2.0 GeV/c. When the spectrometer was set at $\theta = 40^0$, two-proton coincidences were measured with one proton detected by the spectrometer and the other proton detected by one of two plastic counter telescopes placed at $(\theta,\phi) = (40^0, 180^0)$ and $(40^0, 90^0)$, where the spectrometer was located at $\phi = 0^0$.

In inclusive proton spectra strong peaks associated with pp or pn quasi-elastic scatterings (QES) were observed at small angles (15^0 & 30^0), whereas at large angles (40^0 & 60^0) no structures were seen in the momentum spectra. In two-proton coincidences, a peak due to pp QES clearly appeared in the proton momentum spectrum at 40^0 when the other proton was detected with the telescope at $\phi = 180^0$ (in-plane two-proton coincidence); however, no structures were still seen in the spectrum when the coincidence was taken with the $\phi = 90^0$ telescope (out-of-plane coincidence).

The figure shows the target-mass dependences of the yields at the peak regions of QES. Inclusive yields, shown at the top, increase monotonically as a function of the target mass, while the in-plane coincidence yields, shown at the bottom, have a maximum value at a target mass around 40-50. As we increase the target mass, the probability of having pp QES increases, but at the same time, the probability of rescatterings after the pp QES also increases. In the present measurements the spectrometer and the in-plane telescope covered very limited kinematical regions, such that, if either proton from pp QES was rescattered inside the target nucleus, it would not be detected. The probability of detecting in-plane coincidence could, therefore, be lower for heavier-mass targets, due to such rescattering effects.



By parameterizing the rescattering effects before and after the pp QES by the mean free path λ, we fitted the observed target mass dependence. When we take $\lambda = 2.5 \pm 0.5$ fm for protons at 800 MeV, then the data are very well reproduced, as seen in the figure. This value is about 1.6 times larger than the value expected from the free nucleon-nucleon collisions.

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POSSIBLE ISOBAR MECHANISM FOR THE PRODUCTION OF HIGH MOMENTUM PARTICLES IN THE BACKWARD DIRECTION IN RELATIVISTIC NUCLEAR COLLISIONS

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There exists considerable long-standing controversy on the origin of particles with high momentum in the backward direction. Since production of nucleons beyond 90^{o} in the laboratory is kinematically forbidden in free nucleon-nucleon interactions, particle emission in this region is of particular interest. Single hard-scattering combined with internal Fermi motion, multiple scattering cascades, and intranuclear correlations are a few of the most notable backward particle production mechanisms that have been proposed. Inclusive proton momentum density distributions accumulated from recent projectile and target fragmentation experiments in conjunction with theoretical predictions suggest the presence of short-range correlations in the nucleus as an important mechanism.[1]

In the interest of obtaining more-complete-event information on the production mechanisms associated with backward particle emission, the exclusive charged-particle production accompanying backward particle emission has been studied at the LBL Streamer Chamber at the Bevalac. The streamer chamber was triggered on a charged-particle at $\theta_{lab} > 90^{o}$ and approximately 10,000 events were photographed in the bombardment of C, KCl, and BaI_2 targets with 2.1 GeV protons. Since production of the $\Delta(3,3)$ isobar in the reaction $p+p \rightarrow n+\Delta^{++}(1232)$ accounts for a major fraction of the pp total cross section at energies from 1-2 GeV,[2] the effects of the subsequent decay $[\Delta^{++} \rightarrow p + \pi^{+}]$ and/or absorption $[\Delta^{++}+n \rightarrow p+p]$ of isobars on the backward particle spectra are considered. If isobar production is an important mechanism, a back-to-back (180^{o}) correlation between the proton and π^{+} in the Δ^{++} decay frame and between the two protons in the $(\Delta^{++}+n)$ absorption frame is expected. This correlation may be preserved in the laboratory system due to the dominance of low momentum transfer in the production cross section of the Δ^{++} isobar. A 180^{o} correlation between the angles of positive charged-particles is observed in the present experiment providing the first suggestion that $\Delta(3,3)$ isobar production is an important mechanism for the production of high momentum particles in the backward direction. Short-range correlations in the nucleus are not dismissed by the isobar mechanism, but are no longer necessary. However, their presence would enchance such a mechanism.

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NEGATIVE PARITY PARTICLE HOLE EXCITATIONS BY INELASTIC PROTON SCATTERING ON ^{40}Ca AND SPIN ISOSPIN MODE INTERACTIONS

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Inelastic proton scattering on the double closed ^{40}Ca were investigated to study various types of particle-hole excitation mechanism. The present work reports spin flip isoscalar excitation (2^-, T=0), spin flip isovector excitations (2^- T=1, 4^- T=1, 3^- T=1) and natural parity collective excitations (3^-, 5^-). Inelastically scattered protons from the ^{40}Ca (p, p') reaction at Ep=65 MeV were measured from 8° to 90° (momentum transfer q=0.5-3.5 m_πC) by means of the magnetic spectrogroph RAIDEN. Many levels of Δs=1, 0 and ΔT=1, 0 were distinctly excited as shown in Fig. 1. The angular distributions (Fig. 2) for the low-lying 3^- and 5^- states were reproduced by DWUCK-4 calculations for the collective excitations. Unnatural parity 2^- states with T=1 (isovector) and the 2^- states with T=0 (isoscalar) were in accord with the DWBA74 calculations for $(d\frac{3}{2})^{-1}(f\frac{7}{2})$ particle-hole excitations using the central + LS + smooth q - dependent tensor forces. No strong enhancement for the π-like (2^- ΔT=1. Δs=1) excitation was found at q≈2.5 m_πC in contradiction to the theory with π condensation proximity[2]. The q dependence for the π-like excitation (2^-, T=1) is similar to the isoscalar excitation (2^-, T=0). The distortion effect and the two step process are under consideration.

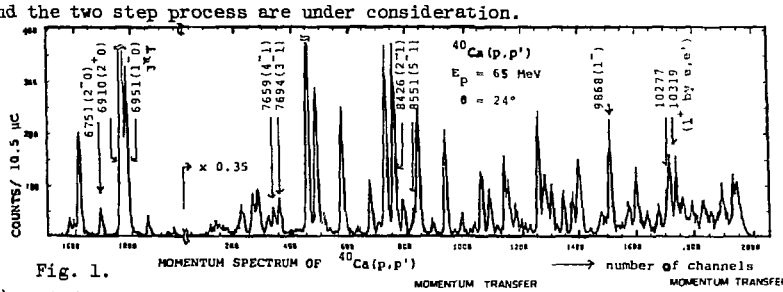


Fig. 1.

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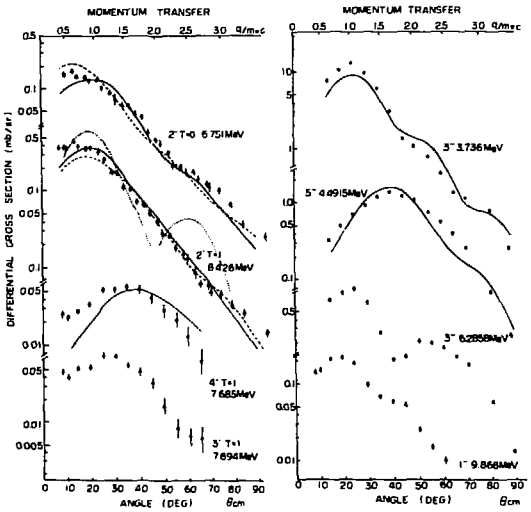


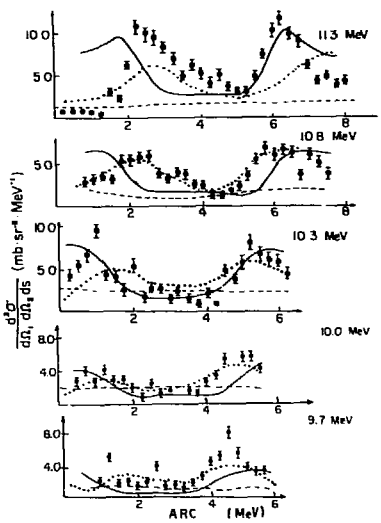
Fig. 2. Angular distributions. Solid lines: DWBA74 for potentials used by Petrovich (P.L. 46B141); dashed lines for those by Ber sch (N.P. 284, 399). Dotted line is the plane wave calculation with the proximity of π-condensation (ref. 2) with g'=0.5. Solid lines for 3^- and 5^- are by DWUCK for collective excitations.

POSSIBLE EVIDENCE FOR THREE-BODY FORCES IN THE $^2H(\alpha,p\alpha)n$ REACTION

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To a good approximation, at low energies, the alpha particle can be considered to be a structureless boson. The alpha-proton-neutron final state three body system is then an obvious next step with respect to three nucleon studies. Experiments to-date have been performed at incident energies $E_\alpha \geq 15$ MeV. We measured the energy dependence of the correlation cross-sections $^2H(\alpha,p\alpha)n$ reaction at $\theta_\alpha = 15^0$ and $\theta_p = -30^0$ between 9.735 and 11.30 MeV incident energies, i.e. 3.07 to 3.77 MeV CM energies, leading to very low kinetic energies for the final-state: 0.84 to 1.54 MeV. An α-particle beam from the Université Laval 7.5 MV Van de Graaff was incident on deuterium at a pressure of 70 torr, contained in a 53 cm diameter scattering chamber, isolated by entrance and exit Havar foils 2.1 mg cm^{-2} thick. A fast-slow coincidence technique was used and data were accumulated on line, consisting of the E_p, E_α and timing pulse. Due to the difference in time of flight of particles along the kinematically allowed region of the E_1-E_2 plane, a correction was calculated event by event, and the resulting prompt time peak has a resolution of 1.5 nsec. The data were corrected for random correlations using a digital gate in different time regions outside the prompt peak. The events within the allowed kinematic band were projected upon the central arc in 250 keV steps, yielding the cross sections $d^3\sigma/d\Omega_\alpha d\Omega_p d\Omega_s$ shown. The dashed lines are phase space curves and the data depart markedly from them. Final state n-α and p-α interactions yield the solid lines which show poor agreement with the data. It has been noticed recently[1] that in the p+d → p+p+n very near threshold there is an excellent agreement of the experimental correlations with calculations based on the two-pion exchange three-body force[2], producing a transition probability proportinal to $p_{23}.p_{13}$, product of the relative momenta of particles 2-3 and 1-3 (3 = neutron). We have tried a similar approach in the present case and the dotted lines of fig.1 show also a much better agreement with the data at 10.8 MeV and below. The incoherent addition of these two contributions should improve considerably all fits to the low-energy data. Hence it is possible that three-body forces and correlations are indeed determining these spectral shapes very near threshold.



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LOW-ENERGY ALPHA-INDUCED DEUTERON BREAKUP STUDIED WITH A SIX-DETECTOR SYSTEM AND A FADDEEV ANALYSIS

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The α-induced deuteron breakup $^{2}H(\alpha,\alpha p)n$ has been studied at three different energies at the Tandem Accelerator Laboratory in Uppsala (TLU).

The $^{2}H(\alpha,\alpha p)n$ reaction has been studied previously at TLU at 15 MeV laboratory energy [1]. Three-body model calculations based on the assumption that the α-particle can be regarded as elementary has been performed by Doleschall [2] and Koike [3]. These calculations have been rather successful in reproducing the experimental spectra. However, Koike has pointed out that a 1^{+} resonance in ^{6}Li, corresponding to about 13 MeV laboratory energy of the incoming α-particle, has significant influence on the reaction mechanism over a rather large energy interval. The resonance behaviour is also seen in the eigenphases from the Doleschall calculation. To investigate the influence of the structure of the compound system ^{6}Li on the validity of the three-body assumption the $^{2}H(\alpha,\alpha p)n$ reaction has been studied at 13, 15 and 18 MeV laboratory energy.

The TLU experiment was kinematically complete and made with a $(CD_2)_n$ target and a multiparameter system consisting of six Si surface barrier detectors and a CAMAC interface with eight ADC's. It was thus possible to detect coincidences in 15 detector pairs at the same time. To be able to handle coincidences from the $^{2}H(\alpha,\alpha p)n$ and $^{12}C(\alpha,\alpha\alpha)^{8}Be$ reactions it was necessary to identify protons which was done with a time-of-flight technique.

A preliminary analysis indicates that the agreement between experiment and calculation is not as good at 13 MeV as at 15 MeV.

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SEARCH FOR THE 11.26 MeV 1^+ T=1 LEVEL IN ^{20}Ne AS A PARITY FORBIDDEN RESONANCE IN THE $^{16}O(\alpha,\gamma)^{20}Ne$ REACTION

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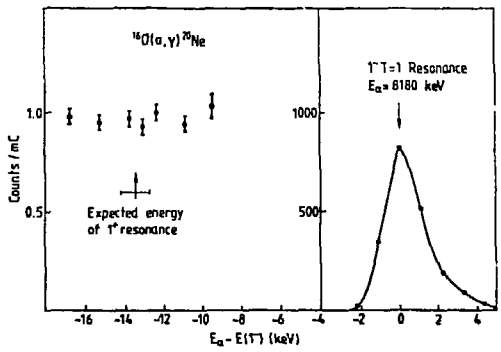
and

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The two levels in ^{20}Ne at 11.23 MeV (1^- T=0) and 11.26 MeV (1^+ T=1) have been proposed as a particularly suitable system in which to search for evidence of an isovector, parity violating weak component in the nucleon-nucleon force. Mixing of these two levels due to such a component would give rise to a parity violating α-particle decay of the 1^+ T=1 level to the ^{16}O ground state. We have therefore searched for the 1^+ T=1 level as a parity-forbidden resonance in the $^{16}O(\alpha,\gamma)^{20}Ne$ reaction at E_α = 8.17 MeV.

The experiment employed the Oxford differentially pumped gas target, and γ-rays were detected in a 25.4 x 30.5 cm NaI(Tl) crystal with a plastic scintillator anticoincidence shield. The detector was heavily shielded by lead, borated paraffin wax and concrete. The principal source of background at the target thickness used (2 keV for 8 MeV α-particles) was 11.26 MeV γ-rays from broad underlying resonances, with smaller contributions from cosmic rays and fast neutrons. The resonance energy of the 1^+ T=1 level was defined relative to the very narrow 1^- T=1 level at 11.28 MeV [1]. [The separation of this latter level and the 1^+ T=1 level was determined in a separate measurement employing the $^{19}F(^3He,d)^{20}Ne$ reaction]. The measurement consisted of a series of scans, each starting at the 1^- T=1 resonance, followed by 7 steps spanning a total energy interval of 7 keV centred on the expected energy of the 1^+ resonance. The result is shown in the figure, where the number of counts in the 11.26 MeV photopeak/mC of beam charge are plotted as a function of the beam energy. There is no evidence for a resonance at the expected energy of the 1^+ T=1 level, and we extract a 2σ upper limit on Γ_α of 3 x 10^{-5} eV. Using the known properties of the 1^- T=0 and 1^+ T=1 levels, this is related to the matrix element of the parity non-conserving (PNC) potential by [1]



$$\Gamma_\alpha \simeq 2 \times 10^{-5} |\langle 1^+|V_{PNC}|1^-\rangle|^2 \text{ eV}^{-2}$$

From our measured upper limit, we infer that $|\langle 1^+|V_{PNC}|1^-\rangle| < 1.2$ eV.

Further measurements are in progress.

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MAGNETIC MOMENT OF THE FIRST EXCITED 2^+-STATE IN ^{100}Zr

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The transition from spherical to deformed nuclei in the chain of Zr-isotopes is by now well established: between ^{98}Zr and ^{100}Zr a dramatic decrease of the energies of the first excited 2^+ and 0^+ levels was observed[1,2]. Recent theoretical calculations have shown[3]) that this may be due to the interaction between the $\pi g_{9/2}$ and $\nu g_{7/2}$ orbitals.

Since magnetic moments of nuclear states are sensitive to the wave functions, an experiment was undertaken to measure the g-factor of the first excited 2^+ state in ^{100}Zr. We used the integral perturbed angular correlation technique for the $0^+ \rightarrow 2^+ \rightarrow 0^+$ γ,γ-cascade, which is populated after β-decay of ^{100}Y. The ^{100}Y nuclei were obtained at the fission product gas-filled separator JOSEF and brought with an air-jet and tape transport system to the counting position between the pole pieces of an electromagnet (field strength 30.7 ± 0.5 k Gauss). Three Ge(Li) detectors at about 10 cm from the source provided two γ,γ-coincidence pairs at the angles of 210° and 330°.

The g-factor was deduced for both angles from the double ratio

$$R^2(\Theta) = \frac{N_1(\Theta,\infty,B)}{N_1(\Theta,\infty,-B)} \Big/ \frac{N_2(\Theta,\infty,B)}{N_2(\Theta,\infty,-B)}$$

where N_1, N_2 are the intensities of the 213 keV ($2^+ \rightarrow 0^+$) and 119 keV ($0^+ \rightarrow 2^+$) transitions in the corresponding coincidence gates. Thus no normalization was needed. The half-life of the 2^+ level, $t_{1/2}$ = 0.71 ± 0.03 ns, was taken from ref. [4]). The results are given in Table I.

Table I: Values of R(Θ) and g

	R(Θ)	g	$g_{average}$
210°	0.851 ± 0.035	+0.231 ± 0.055	
330°	1.157 ± 0.070	+0.210 ± 0.085	+0.22 ± 0.05

The value of g is significantly smaller than the prediction Z/A = 0.4 of the hydrodynamical model. BCS calculations[5]) predict small (g = 0.14) values of the g-factor for the 2^+ states of $^{94,96}Zr$. The onset of deformation in $^{98,100}Zr$ may definitely cause higher values of g, as actually observed in our experiment. In fact, the value $g(2^+)$ = 0.22 ± 0.05 for ^{100}Zr, reported here, may be considered as intermediate between small g-factors in spherical nuclei and the larger $g \sim Z/A = 0.4$ predicted by the hydrodynamical model.

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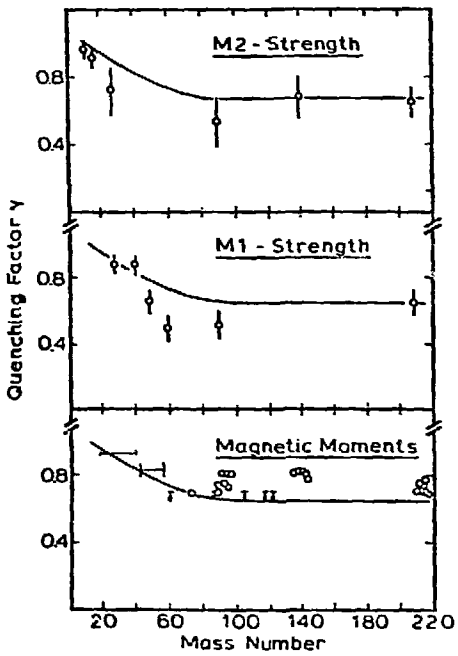
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QUENCHING OF THE MAGNETIC MULTIPOLE STRENGTH DISTRIBUTION AND OF THE ANOMALOUS MAGNETIC MOMENT IN COMPLEX NUCLEI AND MESONIC RENORMALIZATION OF THE NUCLEAR SPIN CURRENT

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A strong mass dependent quenching of the g_S-factor of the magnetic transition-operator has recently been established through the M1 and M2 strength distributions in light and heavy nuclei investigated by high resolution inelastic electron scattering experiments in Darmstadt[1]. Phenomenologically the reduction of M1 and M2 strengths from light to heavy nuclei can be accounted for by effective g-factors in the shell model calculations. Adjusting the g_S-value, such that $g_S^{eff} = \gamma \cdot g_S^{free}$ both for protons and neutrons, a mass dependent quenching factor γ for g_S is obtained. As shown in fig. 1 this quenching factor γ which fits the M1 and M2 strengths deduced from the (ee') measurements is also capable to reproduce the behaviour of the magnetic moments in proceeding from light to heavy nuclei.

In order to explain the amount of quenching beyond the usual core polarization contributions we calculated the renormalization effect of the nuclear medium on the pionic contribution to the anomalous nucleonic magnetic moment. The mechanism, controlled by the Landau Migdal parameter g_0, is similar to the renormalization of the axial current in nuclei[2] and also governs low energy p-wave pion nucleus scattering (Lorentz-Lorenz effect). With the phenomenologically determined value $g_0' \approx 0.7\text{-}0.75$[1] the anomalous nucleonic magnetic moment is quenched in heavy nuclei due to the renormalization of the πNN-coupling constant $f_{\pi NN}$ in the medium. We find $\gamma \approx 2/3$ in reasonable agreement with the phenomenologically derived quenching factor from the data in the realm of heavy nuclei. As a consequence the quenching of the magnetic moments in heavy nuclei amounts to 50 % and 50 % through core polarization and mesonic renormalization of the spincurrent, respectively. Since the M1 transitions are strongly inhibited the Arima Horie effect is less important.



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++Supported by Deutsche Forschungsgemeinschaft

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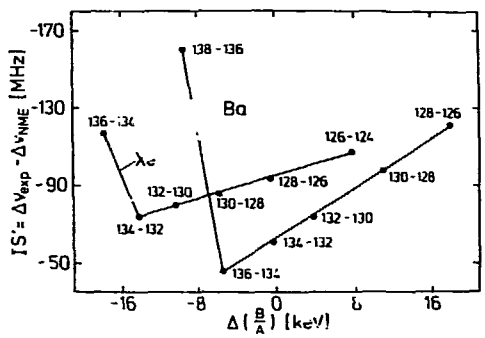
FURTHER EVIDENCE FOR A LINEAR RELATIONSHIP BETWEEN CHANGES IN NUCLEAR CHARGE RADII AND BINDING ENERGIES PER NUCLEON

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Among other methods for determining nuclear charge radii, optical isotope shift measurements have recently gained considerable attraction because of the greatly improved accuracy achieved in high resolution laser spectroscopy. Discussing isotope shifts in the vicinity of magic neutron numbers N, Gerstenkorn[1] suggested a linear relation between the change in the nuclear mean square charge radius $\delta\langle r^2\rangle$ and the change in the binding energy per nucleon, $\delta(B/A)$ for the isotopic pair (A+2,A). This relation was supposed to apply to the pairs (N-2,N-4), (N,N-2) and (N+2,N) only. On the other hand, from precise isotope shifts of Xe and Ba we conclude that the linear relationship between $\delta\langle r^2\rangle$ and $\delta(B/A)$ holds for <u>all</u> pairs of even-even nuclei throughout the $h_{11/2}$ shell except for the last pair (N,N-2), indicating the existence of a shell-closure effect.

We have plotted experimental isotope shifts of Xe[2] and Ba[3] in the transitions at 467 nm and 554 nm, respectively, versus $\delta(B/A)$ for neighboring isotopes. The isotope shifts (IS') have been corrected for the normal mass shifts, experimental uncertainties correspond to the size of the dots. For the cases considered here the specific mass shift, contained in IS', is nearly independent of A and causes the same vertical displacement for all isotopic pairs of Xe and Ba, respectively. Hence the perfectly linear dependence of IS' and $\delta(B/A)$ for all pairs of neighboring even-even nuclei of Xe and Ba - with the exception of the last pair - holds between $\delta\langle r^2\rangle$ and $\delta(B/A)$, too. From the isotope shift data of Ca and Kr[4], for which similar plots can be made, the same result is obtained for the $f_{7/2}$ and $g_{9/2}$ neutron shells, respectively. Therefore, we propose that the linear relationship between $\delta\langle r^2\rangle$ as well as the existence of a shell-closure effect are general features of pairs of even-even isotopes in major neutron shells.



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MEASUREMENT OF THE HYPERFINE STRUCTURE AND ISOTOPE SHIFT FOR THE RADIOACTIVE Cd ISOTOPES ($102 \leq A \leq 120$) BY ON-LINE LASER SPECTROSCOPY*

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To study the hyperfine structure and the isotope shift of the Cd isotopes far from stability, an on-line system had been connected with the ISOLDE mass separator at CERN.

The ions, produced by proton induced spallation in a Sn target, are directed onto a MO-foil which is mounted inside a quartz resonance cell heated to about 500^0 C. After a collection time up to one half-life, the Cd is heated off as an atomic vapour. The cell is filled with 200 Torr helium buffer gas in order to prolong the diffusion time out of the vessel. By these means we could observe the free atoms for about one minute.

The atomic transition $5\ s^2\ {}^1S_0 \rightarrow 5\ s5p\ {}^3P_1$, $\lambda = 3261$ Å, was excited by the light of a tunable dye laser pumped with a pulsed nitrogen laser. The laser frequency is tuned by means of a grating and an internal etalon, both controlled by a mini-computer. The line $\lambda = 3261$ Å is reached by frequency doubling the $\lambda = 6522$ Å laser action of the CVP-R6G dye in an angle phase matched KDP-crystal. The resonance fluorescence is observed by a photomultiplier. In order to normalize to constant laser light intensity, the latter is monitored by a photodiode. The laser frequency is calibrated by recording simultaneously the resonance of stable ^{114}Cd in a reference cell. This cell is placed in the gap of a magnet in order to split the Zeeman-components providing a frequency scale by the known g_J-factor. Since the lifetime of the $^3P_1$-state ($\tau = 2.2$ µs) is long as compared to the length of the laser pulse ($\tau = 3$ ns) we could suppress the background from scattered laser light by delayed observation of the fluorescence. The currents of the photomultipliers are analysed by a 10-bit ADC and stored in the memory of the mini-computer. In cases of very low vapour density in the resonance cell we used the photon counting technique instead.

A survey over the results, as evaluated until now, is given in the following table :

^xCd	A(MHz)	$\delta\nu^{114-x}$ (MHz)	$\delta\langle r^2\rangle^{114-x}$ (fm^2)
102	-1150(100)	3400(100)	1.08
103		3000(100)	0.94
104		2450(100)	0.79
105		2170(100)	0.70
118		-520(100)	0.18
120		-550(100)	0.21

* This work was supported by the Bundesministerium für Forschung und Technologie and the Deutsche Forschungsgemeinschaft.

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NUCLEAR SIZES OF ^{40,42,44,48}CA, ^{50}TI, ^{52}CR FROM ELASTIC SCATTERING OF 104 MEV α PARTICLES

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The root mean square (rms) radii of the nuclear *charge* distributions of the Ca isotopes show a surprising behavior characterized by an increase from ^{40}Ca to ^{44}Ca followed by a decrease up to ^{48}Ca with ^{48}Ca having the same rms radius as ^{40}Ca [1]. For the nuclear *matter* radii which are experimentally excessible only via strong interacting probes a different behavior is expected [2]. The experimental investigations, however, are contradicting and considerably model dependent. In addressing these questions the elastic scattering of 104 MeV α particles from ^{40,42,44,48}Ca and ^{50}Ti, ^{52}Cr was measured with high angular accuracy over a wide angular range. The analyses used a single folding model with a density dependent effective interaction which is well-founded by full microscopic calculations [3]. The nuclear density distributions were described by Fourier-Bessel series which distinctly reduces the model dependence of the results and enables realistic estimates of errors [4]. The extracted differences of the density distributions displayed in fig. 1 are well determined showing evidence for a neutron skin in ^{48}Ca. The behavior of the Ca charge (proton) distributions is obviously due to a polarization of the protons by the added neutrons [5]. This polarization effect being strongest in ^{48}Ca is considerably reduced when adding two or four protons in the $f_{7/2}$ shell in ^{50}Ti and ^{52}Cr. For the latter no significant differences between proton and neutron densities is found.

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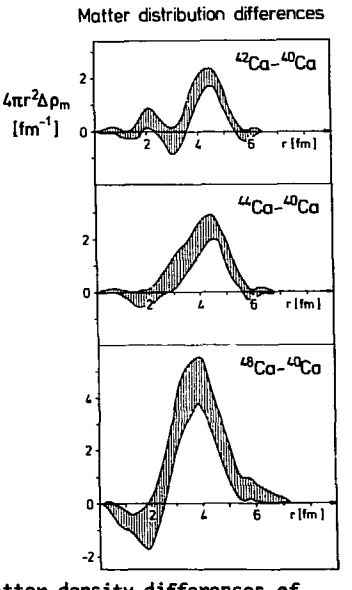


Fig. 1 Matter density differences of Ca-isotopes (Error band hatched)

HAVE THE LOW $K^\pi = 0^-$; $I = 1^-$ STATES IN THE HEAVY ($A \gtrsim 218$) EVEN-EVEN NUCLEI STABLE OR DYNAMICAL OCTUPOLE DEFORMATION?

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To understand the unusually low levels with $K^\pi=0^-$; $I=1$ in Rn, Ra, Th nuclei[1,2] three different models were proposed. One[1,3] considered these levels as octupole vibrational states (with dynamic octupole deformation). The existence of unusually low $I^\pi=1^-$ levels was considered as evidence for stable octupole deformation in the ground states of these nuclei[1]. Möller et al.[4] proposed that the deformations of the $K^\pi=0^-$ and $K^\pi=0^+$ states are quite different because they belong to different minima in the potential energy surface. Because all of the properties of heavy nuclei depend on their shape, it is very important to know if heavy nuclei indeed have any significant stable octupole deformation.

Strong arguments against a vibrational nature for the $K^\pi I=0^-1$ states in $A \gtrsim 218$ nuclei are low energy, $\lesssim 250$ KeV, of these states in some $_{88}$Ra and $_{90}$Th nuclei and the absence there of 2-phonon octupole states with $K^\pi=I^\pi=0^+$ at twice the 1-phonon energy[2]. However, more critical and clear evidence on the possible shapes of nuclei can be provided by the analysis of the energies of several members of a negative parity band. Analyzing the level energies of the $I^\pi=1^-$; 3^- and 5^- levels, and first 3 ground band levels in $^{220-226}$Ra, $^{224-230}$Th in terms of $E_{rot}(I) = A[I(I+1)-I_0(I_0+1)]+B[I(I+1) - I_0(I_0+1)]^2$ one finds A_1 ($K^\pi=0^+$) is always much larger than A_2 ($K^\pi=0^-$), and B_1 ($K^\pi=0^+$) is a significant parameter, whereas B_2 ($K^\pi=0^-$) is much smaller. These data were one of the strongest arguments[4] that the $K=0^-$ and $K=0^+$ states belong to different minima in the potential energy surface.

However, a careful analysis of the energies of the negative parity bands shows that they can be understood if the nonadiabaticity of the $K=0^-$ band is caused by strong Coriolis coupling with higher $k \geq 1^-$ bands[4] as is typical for octupole vibrational states which involve large j, unique parity nucleon orbitals. From qualitative estimations, it follows that with increasing strength of the Coriolis coupling the value of $E_\gamma(3^- \rightarrow 1^-)$ decreases and can be very small (it is only 10.2 KeV in ^{154}Gd). So the unusual properties of A_2 and B_2, contrary to earlier opinion[4], can be considered as a strong argument for the vibrational nature of the $K=0^-$ bands.

In A=150-160 nuclei such decreasing of $E_\gamma(3^- \rightarrow 1^-)$ with N led to the crossing of the $I^\pi=3^-$ and $I^\pi=1^-$ octupole vibrational levels. From a careful analysis of the levels in $^{218-222}$Rn, we assign 3^- to the levels at 797, 663 keV, respectively. We find in these nuclei a similar crossing of the 3^- and 1^- levels. Also our analysis shows that all known α,β, and γ-transitions to or from these $I^\pi=1^-$ states in this region have no additional retardation, which strongly suggests there is no significant difference in the shape of the ground states and the $K^\pi I=0^-1$ states. In summary, both level energies and transition probabilities strongly favor the conclusion that the $K^\pi=0^-$; $I=1^-$ have no stable octupole deformation and are ordinary, though anharmonic, octupole vibrational states in this mass region.

This work was supported by the U.S. Department of Energy.

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CHARGE FORM FACTOR OF ^{7}Li†

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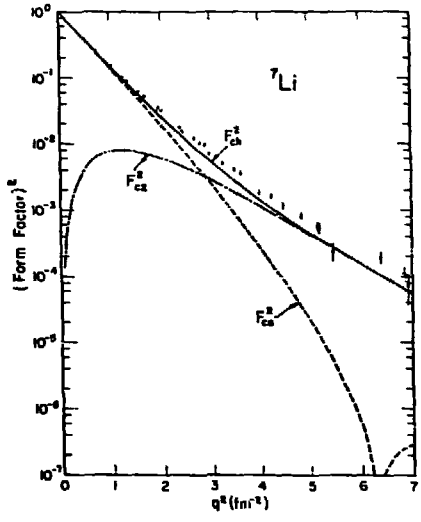
The charge form factor of ^{7}Li is calculated with a single-channel t+α resonating-group wave function[1] which has the form

$$\psi_M = \mathcal{A}\{\phi_\alpha \phi_t \, [\frac{1}{R} f_{J\ell}(R) Y^M_{J\ell S}] Z(\vec{R}_{cm})\},$$

where $\mathcal{A}$ is an antisymmetrization operator and $Z(\vec{R}_{cm})$ is a normalizable function describing the total center-of-mass motion. The functions ϕ_α and ϕ_t represent, respectively, the internal spatial structures of the α and t clusters, and $Y^M_{J\ell S}$ is a spin-isospin-angle function having ℓ=1, S=1/2 and J=3/2 with z-component M. The relative-motion function $f_{J\ell}$ is obtained by solving an integrodifferential equation to yield the experimental triton separation energy in the ground state of ^{7}Li.

The main advantages of this calculation are: (i) a totally antisymmetric wave function is used, (ii) the c.m. motion is properly considered, and (iii) the relative-motion function has a correct asymptotic behavior. In addition, it should be emphasized that there exist no adjustable parameters in this calculation.

Both C0 and C2 contributions are included in the calculation, and proton and neutron distributions are separately taken into account. The results are shown in the figure, where one sees that the C0 contribution is important for low-q^2 values, while in the higher-q^2 region the C2 contribution dominates.



From the low-q^2 behavior of the form factors, one determines the rms charge radius R_{ch} and the spectroscopic quadrupole moment Q. The results are R_{ch} = 2.44 fm and Q = -3.70 fm^2. Both of these values are in good agreement with the corresponding values empirically determined.

At present, we are improving the calculation by adopting a more flexible triton internal function and by taking specific distortion effects into account[1]. Both of these improvements should lead to an even better agreement between theory and experiment.

†This work was supported in part by the U.S. Department of Energy.
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MESON EXCHANGE CURRENTS AND THE MAGNETIC FORM FACTOR OF NUCLEI AT HIGH MOMENTUM TRANSFER

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The measurement of the magnetic form factor of various nuclei (^{51}V, ^{49}Ti, ^{87}Sr, ^{93}Nb) for momentum transfers from 2 to 3 fm^{-1} where it is dominated by the highest multipole, has shown that it was not decreasing as fast as expected from calculations using Hartree-Fock wave functions. The discrepancy may be due to these wave functions but also to corrections arising from configuration mixing or meson exchange currents (MEC).

We have considered the contribution of MEC by assuming they can be described, as far as the highest multipole is concerned, by an effective zero-range operator

$$V_{ex} = -\frac{ie}{2M} \cdot Ct \left(\frac{\vec{\tau}_1 \times \vec{\tau}_2}{2} \right)^Z \frac{\vec{\sigma}_1 - \vec{\sigma}_2}{2} \cdot \vec{q} \times \vec{\varepsilon} \cdot e^{-i\vec{q}.\vec{R}} \delta(\vec{r}_1 - \vec{r}_2)$$

which has to be used with uncorrelated wave functions. The strength of this operator is determined from the contribution attributed to MEC in the radiative thermal capture $n + p \to d + \gamma$ and is found to be of the order of 40 fm^3.

The advantage of this approach is to show that, on the average and in a first approximation, MEC gives rise to an effective one body contribution, $\pm Ct\, \rho_{n,p}/2$, which has to be added to the nucleon magnetic moment $\mu_{p,n}$, and which to some extent, represents the correction to the nucleon magnetic moment due to the presence of other nucleons. This correction tends to enhance the magnetic form factor at large momentum transfers.

The present approach gives a contribution of MEC from 2 to 3 times larger than the one calculated recently [1,2]. The discrepancy is essentially due to the fact that we incorporate implicitly the effect of the $^3S_1 - ^3D_1$ tensor coupling, which has been neglected by these authors, but which is known to be responsible for 60% of the MEC contribution in the thermal capture.

Calculations which are in progress with the standard model of MEC show that the above effect due to the $^3S_1 - ^3D_1$ tensor coupling is also present in complex nuclei. A final conclusion has to however await the calculation of the effect of the short range correlations on contributions involving other NN states.

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STATIC QUADRUPOLE MOMENTS OF THE FIRST EXCITED STATES OF THE EVEN-MASS ISOTOPES OF MERCURY

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The static quadrupole moments Q_{2^+} and B(E2; $0^+ \rightarrow 2^+$) values of the 2^+ first excited states of ^{200}Hg and ^{202}Hg have been determined using the reorientation effect in Coulomb excitation. An annular silicon surface-barrier detector was used to detect backscattered ^{4}He, ^{12}C and ^{16}O projectiles. It is found that for ^{200}Hg, $Q_{2^+} = +1.07 \pm 0.19$ e.b ($+0.98 \pm 0.19$ e.b) for destructive (constructive) interference from the 2+' state, and B(E2; $0^+ \rightarrow 2^+$) = 0.853 ± 0.007 $e^2.b^2$. For ^{202}Hg, we find $Q_{2^+} = +1.01 \pm 0.13$ e.b ($+0.87 \pm 0.13$ e.b) and B(E2; $0^+ \rightarrow 2^+$) = 0.605 ± 0.005 $e^2.b^2$. The Q_{2^+} value obtained for ^{200}Hg is in good agreement with previous work[1]), but that for ^{202}Hg is not. Results for ^{204}Hg will also be presented. The present results, together with those for ^{198}Hg obtained by Esat et al.[2]), will be compared with the predictions of various nuclear models, and the mass dependence of Q_{2^+} in the transition region will be examined.

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MEAN-SQUARE RADIUS CHANGE FROM CHEMICAL NEUTRON RESONANCE SHIFTS

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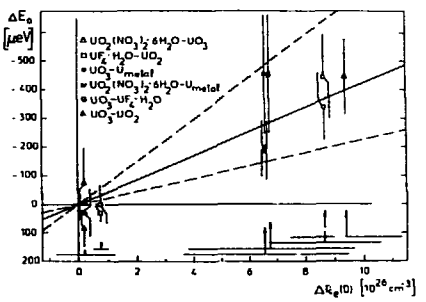
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The chemical shift of neutron resonances[1-3] is analogous to the Mossbauer isomer shift [4]. It may be determined by precise measuring the related minute displacement between the resonance dips in the neutron transmission curves of appropriate chemical compounds containing the nuclide under investigation. Such experiments were carried out at Dubna IBR-30 reactor with five compounds of ^{238}U employing the time-of-flight method. Using common symbols, the shift between the resonance energies of any two compounds is given by

$$\Delta E_o = (Ze^2/6\varepsilon_o)\, k\, \Delta\rho_e(0)\Delta\langle r^2\rangle$$

with the factor k (about 0.9 for U) allowing for the electron density inconsistency near the nucleus. The determination of ΔE_o is difficult due to the influence of the crystal lattice vibrations on the resonance line shape to be taken into account computationally.

Fig.1 presents experimental data for the chemical shift of the 6.67 eV resonance of ^{238}U. The electron density differences have been computed using available data on chemical X-ray shift in U compounds, on Mossbauer isomer shift in comparable Np compounds, and on free ions obtained from HFS calculations.



The analysis of the data given in Fig.1, yields a value of $-(1.7\ ^{+1.2}_{-0.8})\times10^{26}$ cm^2 for the change in $\langle r^2\rangle$ on passing from the ground level of ^{238}U to the excited level of ^{239}U. the errors indicated correspond to a confidence level of 95%. This result may intuitively be interpreted in terms of a change of the nuclear deformation with the nucleus reshaping its ground - level prolate form to a spherical one upon capturing the neutron.

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SPECTROSCOPIC QUADRUPOLE MOMENTS OF ^{27}Al AND ^{25}Mg FROM MUONIC X-RAYS

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From measurements of the h.f.s. splitting of muonic ^{27}Al and ^{25}Mg we can determine its nuclear spectroscopic quadrupole moments without systematic errors from the evaluation of the field gradient. These errors can be kept small, which is not the case with electronic ^{27}Al or ^{25}Mg experiments. The reason is that the field gradient in muonic atoms can be calculated with high precision, as we are dealing with a hydrogen-like-system, and that the muon-nucleus penetration effect is not important. With the bent-crystal spectrometer installed at the superconducting μ-channel of S.I.N. [1) 2)] we could for the first time apply this technique to as light isotopes as ^{27}Al and ^{25}Mg. By measuring the $3d_{5/2}$-$2p_{3/2}$ X-ray transition (Al-66 keV, Mg-56 keV) it was possible to observe the h.f.s. splitting of the $2p_{3/2}$ state. The Bragg reflexes from two 3.2 mm thick quartz crystals (003 planes), placed one upon another, were measured symultaneously in the third order. The results for our ^{27}Al measurement are shown in the table together with a value obtained from electronic atoms.

	Q [barns]	Reference
crystal 1	0.158(9)	
crystal 2	0.157(9)	
average value	0.157(7)	this work
Atomic beam magnetic resonance	0.140(2)	(3)

Table: Measured spectroscopic quadrupole moment of the ^{27}Al ground state.

The disagreement of more than two standard deviations reflects the difficulty in the evaluation of the field gradient of electronic ^{27}Al. Preliminary results of the ^{25}Mg measurement will be given.

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ISOBARIC ANALOG STATES IN RARE-EARTH NUCLEI AND HEXADECAPOLE DEFORMATION

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The (^{3}He,t) charge exchange reaction to g.s. isobaric analog states (IAS) has been studied at $\theta=0^0$ and $E(^3He)=60$ MeV on targets of $^{152,154,156,158,160}Gd$, $^{160,162}Dy$, $^{162,164,166,168,170}Er$, $^{170,172,174,176}Yb$ and $^{176,178,180}Hf$. The reaction $^{28}Si(^3He,t)^{28}P$ (Fig. 1) was used for energy calibration, and the centroid energies of the IAS were determined to about ±10 keV. A typical spectrum is displayed in Fig. 2. The Lorentzian line shape is apparent. Background from $T_<$ states is present but weak. The 2^- state in ^{16}F at $E_x=424$ keV from oxygen contaminants interferes with a few of the states. Coulomb displacement energies are extracted from the measured Q-values. They are lower by typically 100 keV than the values expected for spherical nuclei since deformed shapes result in increased rms radii. The data display a dip near A=164-170 which seems to suggest smaller deformation than for the neighboring nuclei. However, Coulomb displacement energies are in lowest order reduced by the factor $(1-(\beta_2^2+\beta_4^2)/4\pi)$ due to quadrupole and hexadecapole deformation. The observed dip marks the region where the hexadecapole deformation changes sign, A ≈166. A preliminary analysis of the data yields agreement with the known β_2 and β_4 deformations. The 0° cross sections increase with neutron excess. The observed widths are in the range 60 to 140 keV. They are related to the excitation and binding energies of the IAS which determine the T-allowed and T-forbidden decay channels.

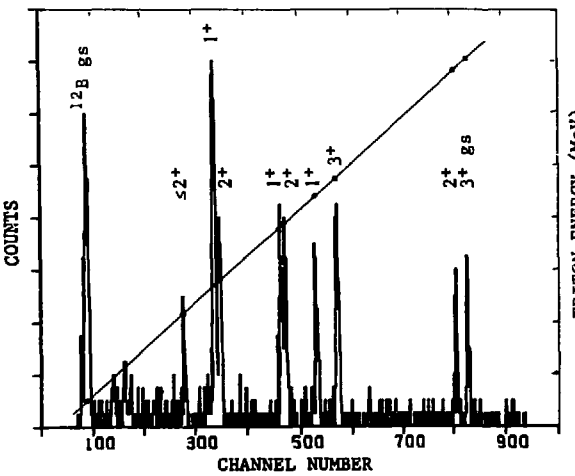


Fig. 1
$^{28}Si(^3He,t)^{28}P$, $E(^3He)=60$ MeV, $\theta=0^0$

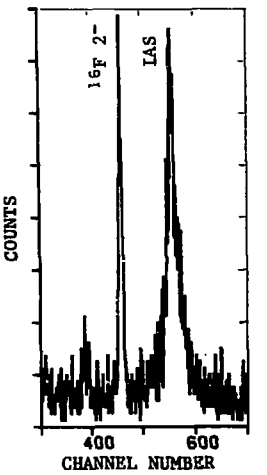


Fig. 2
$^{160}Dy(^3He,t)^{160}Ho$(IAS)

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PROTON ELASTIC SCATTERING AT 200 TO 500 MeV[†]

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Elastic scattering of 200 to 500 MeV protons from ^{208}Pb and Ca has been studied using the polarized proton beam and proton spectrometer at TRIUMF. Cross section and analyzing power angular distributions were obtained out to momentum transfers of approximately 4 fm^{-1}. Nuclear matter radii deduced by fitting these results in a multiple scattering formalism will be reported and compared with 0.8 and 1.0 GeV results.

[†]Work supported in part by the Natural Sciences and Engineering Research Council of Canada.

$B(E2;0^+\rightarrow 2^+)$ AND Q_{2+} MEASUREMENTS IN ^{100}Ru

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The rather complex level structure of ruthenium isotopes, characterized by both vibrational and rotational modes of excitation, has focussed a strong interest in the properties of the quadrupole operator for these nuclides. We report here on results of a measurement of the reorientation effect for the first 2^+ excited state of ^{100}Ru.

The experimental method and procedures for data reduction were essentially the same as in Ref.[1]. Beams of ^4He(8-9 MeV) and ^{16}O(35-37 MeV) obtained from the São Paulo tandem accelerator were scattered from thin Ru targets enriched in ^{100}Ru(97.2%) and evaporated onto 10μg/cm^2 carbon foils. The scattered ions were detected in silicon surface barrier detectors placed at 174° (annular detector), 130° and 110°. A typical heavy-ion spectrum at 174° is shown in Fig.1 together with the fit used in the analysis of the data to determine the experimental excitation probability (R_{exp}).

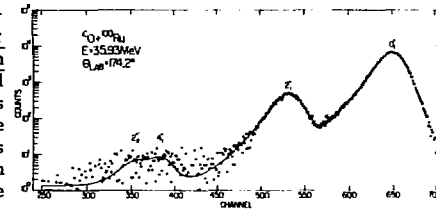


Figure 1

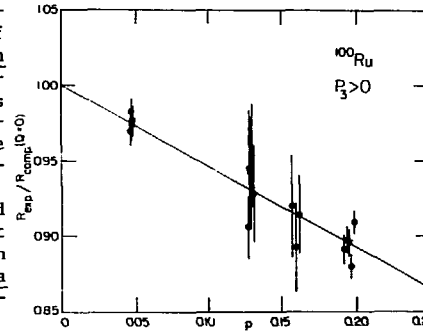


Figure 2

The electric quadrupole matrix elements $M_{02}=[B(E2;0^+\rightarrow 2^+)]^{1/2}$ and $M_{22}=-1.32Q_{2+}$ were deduced by comparing the measured R values with those calculated (R_{comp}) using the multiple Coulomb excitation program of Winther and de Boer. The first five levels of ^{100}Ru and their associated electric quadrupole matrix elements were used in the calculation. The results of the analysis are presented in Fig.2 where the ratio $R_{exp}/R_{comp}(Q=0)$ (computed in this case for the positive sign of the interference term involving the $2^{+\prime}$ state at 1.36 MeV) has been plotted against the sensitivity parameter ρ[1].

We find a reduced transition probability $B(E2;0^+\rightarrow 2^+)=0.493\pm0.003e^2b^2$ and a quadrupole moment of $Q_{2+}=-0.54\pm0.07$eb (for constructive interference) or $Q_{2+}=-0.33\pm0.07$ (for destructive interference), indicating a prolate deformation for this nucleus. This follows the trend observed for the other stable isotopes. The present result is in agreement, within the stated uncertainties, with the result of Fahlander et al.[2] and with the recently reported result of Landsberger et al.[3], but disagrees with measurements by Maynard et al.[4].

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TOWARDS AN ACCURATE DESCRIPTION OF NUCLEAR GROUND STATE PROPERTIES

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A carefull study of mass and charge density predictions obtained from the energy density method[1]) as a function of the particle numbers shows that discrepancies with respect to experimental values are strongly correlated with the nuclear shell structure : for the binding energies, the largest differences are observed in the middle of major shells ; measurements of the ^{208}Pb charge density[2]) indicate clearly the need for two particles-two holes contributions to the ground state.

In order to account for such effects we propose to include a semi-empirical quadrupole correlation term in the usual energy density functionals. It is essentially proportionnal to the size of the configuration space available to two particles-two holes contributions. Such a possibility as already been investigated for the binding energies[3]). It is extended here, in order to provide us with an accurate description of binding energies and particle densities. Preliminary results will be presented and discussed.

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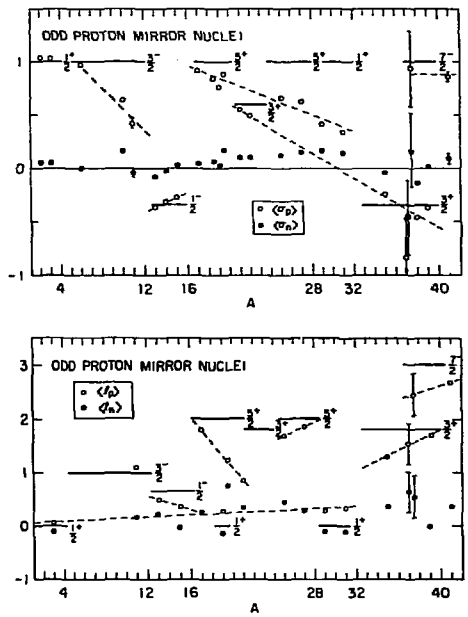
MAGNETIC MOMENTS OF MIRROR NUCLEI[†]

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The magnetic moments of the mirror nuclei $^{25}A\ell$, ^{27}Si, ^{31}S, and ^{39}Ca have been measured[†††] by polarizing these beta-emitters in $(\vec{p}, n)$ reactions and by observing nuclear magnetic resonance while detecting the asymmetric beta decay. The polarization transfer can be described by a quasi-elastic scattering model in which the proton and neutron in a mirror transition exchange charge but not spin. The spin-tensor interaction dominates the spin-orbit interaction and the scattered neutron has spin preferentially aligned parallel with the projectile proton in a transverse polarization transfer reaction. The spin-tensor interaction changes sign in a longitudinal polarization transfer reaction and the scattered neutron is polarized antiparallel to the projectile proton. The results of a distorted-wave Born approximation calculation which includes a strong spin-tensor interaction are consistent with the quasi-elastic scattering polarization transfer model.

The magnetic moments of mirror nuclei have been analyzed in a simple jj-coupling shell model in which effective bound nucleon g-factors are obtained by fitting the measured magnetic moments for $2 \leq A \leq 41$. These renormalized g-factors are indicative of meson exchange contributions to the nuclear current. The distribution of spin and orbital angular momentum of the nucleons in mirror nuclei are determined in this model and are displayed for odd proton mirror nuclei (see figure). Solid horizontal lines indicate single particle jj-model expectation values for each shell orbit. Systematic linear variations within each shell orbit are indicated by dashed lines. From these regularities we predict the unmeasured mirror magnetic moments: $\mu(^{23}Mg) = -0.52$ and $\mu(^{33}C\ell) = 0.87$.



[†]Supported by National Science Foundation.

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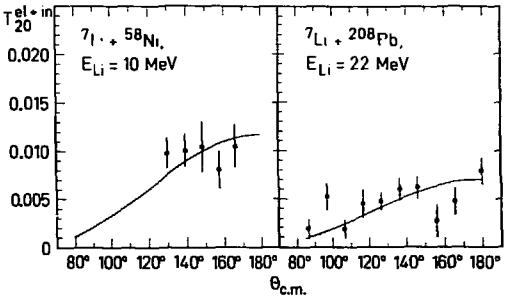
[†††]Measured values: $\mu(^{25}A\ell) = +3.6454(11)$, $\mu(^{27}Si) = -0.8554(5)$, $\mu(^{31}S) = -0.48793(8)$, and $\mu(^{39}Ca) = +1.0215(3)$; all values corrected for diamagnetic shielding in host crystals.

DETERMINATION OF THE ELECTRIC QUADRUPOLE MOMENT OF ^{7}Li BY COULOMB SCATTERING OF AN ALIGNED ^{7}Li BEAM

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With the development of polarized heavy ion beams[1]) a new method for determining nuclear electric quadrupole moments became possible. In an aligned beam the nuclear spectroscopic quadrupole moments are aligned along with the spins. The elastic scattering (σ_{al}) of such a beam in Coulomb fields of target nuclei yields certain deviations with respect to the scattering of unpolarized beams (σ). An exact calculation using the formalism of Coulomb excitation shows[2]) that the tensor analyzing power $T_{20} = (\sigma_{al}-\sigma)/\sigma$ is directly proportional to the spectroscopic quadrupole moment Q whereby the proportionality factor is a well-known function of Θ and E. Besides the contribution due to the deformation of the ground state of the projectile there are other contributions to the tensor analyzing power of the elastic channel due to the real and virtual excitation of the projectile (dynamic polarization) which have to be taken into account. A detailed discussion[3]) shows that the sum of elastic and inelastic scattering (^{7}Li: 0.478 MeV) corresponds nearly exactly to pure Coulomb scattering for which the theory is applicable. In a first experiment the scattering of aligned ^{7}Li from ^{58}Ni at 10 MeV and from ^{208}Pb at 22 MeV has been investigated. The figure shows the measured angular distribution of T_{20} for the sum of elastic and inelastic scattering. The spectroscopic quadrupole moment of ^{7}Li was extracted from the data by a fit (solid line) using Q as the only free parameter. After correction for the effect of virtual E1 excitation (10-20% of the total effect), other possible contributions having been considered and shown to be negligible, the averaged value turned out to be Q = (-34 ± 6)emb. This observed value agrees quite well with the ones obtained in atomic spectroscopy[4]). A more extensive experiment (better statistics) together with a more sophisticated analysis (coupled channels) promises considerable improvements in accuracy. The results of these experiments can then be used as an additional check of the calculation for field gradients in atoms and molecules.



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DEUTERON MAGNETIC MOMENT AND MESON EXCHANGE CURRENT

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The observed value of deuteron magnetic moment deviates from the calculated value of impulse approximation by $\Delta\mu$ = 0.0145 n.m., if we use the deuteron wave function of Reid[1]). Although this deviation is small, it is one of the most fundamental quantities to be answered in the meson theory, and has been studied by many people. The quantity $\Delta\mu$ involves the relativistic correction to static one-body operator and the meson-exchange current effect. Since the deuteron magnetic moment is of iso-scalar type, the static one-boson-exchange current does not contribute. Therfore, we must study the contributions of non-static one-boson-exchange and also two-boson-exchange currents. An important caution is that we must define the exchange current so as to avoid the double counting between the impulse calculation with nuclear wave function and the meson-exchange current.

In order to avoid this, we defined the nuclear force and the exchange current consistently by eliminating degrees of freedom of nuclear constituents except nucleons from the nuclear wave function by the unitary transformation[2]). As a result, we obtained the same exchange current for the one-boson-exchange process, except for the nucleon-recoil term, as in ref.[3]), but different results for the two-boson-exchange process from those obtained in the S-matrix approach[4]). We found that this difference is due to the incorrect treatment of nuclear force and meson-exchange current in the previous work[4]). To obtain the correct two-boson-exchange current, we must treat the non-static one-boson-exchange nuclear force and the non-static one-boson-exchange current in the S-matrix approach very carefully by paying attention to the non-uniqueness of these operators. In the present work, we fixed the unitary transformation to as to maintain the gauge-invariance of the interaction.

To estimate the quantity $\Delta\mu$, we took into account π, ρ, ω mesons and Δ isobar in the exchange current. We assumed the vector-dominance model for ρNN interaction, and quark model predictions for the other interactions. By using the deuteron wave function of Reid's soft core potential, we obtained the following results: The relativistic correction is -0.0079 n.m. The one-boson-exchange current consists of the recoil, nucleon pair and meson dissociation terms, whose contributions are -0.0012, 0.0109 and 0.0049 n.m. The net correction of one-boson-exchange current is 0.0146n.m. The two-boson-exchange current gives correction 0.0070 n.m. Then we obtain $\Delta\mu$ = 0.0140 n.m. which should be compared with the observed value $\Delta\mu$ = 0.0145 n.m.

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EFFECTS OF MESON EXCHANGE CURRENT AND THREE-BODY FORCE ON THE CHARGE FORM FACTOR OF THE ^{3}He NUCLEUS

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In a recent article[1] we have investigated effects of meson exchange currents (MEC) on the charge form factors (CFF) of ^{3}H and ^{3}He with the use of full components of variational wave functions obtained by the ATMS method for some realistic N-N potentials. We have shown the importance of using accurate solutions for the D-state wave function because of the tensor nature of MEC operators. As for a treatment of MEC, we have followed the FST-Okubo method which has been used by Ohta-Wakamatsu, Gari-Hyuga and others[2].

In this note, besides MEC, we study the effect of three-body force (TBF) on the CFF of ^{3}He by employing the effective two-body potential[3] which takes into account the effects of TBF and three-body-cluster correlation (TCC): $V = V_2 + V_{TBF} + V_{TCC}$, where V_2 is an original N-N potential. The TCC is introduced because it gives fairly large repulsive contribution to binding energies of finite nuclei at higher density than the normal density[3].

Fig. 1 shows the result for the CFF of ^{3}He using the Tamagaki's OPEG potential as V_2. Curves show the results as follows. Curves a and c: with and without the three-body effects (TBF + TCC) in the impulse calculations, curves b and d: with and without the TBF + TCC including the πNN pair current correction whose contributions are given by the solid and dashed curves π, respectively. Curves πa, πb, πc and πd: the isoscalar (I=0) S-S, I=1 S-S, I=0 S-D, and I=1 S-D matrix elements of the πNN pair current using the total potential V. In Fig. 2 contributions from the $\rho\pi\gamma$ (curves ρ), $\omega\pi\gamma$ (curve ω) as well as πNN pair currents are given for comparison[1] using the Hamada-Johnston (curves e, solid curves f, π, ρ, ω) and OPEG potentials (curves c, d, dashed π).

The three-body effects considered in the present calculation gives small enhancement of the MEC contribution. The OPEG potential gives good fits in the region of $q^2 = 5$-10 fm^{-2} if MEC corrections are included.

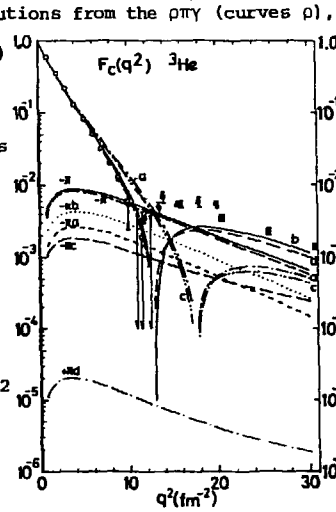


Fig. 1

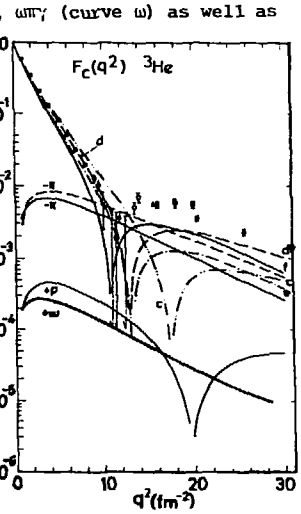


Fig. 2

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TRIAXIAL DEFORMATION EFFECTS IN THE 2^+ TRANSITION CHARGE DENSITY OF ^{58}Ni

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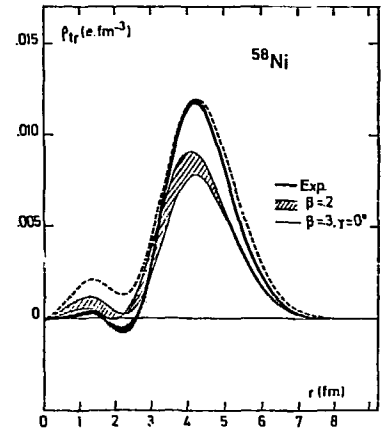
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Microscopic calculations of transition charge densities for deformed nuclei have been determined up to now within the framework of axial models. In the present paper, we investigate the effects of triaxial deformations on the shape of the first 2^+ transition charge density $\rho_{tr}(r)$ of ^{58}Ni. This nucleus is a good example of soft nucleus : (i) the energy deformation surface is very flat for $\beta \lesssim .3$. (ii) A definite improvement of the shape of the ground state charge density is found by taking into account dynamical corrections [1] (iii) The solution of Bohr's hamiltonian gives an average dynamical deformation of the ground state around $\beta = .2, \gamma = 30°$.

The intrinsic states have been determined in a β and γ constrained Hartree-Fock-Bogolyubov calculation with the Gogny interaction [2]. To test the dynamical effects, we have performed the calculations at different fixed and γ values, in the model of Davydov and Filippov.

In the figure, we compare the theoretical predictions to the experimental result determined by electron scattering [3]. The shaded area includes all the different shapes at $\beta = .2$ and $0 \leq \gamma \leq 60°$. The phasing of the oscillations is correct but the theory finds a less pronounced structure. The intensity of the surface peak is too weak and a negative lobe is not found in this part of the β, γ plane. We have also represented a calculation for $\beta = .3$ $\gamma = 0°$. A much better agreement is found at the surface, but the agreement in the interior of the nucleus with experiment is less good.



The present results suggest that in order to agree with the experimental result, the collective wave functions must have a complex behaviour in the β, γ plane. It is then, imperative to solve the full dynamical problem.

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E2 AND E3 TRANSITIONS IN THE $K^{\pi}=0^{\pm}$ BANDS OF ^{24}Mg WITH AN EXTENDED DEFORMATION MODEL

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In the low-energy region of ^{24}Mg strong E3 transitions are observed,[1] which neither the shell nor the cluster model can be expected to explain. We put forward an extended deformation model[2] where a parity-violating quadrupole(Y_2) plus octupole(Y_3) type of the deformation is assumed and the single-particle modes in the corresponding field are dealt with. All the twenty-four nucleons are explicitly taken into account in this model. We confine our considerations, here, to E2 and E3 transitions in the lowest $K^{\pi}=0^{\pm}$ bands of ^{24}Mg.

Table 1 shows the presently calculated B(E2) values together with other theoretical results[3,4] and the experiment.[1,5] The absolute values and their spin dependence are well reproduced in our model. It should be noted that the tendency of the present prediction is very similar to that of the SU_3 model[3] in the $K^{\pi}=0^{+}$ band. The B(E3) values are listed in Table 2. The agreement between our calculation and the experiment is excellent, which exhibits a striking contrast to the cluster model calculation[4] giving only one-fifth of the observed value even by the use of an effective charge of $\delta_{eff}=0.5$.

We remark the following points. A large model space is severely required for a high-multipole transition . In the present calculation we take the major shells up to five(pfi-shell) in the harmonic oscillator expansion of the single-particle orbitals. A restriction of the major shells N=5 → 3 yields only ∿58% and ∿14% of the initial B(E2) and B(E3) values, respectively. The main reasons for the E3 enhancement are the core-polarization and the higher-major-shell mixing appreciably caused by the parity-violating component in some particular deformed orbitals. Moreover, it is the Y_3 correlation inherent to some extent in the $K^{\pi}=0^{+}$ band rather than in the well polarized $K^{\pi}=0^{-}$ band that plays a predominant role in the E3 enhancement mechanism mentioned above. In fact a modification of the Y_3-strength of the 0^{+}-state $\delta_3=0.14 \rightarrow 0$ reduces the B(E3) value by ∿72%. This supports, therefore, the picture that the $K^{\pi}=0^{\pm}$ bands make the inversion doublet, i.e. the two rotational bands built upon the parity-violating deformed intrinsic state.

Table 1 B(E2) in $K^{\pi}=0^{\pm}$ bands of ^{24}Mg(W.u.)

$K^{\pi}=0^{+}$	experiment[5]	present	SU_3[3]	cluster[4]
$2^{+} \rightarrow 0^{+}$	20.5 ± 0.6	22.4	25.4	17.6
$4^{+} \rightarrow 2^{+}$	23 ± 4	31.7	34.2	22.4
$6^{+} \rightarrow 4^{+}$	34 $^{+36}_{-10}$	35.9	33.5	17.4
$8^{+} \rightarrow 6^{+}$	16 $^{+25}_{-6}$	30.5	29.2	6.5
$K^{\pi}=0^{-}$	experiment[1]			
$3^{-} \rightarrow 1^{-}$	< 200	40.8		16.9
$5^{-} \rightarrow 3^{-}$	20 $^{+8}_{-5}$	31.8		13.5
$7^{-} \rightarrow 5^{-}$	51 ± 10	38.9		8.5

Table 2 B(E3) between $K^{\pi}=0^{\pm}$ bands of ^{24}Mg(W.u.)

$K^{\pi}=0^{-}$ $K^{\pi}=0^{+}$	experiment[1]	present	cluster[4]
$3^{-} \rightarrow 0^{+}$	10.5	8.8	0.51($\delta_{eff}=0.0$)
$5^{-} \rightarrow 2^{+}$	11.0	11.9	2.0 ($\delta_{eff}=0.5$)
$7^{-} \rightarrow 4^{+}$	< 38	13.9	

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NUCLEAR CHARGE DISTRIBUTION BETWEEN DOUBLE MAGIC ^{40}Ca and ^{48}Ca

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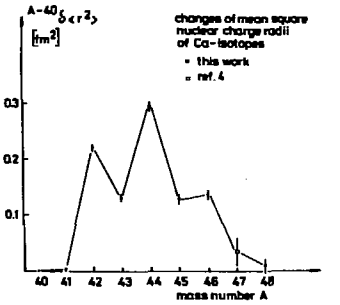
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The great interest, which the Ca-nuclei have provoked is due to several reasons: ^{40}Ca as well as ^{48}Ca are double magic nuclei. The long chain of isotopes exhibits a large relative change of the mass-number (20%) and the neutron-number (40%). It opens the way for a systematic study of nuclear properties as the $f_{7/2}$-neutron-shell is filled up. More specific, the changes of the rms charge radii provide a sensitive test for nuclear theories[1] and are of interest in connection with the understanding of Coulomb displacement energies. So far, accurate values for the charge radii were available only for a few pairs of isotopes from a combined analysis[2] of muonic X-ray and electron scattering data.

In this paper a series of experiments on eight stable and radioactive Ca-isotopes is reported. The rms charge radii have been extracted from the optical isotope shift in the Ca intercombination line. This very weak transition with its small natural width of 410 Hz and a Dopplerfree experimental technique guarantee a high accuracy in the measurements. The experiment applies a collimated atomic beam and a narrow-band, electronically stabilized cw dye laser.



A combined analysis of the results with muonic X-ray data yields highly accurate, model-independent values for the changes of the rms nuclear charge radii $\delta\langle r^2\rangle$ from ^{40}Ca to ^{48}Ca. Moreover, the nuclear quadrupole moments of the three odd-mass isotopes ^{41}Ca, ^{43}Ca and ^{45}Ca have been determined yielding information on the nuclear charge distribution.

The very peculiar dependence of $\delta\langle r^2\rangle$ on the mass-number (see figure) can be understood in terms of a phenomenological model and a microscopic theory[1]. In addition, it can be well fitted to an empirical formula[3], which also well describes the binding energies in the $f_{7/2}$-shell.

This work was supported by the Deutsche Forschungsgemeinschaft.

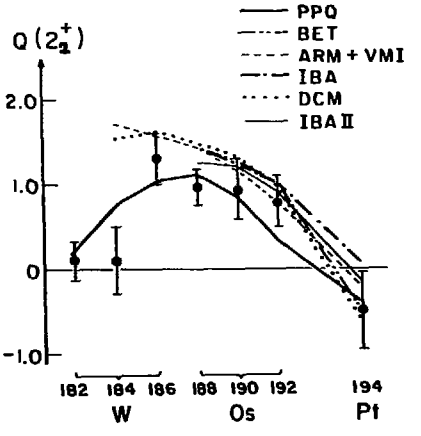
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QUADRUPOLE MOMENTS OF 2_2^+-STATES IN THE W-OS-PT REGION

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It is by now well established that the determination of the electromagnetic properties of nuclei in the transition region plays a crucial role in assessing the validity of various nuclear models.[1] As part of an ongoing systematic effort we present here (see figure) the quadrupole moments of the 2_2^+ states in this region. The measurements were based on the reorientation effect in Coulomb excitation. Both particle-spectroscopy and particle-gamma coincidence experiments were carried out, using α, ^{16}O, and ^{32}S beams. Fig.1 compares the experimental values with predictions of the pairing plus quadrupole model[2] (PPQ), Boson expansion theory[3] (BET), the dynamic collective model[4] (DCM), the IBA[5] and the asymmetric rotor model with variable moment of inertia[6] (ARM+VMI). Only PPQ and DCM reproduce the decrease in $Q2_2^+$ between ^{186}W and $^{182,184}W$. Looking at the PPQ wavefunctions this trend can be traced to a significant amount of mixing in the 2_2^+ state between the β and γ degree of freedom. A detailed analysis of ^{194}Pt involving many matrix elements favours the predictions of γ-soft models (PPQ, BET and IBA) over the rigid asymmetric rotor model. It is interesting to note that PPQ encompasses both features, the mixing of the β and γ degree of freedom in $^{182,184}W$ as well as the occurrence of γ-softness in ^{194}Pt.



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Core-Polarization Effects on the Magnetic Form Factor of ^{208}Pb (14^-, 6.74 MeV)

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A magnetic transition to the 14^- (6.74 MeV) state of ^{208}Pb was recently observed by electron scattering.[1] The magnitude of the squared form factor was found to be reduced by 50% from that given by the pure particle-hole $(j_{15/2}\, i_{13/2}^{-1})$ model although its shape is well reproduced by the model.

We investigate the core polarization effects on this form factor by the Tamm-Dancoff approximation (TDA) as well as the first-order perturbation (FOP). In the case of FOP, both forward and backward amplitudes are included. Harmonic oscillator radial dependence is assumed for the single-particle wave function ($\hbar\omega$ =6.9 MeV). The effective interactions we use are phenomenological interactions of Gaussian type with the Rosenfeld and Serber mixtures, a three-range Yukawa interaction by Bertsch et al.[2] which also includes tensor and spin-orbit components, and the Migdal-type δ-interaction.[3]

The calculated energy shifts and the peak ratios of the calculated form factor to that of the pure p-h model are shown in the table. There is a strong dependence on both the range and the exchange character of the interaction. The shape of the form factor is found to be little affected by the core polarization. One can expect from the table that for the δ interaction the reduction of the form factor is much enhanced by the inclusion of higher excitations. The present result by δ interaction is consistent with the result by Hamamoto et al.[4] in which the contribution from the continuum states is treated more accurately.

interaction	RM	Serber	Bertsch	δ	δ	δ
method	TDA	TDA	TDA	TDA	FOP	FOP
space	$3\hbar\omega$	$3\hbar\omega$	$3\hbar\omega$	$3\hbar\omega$	$3\hbar\omega$	$5\hbar\omega$
energy shift (MeV)	0.11	0.33	-0.04	0.82	0.89	0.89
peak ratio	1.006	0.95	1.013	0.84	0.70	0.55
volume integral $(\nu_\sigma+\nu_{\sigma\tau}$, MeV·fm$^3)$	213	228	284	494	494	494

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EFFECTIVE RANGE EXPANSION OF THE WOODS-SAXON PHASE SHIFTS

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For a large class of one body potentials for a semi-infinite system of nuclear matter, the s-wave phase shift in JWKB approximation (which is good for high momentum states) is a linear function of diffuseness of such potentials. As a result of this fact the shape parameter and surface energy in ref. 1), are approximately proportional to the above diffuseness.

It would be interesting to see if for low momentum states a simple relation between phase shift and diffuseness will hold or not. Using effective range theory we have

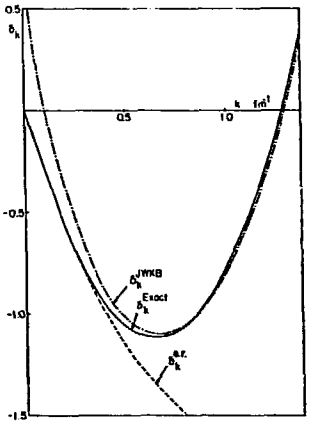
$$k \cot \delta_k = \delta_0'^{-1} + (k_1 \cot k_1 - \delta_0'^{-1})\,(k/k_1)^2 + \ldots$$

where δ_0' is the derivative of the phase shift respect to momentum at k=0 and k_1 is any arbitrary but small value of k. For a Woods-Saxon potential $U(\infty)(\exp(-\alpha z)+1)^{-1}$ the first term in expansion of exact δ_k in powers of k is

$$\delta_k = 2\Big\{ (2\gamma)^{-1} + (\gamma+\alpha)^{-1} - \alpha^{-1} - \gamma^{-1}\sum_{n=2}^{\infty}(-)^n [\zeta(n)-1](\gamma/\alpha)^n \Big\} k + \ldots$$

where $\gamma^2+k^2=-U(\infty)$ and $\zeta(n)$ is the Riemann Zeta function. This is a complicated function of diffuseness and thus the answer to the above question is negative.

In the figure the exact and approximate phase shifts are plotted for $U(\infty)=-2.62$ fm^{-2} and $\alpha=0.8$ fm^{-1}.



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EXCHANGE CURRENTS IN EXCLUSIVE STRIPPING REACTIONS AT LARGE MOMENTUM TRANSFERS

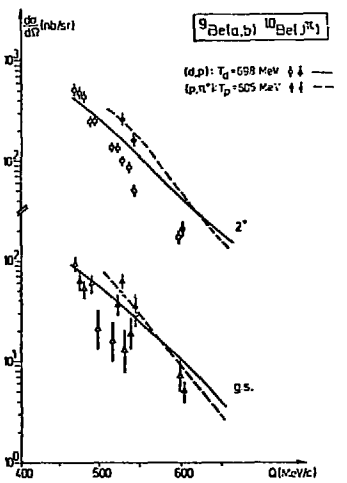
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The exclusive one nucleon transfer reactions (p,π), (γ,p) or (d,p) were increasingly investigated in the last years. The growing amount of experimental information made it possible, to pin down details of the reaction mechanism: the data indicate that at recoil momenta Q larger than 500 MeV/c the stripping reactions mentioned above are all dominated by π-induced Δ-isobar excitation.

Concentrating on scattering energies around or above the 33-resonance the characteristic features of the (p,π), the (γ,p) and the (d,p) reaction are investigated in the rescattering model. Various problems are addressed in detail:

- the role of the direct versus the single rescattering contribution to the nuclear amplitude is extracted from a coherent analysis of the excitation function of the (p,π) and the (γ,p) process, yielding the dominance of the two-nucleon mechanism for $Q \gtrsim 400$ MeV/c;
- within the rescattering model the interplay between the real and the virtual isobar excitation is discussed and an estimate for the admixture probability of virtual isobar components in the nuclear ground state is given;
- we establish a transparent relation between the (p,π) and the (d,p) process at energies far above the 33-resonance; the model accounts qualitatively for the strong similarity between both reactions observed in recent data[1] (in the figure enclosed the (d,p) and the (p,π) differential cross section are compared a function of the recoil momentum Q).



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1. A. Boudard, P. Couvert and M. Dillig preprint DPh-N/ME, CEN Saclay (1980)

ELASTIC SCATTERING OF 0.8 GeV POLARIZED PROTONS OFF ^{46,48}Ti*

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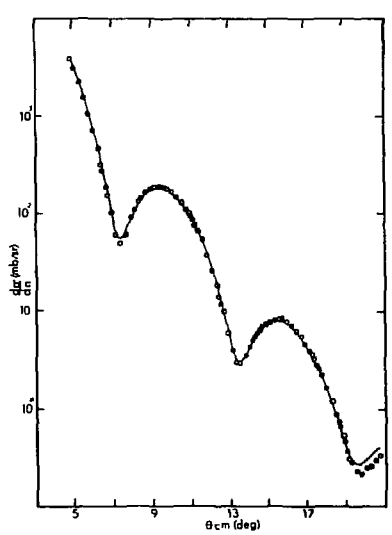
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Differential elastic cross sections and analyzing powers for the scattering of polarized protons off ^{46,48}Ti have been measured at angles ranging between 4.5° and 7.5° (c.m.) using the High Resolution Spectrometer at the Clinton P. Anderson Meson Facility (LAMPF). The absolute laboratory angle was determined to ± 0.03°. The statistical errors in the differential cross sections are typically < ± 1% while those of the analyzing powers range between 0.01 and 0.05. The absolute normalization is believed reliable to ± 5%. Differential cross sections for ^{48}Ti are shown in the accompanying figure. The solid curve in this figure represents a calculation using a spin-dependent KMT optical model in the Schrödinger equation with relativistic kinematics. Details of the method have been reported elsewhere.[1] Analyzing powers (not shown here) are also calculated. Neutron matter distributions which are adjusted to obtain the best fit to the data, will be presented and compared with Hartree-Fock calculations.



*This work was supported in part by the U.S. Department of Energy.

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1. L. Ray, et al., Phys. Rev. C18, (1978) 2641 and refs. therein.

ON THE ZERO-POINT GOLDHABER-TELLER (GT) MOTION

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In ref.[1] a beautiful model-independent interpretation of the bremsstrahlung weighted photoabsorption cross-section σ_{-1} has been given : $\sigma_{-1} \equiv \int (\sigma(\omega)/\omega) d\omega = (4/3)\pi^2 (e^2/\hbar c)(NZ/A)^2 \langle 0|r_{ZN}^2|0\rangle$ where r_{ZN} is the relative coordinate of the center of mass of protons with respect to the center of mass of neutrons. The above equation tells that σ_{-1} is a direct measure of the GT zero-point motion. We analyse the experimental data to extract the amplitude of this motion (see table). From the experimental knowledge of σ_{-1} [2] (first column) is extracted the value of $\langle r_{ZN}^2 \rangle^{1/2}$ (second column). The ratio R of $\langle r_{ZN}^2 \rangle^{1/2}$ to the experimental charge root mean square radius r_c (third column) is given in the fourth column. The fifth column gives the following estimation of R : take $H_{ZN} = (p^2/2\mu) + (1/2)\mu\Omega^2 r_{ZN}^2$ to describe the relative proton-neutron motion, with $\mu = (NZ/A)m = (A/4)m$ and $\hbar\Omega = 79\ A^{-1/3}$ MeV in agreement with the systematics on the GDR. One obtains $\bar{R} = 1.87\ A^{-2/3}$, shown on the fifth column, in good agreement with the value of R extracted from experiment. The last column ($R_{GDR} = \sqrt{5/3}\ R$) corresponds to the ratio of the root mean square radius of proton-neutron motion of the GDR to r_c. For light nuclei, R and R_{GDR} are large and therefore there are good chances that during the dipole oscillation proton and neutron distributions have a relatively small overlap. One can then imagine that the study of the deexcitation of the GDR of light nuclei may provide information on, for instance, neutron-neutron correlations. In particular, the possibility to observe multineutron bound states in this way should be explored (in ^{7}Li, for which R_{GDR} is 0.68, the 2n threshold is at 10.9 MeV and the 3n is at 31.5 MeV, not too far from the GDR).

	σ_{-1} (mb)	$\langle 0\|r_{ZN}^2\|0\rangle^{1/2}$ (fm)	r_c (fm)	R	$\bar{R}$	R_{GDR}
^{7}Li	4.64	1.28	2.41	0.53	0.51	0.68
^{9}Be	5.19	1.05	2.51	0.42	0.43	0.54
^{12}C	8.81	1.01	2.45	0.41	0.36	0.53
^{16}O	14.50	0.97	2.72	0.36	0.29	0.46
^{40}Ca	45.5	0.69	3.48	0.20	0.16	0.26
^{90}Zr	70.6	0.39	4.28	0.09	0.09	0.12
^{208}Pb	229.2	0.31	5.50	0.06	0.05	0.07

[1] A. Dellafiore and D.M. Brink, Nucl. Phys. A286 (1977) 474.
[2] J. Ahrens et al., Nucl. Phys. A251 (1975) 479 ; R. Bergère in "Lecture Notes in Physics", Vol. 61, Springer-Verlag.

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INELASTIC ELECTRON SCATTERING FROM ^{152}Sm

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A precise shape of ground state and transition charge densities has never been determined up to now in the central region of a deformed nucleus. This was due to the absence of data at higher momentum transfer than 2.5 fm^{-1}, because of the high energy and good energy resolution simultaneously required. It prevented a conclusive interpretation of the comparison with microscopic theories, since it is precisely the shape of the densities in the interior region of nucleus that is the touchstone of modern theories.

We report here an electron scattering experiment reaching $q_{max} \sim 3$ fm^{-1} from the low-lying levels of ^{152}Sm. The experiment has been performed at Saclay at an incident energy of 500 MeV. For the first time a resolution of 1.1×10^{-4} at 500 MeV has been achieved sufficient to separate the 2^+, from 0^+ ($E^* = 122$ keV) (Fig.1). Cross sections have been measured down to 10^{-9} mb/sr. Background was absent. Cross sections are shown in Fig. 2 together with a coupled channel prediction[1]) adjusted to previous lower momentum transfer data $q \sim 2.2$ fm^{-1}. It is quite interesting to see that the disagreement is large with our new data at high q. The analysis of these data together with previous data will be completed in the near future.

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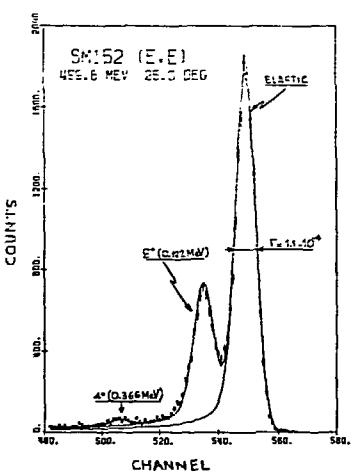


Fig. 1

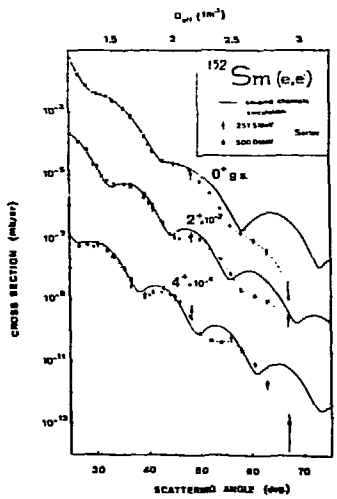


Fig. 2

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CHARGE DENSITY DIFFERENCE BETWEEN ^{124}Sn AND ^{116}Sn ISOTOPES

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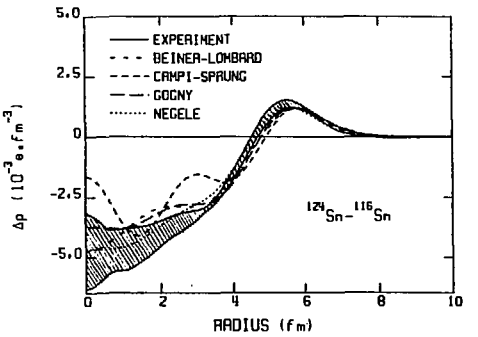
University of Basel, Switzerland

We have performed at Saclay an elastic electron scattering experiment on ^{124}Sn and ^{116}Sn isotopes, up to a momentum transfer q_{max} = 3.55 fm^{-1}. Our medium and high-q data have been combined in the analysis with previous low and medium-q data[1,2]) and muonic X-ray transitions[3]). The charge densities for both isotopes are now determined with an accuracy of ± 1 % in the surface and in the interior of the nucleus.

The smooth behavior of both densities confirms a systematic trend of mean-field theoretical calculations, that predict too much structure in the interior of the nucleus.

In contrast with this trend, nearly all calculations are able to reproduce quite well the charge shift induced by adding 8 neutrons in an open shell. The figure shows the agreement of the charge density difference with a number of calculations.

1. J.R. Ficenec, L.A. Fajardo, W.P. Trower et I. Sick, Phys. Lett. 42B (1972) 213.
2. T.H. Curtis, R.A. Eisenstein, D.W. Madsen et C.K. Bockelman, Phys. Rev. 184 (1969) 1162.
3. J.W. Kast et al., Nucl. Phys. A169 (1971) 62.



RADII OF VALENCE ORBITS FROM MAGNETIC ELECTRON SCATTERING

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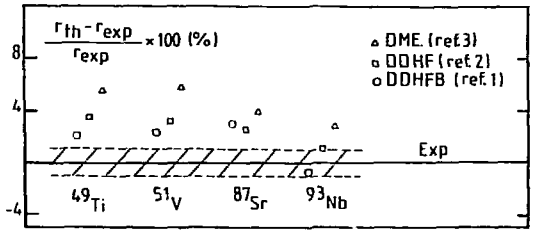
I. Sick

University of Basel, Switzerland

We present here the final results of the analysis of experiments carried out at Saclay on $f_{7/2}$ and $g_{9/2}$ nuclei. These experiments have mapped out respectively the M7 and M9 magnetic form factors in the momentum transfer range $q = 1.8 - 3.0$ fm^{-1}.

We have investigated in detail the effects of coulomb distortion, model dependence and mesonic exchange currents. We believe that the radii of the valence orbits deduced from our analysis are determined with an accuracy of $\sim$ 1.2 %. For the $f_{7/2}$ shell we find $r_n = 3.99$ fm in ^{49}Ti and $r_p = 4.01$ fm in ^{51}V. The corresponding values for $1g_{9/2}$ shell are : $r_n = 4.76$ in ^{87}Sr and $r_p = 4.90$ in ^{93}Nb. The figure presents percentage deviations from some of the best mean field calculations[1-3]). Core polarization has negligible effect on the rms radii while meson exchange currents tend to improve the agreement by $\sim$ 1 %, but further calculations are needed before drawing a truly quantitative conclusion.

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3. J.W. Negele and D. Vautherin, Phys. Rev. C5 (1972) 1472 and private communication.



THE STRUCTURE OF THE TRANSITION CHARGE DENSITY FOR THE FIRST EXCITED STATE ($J^{\pi}=2^{+}$) OF ^{58}Ni

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J. Heisenberg

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The structure of the ground state charge density of ^{58}Ni has revealed the existence of dynamical deformation effects[1,2]. Since these effects are rather small in the ground state, it is only in the transition charge densities that a really meaningful study can be carried out. Inelastic electron scattering brings out the fine details of the transition charge densities. However, it is well known that the lack of data at high momentum transfers may lead to improper shapes and errors[3]. In order to determine accurately the 2^{+} transition charge density of the first excited state of ^{58}Ni($J^{\pi}=2^{+}$, E = 1.45 MeV), we have measured (e,e') cross sections for momentum transfers up to 4 fm^{-1} (Fig.1). The experiment was carried out at Saclay Linear Accelerator (ALS) simultaneously with the measurement of elastic cross sections[2]. The analysis of these data together with previous results[3] has been made with a Fourier-Bessel expansion of $\rho_{tr}(r)$. The shape of $\rho_{tr}(r)$ (Fig.2) is now extremely well determined and will allow a significant discussion of the theoretical hypotheses.

1. M. Girod and D. Gogny, Phys. Lett. 64B (1976) 5.
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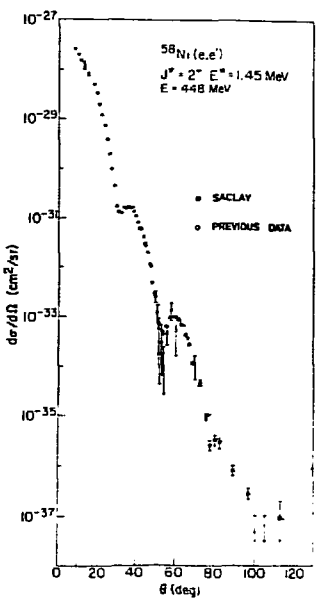


Fig. 1

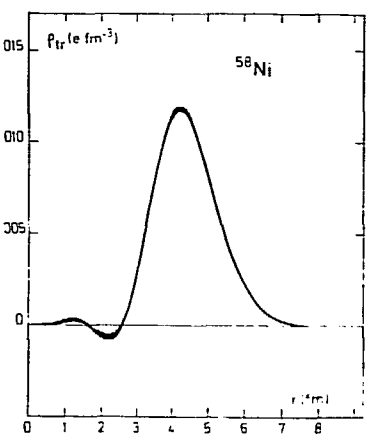


Fig. 2

CAN NUCLEAR OPALESCENCE BE SEEN IN MAGNETIC FORM FACTORS OF 1p SHELL NUCLEI ?

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It has recently been suggested [1] that strong critical effects could explain the anomaly seen in (e, e') excitation of the 1^+ (15.11 MeV) state of ^{12}C in the region of the critical momentum (2 to 3 m_π) of pion condensation. This interpretation implied that nuclei might be much closer to the condensation threshold than previously expected. In view of the importance of the issue a systematic investigation has been undertaken to check whether this exciting possibility survives comparison with other available magnetic data. We have limited our study to the 1p shell because it was of primary importance to insure that the wave functions are good enough at low transfers to reproduce data on spin flip processes like β decay rates an Ml widths. The nuclear size parameters were determined from charge scattering where critical effects are absent at least in the momentum range of interest. Cases like ^6Li and ^{14}N where either charge scattering or low momentum data are not well understood were discarded.

We found that according to the structure of the states, the core polarization produced by the pion field (and more generally interactions which couple to spin longitudinally) interferes additively or destructively with the standard 1p shell magnetic form factor in the region between 2 to 3 m_π. In contrast the polarization due to transverse interactions like the rho meson exchange is always additive at these momenta. Therefore the overall size and sign of polarization effects are much state dependent so that critical phenomena which are an enhancement of the longitudinal polarization do not necessarily appear as an increase of the form factors. Extreme cases are represented by the ^{12}C 1^+ state (enhancement of the second maximum) and the ground state of ^{13}C (depression) and their comparison is crucial for opalescence calculations [2]. Less spectacular effects are predicted for other transitions. Our model is found to provide a coherent description of the available data which are thus compatible with proximity of pion condensation.

1. J. Delorme, M. Ericson, A. Figureau and N. Giraud, Phys. Lett. 89 B (1980) 327 ; J. Delorme, A. Figureau and N. Giraud, preprint LYCEN 7975 (to appear in Phys. Lett. B).
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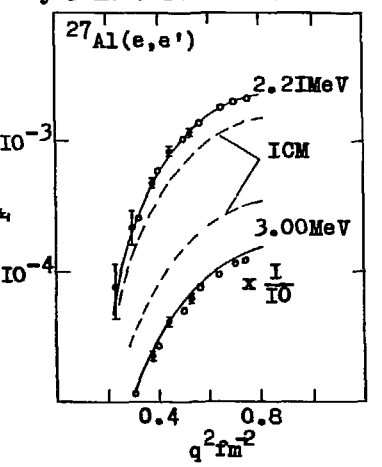
STUDY OF ^{27}Al BY LOW-MOMENTUM TRANSFER ELECTRON SCATTERING.

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An investigation of light deformed nuclei gives an interesting information about nuclear structure. Particularly, ^{27}Al lies in the transition region where the nuclear deformation changes its sign. In spite of extensive experimental data on ^{27}Al it is among the nuclei whose ground-state charge distribution was not studied with good accuracy. A rather big difference exists for the data concerning levels 2.2I, 2.73 and 3.00 MeV. The states at 0.84 and I.0I MeV were not so far studied in detail by electron scattering. In this work all these levels were investigated and we compare our experimental results with predictions existing nuclear models.

The experiment was performed using electron scattering facility[1] at INR, Moscow. The differential cross section of ^{27}Al were measured in the momentum transfer range 0.23 - 0.54 fm^{-1} up to excitation energies approximately 3 MeV. The elastic cross sections were normalized to known ^{12}C ones. With total energy resolution 40 - 75 KeV all levels of ^{27}Al having at this energy interval were clear distinguished.



In our experimental conditions magnetic scattering contribution into elastic scattering was negligible. Quadrupole contribution was evaluated to be less than 0.2%. Elastic scattering formfactor dependence is near to that determined by Fermi charge distribution parameters c_{eff}= 2.95 fm t_{eff}= 2.48 fm. A preliminary analysis gave the mean square radius of ^{27}Al to be 3.I0 ± 0.04 fm.

Experimental formfactors of the excited states were defined as $\sigma_{exp}/\sigma_{MKF}$, where σ_{MKF} -the point cross section in the second Born approximation. Formfactors for the levels 2.2I and 3.00 MeV are shown on fig. by black points. Open points are the results from ref[2]. All data are well described by shell model calculations[2] (the continuos line on the fig.), but are disagreed with intermediate coupling model(ICM), which prediction is shown by the dashed line. According to ICM cross section ratios for states 0.84;I.0I;2.2I;2.73 and 3.00 MeV should be 0.25;0.3;I.0;0.75; I.25. For E_0=75 MeV our experimental ratios are 0.25;0.3;I.0; 0.25;0.5.An analysis of other experimental data is in progress.

I) A.V.Batjunin et al. Proc.Sendai Conf. on Electro- and Photoexcitations, ed. Y.Kawazoe (Japan) p.3I3 (I977).
2) R.L.Singhal et al. Nucl.Phys. A279 (I977) 29.

DETERMINATION OF THE TRANSITION CHARGE DENSITY OF THE OCTUPOLE VIBRATION IN ^{208}Pb

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We have determined the transition charge density of the octupole vibration of ^{208}Pb with an unprecedented accuracy in the interior of the nucleus. Cross sections were measured for inelastic electron scattering at various energies up to 502 MeV. A momentum range of $0.6 \leq q \leq 2.6$ fm^{-1} was explored with the high resolution facility of MIT Bates Laboratory and extended at Saclay in the range $1.7 \leq q \leq 3.4$ fm^{-1} to cross sections as low as 10^{-37} cm^2/sr (Fig.1). These data have been analyzed together with earlier (e,e') results previously analyzed by Röthhaas et al. (Phys. Lett. 51B (1974) 23) and B(E3) values determined by Coulomb excitation measurements.

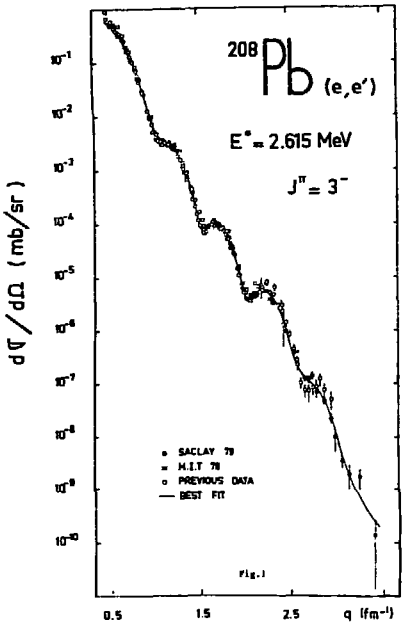
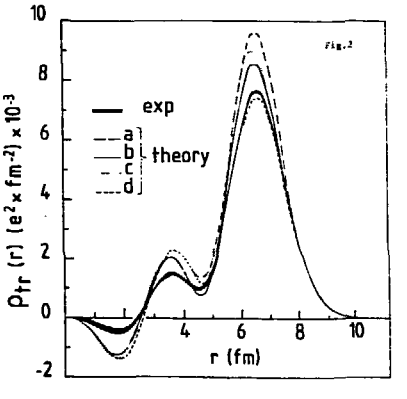


Fig.2 is a comparison of the experimental transition charge density with some theoretical calculations in the RPA framework : a) Hamamoto, b) Dechargé and Gogny, c) Bertsch and Tsai, d) using the Migdal interaction. The error band of the experimental result includes both statistical and completeness error. The discrepancy in the interior of the nucleus offers a measure of the limitation of the various theoretical approaches.



EXPERIMENTAL DETERMINATION OF THE MAGNETIC FORM FACTOR OF ^3He

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We have measured at Saclay the magnetic form factor of ^3He for a momentum transfer range of $q^2 = 8 - 25$ fm^{-2}. Electrons were scattered elastically at an angle of 155° from a high pressure gas target, for incident energies up to 604 MeV.

The purpose of the experiment was to determine the position of the first diffraction minimum and the amplitude of the second maximum. This is a region extremely sensitive to the d-state component of the ground state and to the mesonic exchange currents.

Preliminary results show that the diffraction minimum has been found. It is located at higher q^2 than expected by most calculations. The beginning of the second maximum has also been determined. Additional data will be taken after upgrading the Saclay linac to an incident electron energy of 720 MeV.

PROTON MOMENTUM DISTRIBUTIONS IN p-SHELL MEASURED IN ^{12}C AND ^{16}O (e,e'p) REACTIONS

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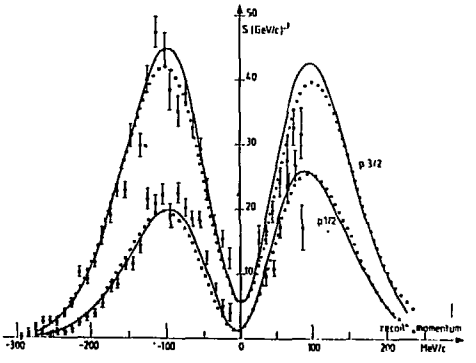
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E. Jans

IKO Amsterdam, The Netherlands

Electron coincidence experiment (e,e'p) on ^{12}C and ^{16}O has been recently carried out at Saclay Linear Accelerator in order to measure in extended kinematical region the spectral function of bound protons. The analysis here reported refers only to p-shell. The influence of different choices of bound state wave function and optical potential parameters in the theoretical description of the measured angular distribution will be discussed. Particularly important is the contribution of spin-orbit component (real and imaginary part) in the distorting optical potential to give account for asymmetric distributions measured in different kinematical configurations. In figure momentum distributions for $p_{3/2}$ and $p_{1/2}$ protons in ^{16}O are shown. The accuracy required by this type of reaction in order to distinguish between different many-body description of nuclear ground state will also be discussed.



M1 AND M2 TRANSITION CURRENT DENSITIES IN ^{12}C

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The present electron scattering experiment was designed to measure the form factors for the magnetic transitions to the isospin T=1 states in ^{12}C at ε = 15.11 MeV (1^+) and ε = 16.58 MeV (2^-), with emphasis on accurate data which extend as far as possible over the second lobe of the form factor. The motivations for this experiment can be summarized as follows.

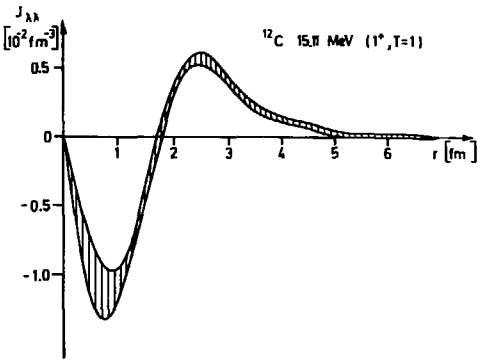
1. In order to obtain the M1 and M2 transition current densities in a relatively model independent way, the corresponding form factors must be known accurately over an extended momentum transfer range.

2. Because of the deep connection between inelastic electron scattering and photoproduction of charged pions, good (e,e') data are a necessary ingredient for a sophisticated analysis of pion photoproduction.

3. Magnetic transitions with $\Delta T=1$ are sensitive to mesonic exchange currents which are believed to increase in importance with increasing momentum transfer.

4. The 15.11 MeV M1 form factor plays an essential role in the present discussion on precritical phenomena of pion condensation in finite nuclei.

The measurements were performed using the energy loss mode of the electron scattering facility at the Mainz 350 MeV electron linear accelerator. In analysing the measured spectra we have taken into consideration the influence of a recently reported [1]) broad state at ε = 15.4 MeV. From some forward angle spectra with high statistical accuracy we have obtained ε = 15.44 ± 0.04 MeV for the excitation energy and Γ = 1.5 ± 0.2 MeV for the width of this new state. The magnetic form factors were determined in a momentum transfer range up to q = 3.0 fm^{-1}. The quality of our data is such that the experimental errors in the M1 form factor squared are 4 % in the second form factor maximum and increase slowly to 11 % at q = 3.0 fm^{-1}. Since the range and quality of the experimental form factors are sufficient for a nearly model independent determination of the transition current densities, we have deduced the M1 (see figure) as well as the M2 transition current density $J_{\lambda\lambda}(r)$ with the formalism described in ref.[2]).



[+]Supported by Deutsche Forschungsgemeinschaft

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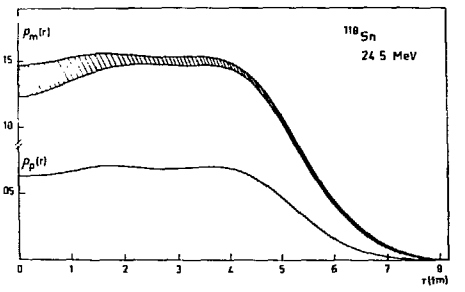
DETERMINATION OF MATTER DENSITY BY LOW ENERGY PROTON SCATTERING

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It is difficult to extract information on the matter density in the interior part of heavy nuclei by scattering of high energy hadrons, because of the strong projectile absorption[1]). For example, the mean free path ($\lambda = 1/\rho\sigma$) of 1 GeV protons is only about 1.4 fm, corresponding to a N-N total cross section σ of about 44 mb. However at low energy the Pauli effect decreases the effective total cross section ; it has been shown[2]), for instance, that λ is about 4 fm for 20 MeV protons. One hopes then that low energy proton scattering could yield accurate information about the density near the nuclear center.

We have analyzed the 24.5 MeV proton elastic scattering by ^{118}Sn by means of the OMP calculations a Tarrats and Escudié[3]). The NN interaction was first calibrated by fitting of range of different nuclei[3]). Then this calibrated interaction was used to extract the neutron density of ^{118}Sn. Following the Sick model (SOG)[4]), we write : $\rho_n(r) = \sum A_i \left[\exp-((r-R_i)/\gamma)^2 + \exp-((r+R_i)/\gamma)^2\right]$. The proton density was taken from Sick et al.[4]). We have determined the i values (i = 10) of A_i for many sets of R_i by fitting the elastic angular distribution data. The envelope of the trial densities gives the uncertainty of the neutron density. The figure shows our results for the matter density ($\rho_m = \rho_p + \rho_n$) and the proton density used in the calculation.



Unfortunately, an unambiguous interaction could not be obtained by fitting the whole range of calibration masses (32-208). While the possible differences of the t-matrix are small, the nuclear densities depend quite sensitively on them. We find that the nuclear surface region is stable against changes in the interaction, while the interior region envelope remains thin but moves by 2 ou 3 times its width for different reasonable interactions.

This clearly indicates that : i) the model is basically realistic ; ii) the extraction of reliable interior nuclear densities from this approach is beyond the present state of the theory ; iii) the sensitivity of low energy elastic observables (due to the long mean free path) to nuclear matter density is established.

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NEUTRON TOTAL CROSS SECTIONS OF ^{208}Pb, ^{232}Th, AND ^{238}U FROM 5 TO 150 MeV[†]

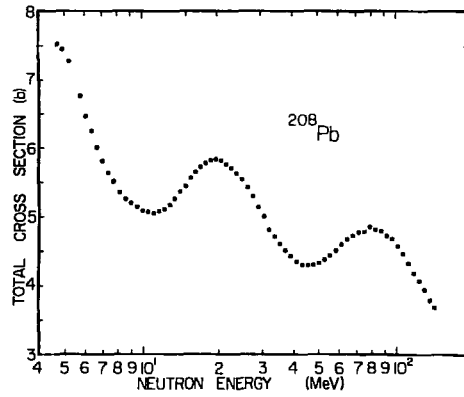
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Neutrons are excellent probes for studying the shape of the nuclear potential because Coulomb effects are unimportant and because elastic, inelastic, and total cross sections all have significant dependences on potential deformation. Total cross section differences have been found to have a particularly interesting dependence; for example, the relative difference $[\sigma_T(^{154}Sm)-\sigma_T(^{148}Sm)]/\sigma_T(^{148}Sm)$, when plotted as a function of incident neutron energy over the range 0.8 to 15 MeV, has an oscillation for which the amplitude and phase depend primarily on the quadrupole deformation parameter and real potential strength, respectively, of the nuclear potential.[1] Total cross section measurements on oriented ^{165}Ho suggest that these oscillations may persist up to 150 MeV neutron energy.

We have measured the total cross section of ^{208}Pb and the total cross section differences for ^{232}Th-^{208}Pb and ^{238}U-^{208}Pb from 5 to 150 MeV using a "white" source of neutrons from the WNR facility.[2] Neutrons were produced by bombarding a Ta target 2.5-cm diam by 15-cm high with a 0.2-ns-wide pulsed beam of 800-MeV protons from LAMPF and collimated by 80 cm of brass, iron, and lead. Neutron flux was monitored in-beam using a 0.3-mm-thick Pilot-B scintillator located just behind the collimator. The neutron detector was a NE 110 scintillator 10.2-cm diam by 15.2-cm thick which was viewed by an RCA 8854 photomultiplier tube and placed 31.78 m from the source. Time-of-flight spectra were obtained at four detector bias settings (~2 to ~10 MeV) simultaneously using an Ortec TDC-100 time digitizer. For this source-detector system the TOF spectrum with a 2-MeV bias was essentially flat over the energy range of interest. The energy spread $\Delta E/E$ and room background were less than 2% over this range. The areal densities of the samples varied from 0.21 to 0.32 (atoms/b). Carbon, used as a standard, gave results consistent with accepted values.[2]

Our results for ^{208}Pb (99% enriched) are given in the figure for an energy binning ($\Delta E/E$) of 5%. The statistical uncertainty shown is representative and is sufficient to show oscillations in the total cross section difference results up to 100 MeV. The σ_T and difference data will be interpreted using a coupled-channel optical model.



[†]Work performed under the auspices of the U. S. Department of Energy.
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EXPERIMENTAL DETERMINATION OF NUCLEAR DEFORMATIONS AND COMPARISON WITH MICROSCOPIC CALCULATIONS

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Neutrons are suitable probes for the study of nuclear deformations. Marked deformation effects appear in the strength functions, total and scattering cross sections at low bombarding energies ($E_n \lesssim 10$ MeV). When such an extensive set of data is included in a consistent analysis, useful information can be obtained with great confidence . At these low energies calculations are more sensitive to small variations of the parameters than above and ambiguities arising from the potential determination or coulomb interaction are avoided.

Experimental data were obtained using a high resolution neutron spectrometer, which enables a clear separation of elastically and inelastically scattered neutron groups. Measurements were performed for some even isotopes of Sm, Gd, W, Th and U. The incident energies ranged from 1 to 3.5 MeV for the actinide nuclei and from 4 to 7 MeV for the rare-earth nuclei. Using statistical and deformed optical potential models, the deformation parameters have been determined with typical uncertainties of ± 5% for β_2 and ± 10% for β_4. The observed differences between the values deduced from our data and from other processes (coulomb excitation ...) suggest that the deformation parameters may be model dependent. As suggested by Mackintosh [1], it has been found that the comparison of the multipole moments of the charge density to those of the potential distribution is more reliable.

The measured 2nd and 4th order moments of the neutron-nucleus potential and the corresponding calculated moments of the matter distribution are shown in Table 1. These moments were derived using the Hartree-Fock-Bogolyubov method and the finite range density-dependent D1 interaction [2] ; the calculations were performed in an axially-deformed oscillator basis including 11 major shells. The general trend (q_λ exp > q_λ DDHFB) cast some doubt on the reliability of directly comparing the moments of the matter distribution with those of the optical potential. In particular, it suggests that the effective interaction, to be used in the folding model, is density-dependent and that exchange effects are also important [1].

Isotope	q_2 (b)		q_4 (b^2)	
	Exp.	DDHFB [3]	Exp.	DDHFB [3]
^{152}Sm	1.86 ± 0.10	1.68	0.63 ± 0.12	0.30
^{154}Sm	2.15 ± 0.10	1.96	0.66 ± 0.13	0.46
^{156}Gd	1.98 ± 0.10	1.82	0.51 ± 0.10	0.32
^{158}Gd	2.09 ± 0.11	2.02	0.54 ± 0.10	0.38
^{182}W	2.22 ± 0.11	2.08	0.19 ± 0.03	- 0.08
^{184}W	2.08 ± 0.06	2.03	0.23 ± 0.02	- 0.16
^{186}W	2.03 ± 0.06	1.85	0.25 ± 0.03	- 0.20
^{232}Th	3.04 ± 0.14	2.84	1.21 ± 0.12	0.89
^{238}U	3.50 ± 0.16	3.30	1.19 ± 0.12	0.89

Table 1

multipole moments of the neutron-nucleus optical potential (Exp.) and the nuclear matter distribution (DDHFB)
$q_\lambda = \langle r^\lambda Y^0_\lambda \rangle$ Z/A.

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PROTON ORBIT SIZES IN ^{209}Bi FROM SUB-COULOMB ^{209}Bi(t,α)^{208}Pb REACTION

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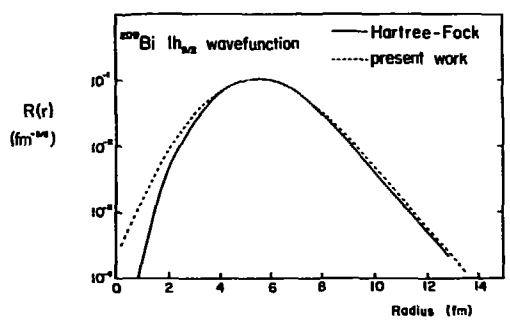
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The established technique[1]) of obtaining nucleon orbit sizes by means of the sub-Coulomb transfer reaction has been employed to determine the rms radii of single particle orbits in ^{209}Bi. The ^{209}Bi(t,α)^{208}Pb reaction has been studied at bombarding energies of 8.5 MeV and 9 MeV using beams of tritons from the McMaster University FN Tandem Van de Graaff. Angular distributions of α-particles leading to the ground state and strongly populated particle-hole states in ^{208}Pb have been measured.

The data have been analysed using a zero-range DWBA code. A normalization constant of (20.8±3.1) 10^4 MeV^2 fm^3 has been used. This is obtained by comparing (t,α) cross-sections from exact finite range calculations with those from zero-range DWBA calculations. In the exact finite range calculation, the radius parameter for the $\langle t,p|\alpha\rangle$ system is adjusted to reproduce the asymptotic amplitude of the $\langle t,p|\alpha\rangle$ wavefunction given by the forward dispersion relation[2]). The analysis yields a rms radius for the $1h_{9/2}$ proton orbit in ^{209}Bi of 6.09(+0.12/-0.08) fm (non-local potential) when the finite proton size is folded in. The result is in excellent agreement with the Hartree-Fock value of 6.083 fm obtained by Sprung[3]). The figure shows a comparison of the Hartree-Fock radial wavefunction[3]) with that obtained from the present work.



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HELION ELASTIC SCATTERING AT E_τ = 130 MeV: A MODEL-INDEPENDENT ANALYSIS

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Angular distributions of helions elastically scattered from ^{24}Mg, ^{58}Ni, ^{90}Zr and ^{120}Sn at 130 MeV[1] have been subjected to a "model-independent-analysis". The real part U(r) of the optical model potential was represented by a spline function. Both volume (Woods-Saxon form) and surface (Woods-Saxon-Derivative-WSD form) types of absorption were investigated.

In general very good fits (average χ^2=1.8) were achieved for both types of absorption. The resulting shapes of U(r) are shown in fig. 1. Except for ^{24}Mg, the best-fit spline potentials appear to be independent of absorption type; in addition, they show significant deviations from the commonly assumed WS-shape. These results are not surprising since the real part of the optical model indirectly reflects the radial distribution of nuclear matter density which is known not to have the WS-shape. The large errors of U(r) in the interior region are consistent with the fact that helions are strongly absorbed particles. The dominance of the Coulomb potential at small angle scattering results in large uncertainties of U(r) in the tail-region. The difference between the two spline potentials for ^{24}Mg may be associated with the large deformation and/or the small size of the ^{24}Mg nucleus.

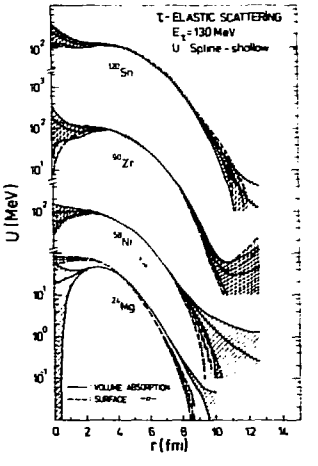


Fig. 1

From the extracted rms-radii $\langle r_u^2\rangle^{1/2}$ of U(r) and the known $\langle r_m^2\rangle^{1/2}$ of matter distribution for ^{58}Ni and ^{90}Zr [ref. 2)], the effective $\langle r_{\tau\text{-}N}^2\rangle^{1/2}$ of the τ-N interaction was derived to be 2.8±0.2 fm. This value leads to $\langle r_m^2\rangle^{1/2}$ = 4.7±0.2 fm for ^{120}Sn.

Consistently better fit quality was obtained with volume absorption (average χ^2=1.1), instead of surface (average χ^2=2.6). This contradicts the results of Chang et al.[3]. The fact that best-fit U(r) is practically independent of absorption type suggests that the relatively worse fits obtained with the surface absorption reflect an inadequate representation of the imaginary potential by the WSD-form.

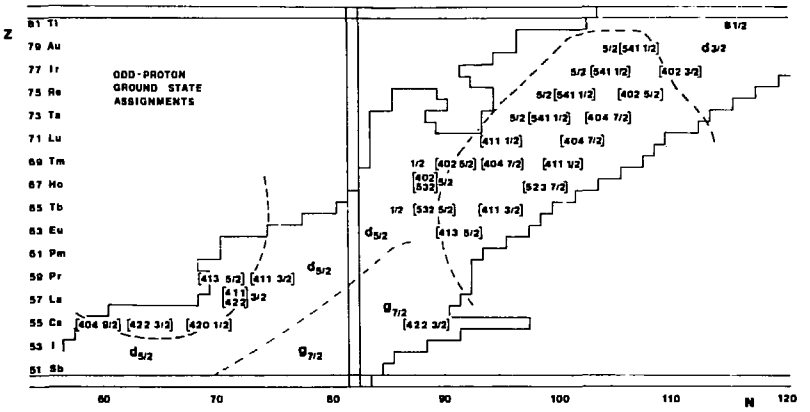
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NUCLEAR SPINS AND MOMENTS OF NUCLIDES FAR FROM STABILITY DETERMINED BY ON-LINE ABMR TECHNIQUES*

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During the last few years, the atomic-beam magnetic resonance (ABMR) apparatus[1]) connected on-line with the ISOLDE mass separator at CERN has been used extensively to measure nuclear spins and moments of nuclides far from the line of beta stability. The following elements have been studied: $_{35}Br^{2}$), $_{37}Rb^{3,4}$), $_{49}In^{5}$), $_{55}Cs^{4,6,7}$), $_{69}Tm^{5}$), $_{79}Au^{8,9}$), $_{81}Tl^{5}$) and $_{89}Fr^{5,10}$).



The results obtained have given information on nuclear level assignments and on changes in nuclear deformation. Evidence for strong deformation effects have been observed in the light rubidium isotopes, in the light as well as heavy cesium isotopes and in the light gold isotopes. The level assignments proposed in cesium and gold are given in the schematic nuclear chart above which also includes previous data proposed for the neutron-deficient rare-earths[11]). Isodeformation curves for $\varepsilon \approx 0.20$ are indicated as well as a line separating the regions with $d_{5/2}$ and $g_{7/2}$ ground states.

* Supported by the Swedish Natural Science Research Council.
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THE T = 4 ISOTOPIC MULTIPLET IN MASS 40

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The Isobaric Mass Multiplet Equation relating the masses of analog states agrees extremely well with experimental measurements. We have initiated a program to push the test of the IMME to a T = 4 multiplet in mass 40.

We have used the Princeton Cyclotron and QDDD spectrometer to make initial measurements on three of the members of this multiplet and have previously reported our result on the mass of ^{40}S.[1] We will report on our initial findings from the eight-nucleon-transfer exotic reactions ^{48}Ca(^{3}He,^{11}C)^{40}S, ^{48}Ca(^{3}He,^{11}B)^{40}Cl and ^{48}Ca(^{3}He,^{11}Be)^{40}Ar. We believe we can eventually reach five of the nine multiplet members using seven or eight nucleon transfer reactions.

*This work supported by the National Science Foundation Grant no. PHY78-01473.

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MASS MEASUREMENTS FOR THE FIRST T = 2 STATE IN ^{32}S AND ^{32}Si : TEST OF THE IMME.

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The excitation energy of the first 0^+ T = 2 state in ^{32}S has been determined from a detailed study of the yield curve and the decay energies of the resonances at 3289 keV (0^+ T= 2) and 3283 keV (4^-T = 1) in the $^{31}P(p,\gamma)^{32}S$ reaction. Accurate energy standards from thermal neutron capture on chlorine were stored simultaneously. The result (see table) is comparable but more accurate than the previous value (E_x = 12 050 ± 4 keV, Ref.1).

The mass difference between ^{32}Si and ^{30}Si has been determined from a measurement of proton groups in the (t,p) reactions induced on mixed ^{28}Si + ^{30}Si targets. A number of instrumental effects and the calibration procedure have been carefully checked, since the result (see table) deviates from the previously accepted value (- 24 092 ± 7 keV, Ref.2).

The coefficients of the cubic Isobaric Multiplet Mass Equation (IMME) are shown in the table, with the input values. The accuracy of the d-coefficient is significantly improved as compared to a previous determination [3] (d = 0.5 ± 2.5), resulting from the first observation of the 0^+ T = 2 state in ^{32}Cl at ISOLDE. It appears that the A = 32 quintuplet is the best example for a vanishing deviation from charge-symmetry in a T = 2 multiplet [4].

	T_z	Mass excess (keV)	E_x(keV)	Reference
^{32}Si	+ 2	- 24 078.0 ± 1.3	0.0	This work
^{32}P	+ 1	- 19 231.6 ± 1.2	5 073.1 ± 0.9	2
^{32}S	0	- 13 970.1 ± 0.7	12 045.0 ± 0.4	This work
^{32}Cl	- 1	- 8 295.6 ± 5.2	5 033.0 ± 10.0	3

$M(T_z) = a + bT_z + cT_z^2 + dT_z^3$:

a = - 13 970.1 ± 0.7 keV
b = - 5 468.4 ± 2.1 keV
c = + 206.5 ± 2.7 keV
d = + 0.35 ± 1.09 keV

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(^{7}Li,^{3}He) REACTION ON THE CARBON ISOTOPES : ^{18}N MASS

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We have measured the (^{4}H transfer ?) reaction (^{7}Li,^{3}He) on the three carbon isotopes. Spectra taken with a $\Delta E_1 - \Delta E_2 - E$ telescope at E_{Li} = 32, 42 and 48 MeV show some selectivity for ^{16}N and ^{17}N levels. The cross sections for the most strongly excited states in ^{16}N and ^{17}N are of the order of 20 μb/sr. The reaction under study is able to populate the $J^{\pi} = 2^{-}$ ground state of ^{16}N with $(d\sigma/d\Omega) = 6$ μb/sr at 32 MeV and 30°lab.

The figure shows a portion of the composite spectrum for the ^{18}N ground state region obtained by summing over two angles and two incident energies, plotted againts Q-value. The ground state peak is somewhat broadened by this procedure.

We performed exact shell-model calculations using the "ZBM" interaction[1] for the nitrogen isotopes. The agreement for the known low-lying states in ^{16}N and ^{17}N is very satisfactory. The predictions for the first states in ^{18}N (with the main configurations) are :

$J^{\pi} = 2^{-}$ g.s. $(d^3_{5/2}\ p^3_{1/2})$ $\quad J^{\pi} = 0^{-}$ 0.79 MeV $(d^2_{5/2}s^1_{1/2}p^3_{1/2})+(d^4s^1p^1)$

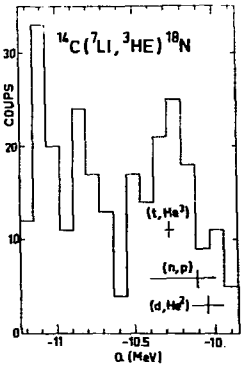
3^{-} 0.41 MeV $(d^3\ p^3)$ $\quad 1^{-}$ 0.82 MeV $(d^2s^1p^3)+(d^4s^1p^1)$

1^{-} 0.56 MeV $(d^3\ p^3)+(d^2\ s^1\ p^3)$ $\quad 2^{-}$ 0.91 MeV $(d^3p^3)+(d^2s^1p^3)$

Based on tendencies observed in the ^{16}N data, we would expect to populate most strongly the 2^{-} g.s. and the 3^{-} level of ^{18}N sequence given above.

The ^{18}N mass excess found from the composite spectrum is 13.29 ± 0.06 MeV, the energy scale being calibrated by known peaks from the ^{12}C(^{7}Li,^{3}He) reaction. There is some evidence for excited states at 0.53 ± 0.06 MeV and 0.83 ± 0.06 MeV. More precise values could be obtained from the individual spectra.

This first reported transfer reaction leading to ^{18}N levels, supplemented with shell model predictions, does not support other preliminary results [2] for the mass and excited states of ^{18}N, but is in agreement within the stated errors with recently reported values [3] ; both latter results being obtained with charge exchange reactions.



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^{180}Ta : AN EXOTIC NUCLEUS CLOSE TO STABILITY

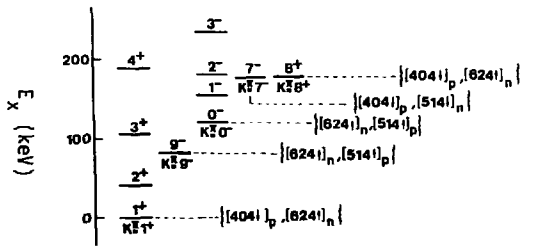
E. Warde, G.J. Costa, R. Seltz, D. Magnac and C. Gérardin

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Two levels are reported in ^{180}Ta, both isomers : one having a life of $\sim 10^{13}$ years and a spin 9^- or 8^+, the other having a half-life of 8.15 h and a spin 1^+. Until very recently it was commonly admitted that the ground state of ^{180}Ta is the long lived isomer (L.L.I.) [1]. From previous measurements and updated values of masses for neighbouring nuclei the neutron separation energy in ^{181}Ta is now compiled to be E_n = 7583 ± 12 keV for the short lived isomer (S.L.I.) of ^{180}Ta. For the L.L.I., a tentative E_n - value of 7653 ± 4 keV has been assigned from the ^{180}Ta(n,γ)^{181}Ta reaction [2].

The level scheme of ^{180}Ta was investigated using the following reactions : ^{181}Ta(p,d)^{180}Ta at 19 MeV, ^{178}Hf(α,t)^{179}Ta at 62.2 MeV and ^{179}Hf(^{3}He,d)^{180}Ta at 36 MeV. In all cases outgoing particles were analyzed with a spectrograph. The overall resolution was 20 to 40 keV depending on the reaction [3].

Experimental cross sections were compared with calculations using Nilsson wave functions and the DWBA in order to identify observed peaks with rotational levels due to the coupling of the unpaired neutron and proton. Levels up to 900 keV in ^{180}Ta have been observed. The low lying excitation region is reported in the figure.



The transfer reactions may not excite all possible configurations in ^{180}Ta. There is however strong evidence for identifying the observed $(1^+,1)$ state with the ground state as its configuration corresponds to the lowest computed energy from a systematic study of active Nilsson orbitals in neighbouring odd-odd nuclei [4]. The Q-value of this $(1^+,1)$ level was obtained from comparison with the Q-value of the ^{180}Hf(α,t)^{181}Ta reaction present as a contaminant in the spectra.

The neutron energy separation for the $(1^+,1)$ state could then be deduced : E_n = 7570 ± 17 keV in good agreement with the value reported for the S.L.I. The excited $(9^-,9)$ level observed at 82 ± 20 keV has E_n = 7652 ± 26 keV, very close to the measured value for the L.L.I. The $(8^+,8)$ level, sometimes believed to be the L.L.I., is more excited (E_x = 177 keV). The two isomers belong respectively to the configurations {[404 ↑]$_p$ [624 ↑]$_n$} for the $(1^+,1)$ and {[624 ↑]$_n$ [514 ↑]$_p$} for the $(9^-,9)$.

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THE "UNITARY ENERGY BAND" STRUCTURE IN THE BARYON-ANTIBARYON SYSTEM

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In this paper a description of the baryon-antibaryon system is proposed on the basis of ref.(1). If P, N and Λ with spin ½ form the basic particles of SU(6)$^{(1)}$, then the $B\bar{B}$ system can be classified into three groups: the pseudoscalar states (S=0,octet) vector states (S=1, 27 states) and a singlet stete (S=0). Using the T_3^3 breaking mass formular and mass mix formula(1), the SU(6) mass relations of $B\bar{B}$ system can be given and the spectrum of $B\bar{B}$ system has two obvious characters: the SU(6) "Unitary Energy Band" (UEB) and the SU(6) "Strangeness Analogy States" (SAS).

In this paper, the experimental spectrum of $B\bar{B}$ system are analysed. The calculations show that: there exist six SU(6) "UEB" in $P\bar{P}$ system(S=1, mass M<2.300Gev.), every "UEB" consists of three levels, and exist the "SAS" between the $P\bar{P}$ system and other $B\bar{B}$ systems such as $N\bar{P}$ system or BB systems which have strangeness S=±1.

It is clear from the longitudinal relations — the "UEB" structure, the levels of the $P\bar{P}$ and $\Lambda\bar{\Lambda}$ systems can be divided into different "UEB" according to its outer symmetry; from the transverse relations — "SAS" structure, the levels of different $B\bar{B}$ systems can be connected by the "SAS" mass relations. We give here a schematic diagram, in which energy levels are denoted by meson symbols.

S = 0 Systems				S = 1 Systems			
$(P\bar{P})(N\bar{N})$	$(P\bar{N})(N\bar{P})$	$(P\bar{\Lambda})(\Lambda\bar{P})$ $(N\bar{\Lambda})(\Lambda\bar{N})$	$(\Lambda\bar{\Lambda})$	$(P\bar{P})^*(N\bar{N})^*$	$(P\bar{N})^*(N\bar{P})^*$	$(P\bar{\Lambda})^*(\Lambda\bar{P})^*$ $(N\bar{\Lambda})^*(\Lambda\bar{N})^*$	$(\Lambda\bar{\Lambda})^*$
η		K	η	ϕ		K^*	ϕ
π^0	$\pi^\pm$			ω			ω
				f	f		

Thus using any two levels in the same "UEB" of $P\bar{P}$ the third one can be obtained. By using $P\bar{P}$ spectrum, the spectra of all other $B\bar{B}$ systems can also be obtained. Otherwise, using the $P\bar{N}(N\bar{P})$ and $\Lambda\bar{\Lambda}$ system or those of $P\bar{N}(N\bar{P})$ and $B\bar{B}$ with strangeness S = ± 1, the $P\bar{P}$ spectrum can also be obtained.

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Coexistence of Neutron Superfluid and π^0 Condensation in Neutron Star Matter

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Interesting aspects of nuclear matter at high density, pion condensation and nucleon superfluid, are expected to occur in the neutron star interior. Neutron $^3P_2$-superfluid was previously shown to be realized at the density $\rho=(0.7\sim2.8)\rho_0$ (ρ_0; the nuclear density).[1] Critrical density of pion condensation is considered to be slightly larger than ρ_0. In this work, we have studied the problem, how the π^0 condensation affects the neutron $^3P_2$-superfluid state, by adopting the ALS (Alternaing-Layer-Spin) model of neutron system which well describes the π^0 condensed phase in the nucleon side.[2]

In the well-developed ALS (π^0-condensed) phase, the pairing correlation is operative only when the attractive effect of spin-orbit force can be utilized as in $^3P_2$. Such a pair is composed of two neutrons with the aligned spin (S=1, $m_S=(-1)^\ell$) in the ℓ-th layer. If we chose the z-axis along the condensed-π^0 momentum, its free wave function is written as

$$\phi_{\ell\vec{q}_\perp}(\vec{r}_\perp,\ z,\ \text{spin}) = \phi_{\text{rel}}(z)\exp(i\vec{q}_\perp\cdot\vec{r}_\perp)\chi_{sm_s}(\text{spin}),$$

where $\phi_{\text{rel}}(z)=(a/2\pi)^{1/4}\exp(-az^2/4)$ is the relative wave function deduced from the one-dimensionally localized wave approximated by the Gaussian shape with a width $a^{-1/2}$ and $\exp(i\vec{q}_\perp\cdot\vec{r}_\perp)$ is the relative wave function of a pair $(\vec{q}_\perp, -\vec{q}_\perp)$ in the two-dimensional (2D) Fermi gas. Since the pairing correlation takes place in this space, the 2D partial-wave expansion in terms of the Bessel function $J_{m_l}(q_\perp r_\perp)$ is suitable (m_l being the 2D angular momentum equal to the z-component of the three-dimensional orbital one). In this scheme, pair states are specified by $\tilde{\lambda}\equiv\{S=1,\ m_S=(-1)^\ell,\ m_l\}$, where m_l should be odd due to the Pauli principle and have the same sign with m_S to utilize the spin-orbit attraction. The $m_l=m_S=1$ (-1) for ℓ=even (odd) is the most important component dominated by the $^3P_2$ pairing. The resulting gap equation showing the 2D character of this pairing is

$$\Delta_\perp(q_\perp) = -\frac{1}{2}\int_0^\infty dq'_\perp q'_\perp \langle q'_\perp|V_{\tilde{\lambda}}|q_\perp\rangle \Delta_\perp(q'_\perp)/E(q'_\perp),$$

where $E(q'_\perp)$ is the quasi-particle energy and $\langle q'_\perp|V_{\tilde{\lambda}}|q_\perp\rangle$ the matrix element of the effective pairing potential for $\lambda=\{1,1,1\}$ state.

Numerical calculations carried out at $\rho=(1\sim3)\rho_0$ by making use of a local realistic potential show $\Delta_\perp(q_{\perp F})\sim\Delta(^3P_2)/3$, where $\Delta(^3P_2)$ is the $^3P_2$ gap,[1] $q_{\perp F}=(4\pi\rho d)^{1/2}$ and we use the ALS parameters (a,d) previously taken.[3] This means the coexistence of the neutron $^3P_2$-dominant superfluid with the π^0 condensation in neutron star matter, confirming the previous result[3] by adopting a different choice with respect to theoretical framework and two-nucleon potentials.

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Coexistence of Proton Superfluid and π^0 Condensation in Neutron Star Matter

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It was previously shown that protons in the neutron star interior are in the $^1S_0$ superfluid because of their small mixture at the density $\rho=(0.7\sim2.8)\,\rho_0$ (ρ_0 being the nuclear density) where the neutron $^3P_2$ superfluid appears.[1] Pion condensation is probably realized at ρ not far from ρ_0. So it is an interesting problem to see whether or not these superfluid states can persist when pion condensation takes place. Concerning the neutron superfluid, it has been shown that the $^3P_2$-dominant one can coexist with the well-developed π^0 condensation,[2] where the neutron system has the ALS (Alternating-Layer-Spin) structure.[3] Here we report preliminary results concerning possible influence of the well-developed π^0 condensation on the proton superfluid in the density region $\rho=(1\sim3)\rho_0$.

The same viewpoint with the neutron case is adopted, but one important difference appears: The proton pairing correlation at low density is operative for the spin-singlet ($S=0$, $m_S=0$) pair composed of two protons in the nearest layers. Therefore, we should start with the single-particle wave functions of the Bloch basis constructed from the localized waves in the z-direction (being the same with the condensed π^0 momentum). They are specified by ($\vec{q}_\perp$, q_z, $\uparrow$ or $\downarrow$), where $\vec{q}_\perp$ specifies the momentum in the two-dimensional (2D) Fermi gas state and q_z the momentum in the first (occupied) band $|q_z|\leq q_{zF}=\pi/2d$ (d being the layer distance). The pair states are specified as $(\vec{q}_\perp, q_z, \uparrow; -\vec{q}_\perp, -q_z, \downarrow)_{S=0}$ as in the usual BCS pair. Making the Bogoliubov transformation and an approximation of taking the interaction between the nearest layers, we have the energy gap equation as follows. The energy gap function $\Delta(q_\perp, q_z)$ is the even function of q_z factorized as $\Delta(q_\perp, q_z)=\Delta(q_\perp)\cos q_z d$. The gap equation for $\Delta(q_\perp)$ becomes

$$\Delta(q_\perp) = -\left(\frac{d}{\pi}\right)\int_0^\infty dq'_\perp q'_\perp \langle q'_\perp|V_{\tilde{\lambda}}|q_\perp\rangle \int_0^{q_{zF}} dq'_z\, \Delta(q'_\perp)\cos^2 q'_z d \Big/ \sqrt{\tilde{\varepsilon}^2_{q'_\perp}+\Delta^2(q'_\perp)\cos^2 q'_z d}\ .$$

Here $\langle q'|V_{\tilde{\lambda}}|q\rangle$ is the effective pairing matrix element for $\tilde{\lambda}\equiv\{S=0, m_S=0, m_l=0\}$ state composed mainly of $^1S_0$ and $\tilde{\varepsilon}_{q_\perp}$ is the single-particle energy difference measured from the 2D Fermi surface, $q_{\perp F}=(4\pi\rho d)^{1/2}$. The gap function averaged over q_z becomes $\Delta(q_\perp)/\sqrt{2}$, which is an average of the maximum $\Delta(q_\perp)$ and 0 for $q_\perp=0$ and $q_z=q_{zF}$.

Numerical results by making use of a local realistic potential at $\rho=(1\sim3)\rho_0$ show that $\Delta(q_{\perp F})/\sqrt{2}$ are smaller than the corresponding $^1S_0$ gap but still $1\sim0.1$ MeV decreasing according to the reduction of effective mass, at a typical proton mixing of 5% and for the ALS parameters previously taken.[2] Thus we can say that the proton superfluid at $\rho=(1\sim3)\rho_0$ survives under the ALS structure (π^0-condensed phase) because the critial temperature is still higher than internal temperature of young neutron stars ($\sim 10^8$K).

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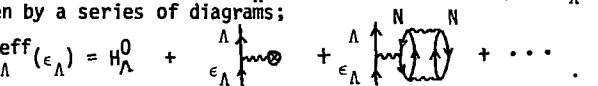
N-N TENSOR FORCE EFFECT ON B_Λ IN S-SHELL HYPERNUCLEI

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Theoretical attempts to explain the observed Λ-particle separation energy B_Λ in s-shell hypernuclei have encountered an "overbinding difficulty." In the calculation by D-H-T[1], reproduction of B_Λ for ${}^{3}_{\Lambda}$H, ${}^{4}_{\Lambda}$H and ${}^{4}_{\Lambda}$He ; 0.13, 2.04 and 2.39 MeV respectively ; leads to $B_\Lambda({}^{5}_{\Lambda}\mathrm{He})\sim 5.5$ MeV in comparison with the experimental value 3.12 MeV, with an overbinding of $\sim$2.4 MeV. It seems that little attention has been paid to the reality of the nucleon-nucleon interaction (v_{NN}) which determines the property of nuclear core of Λ-nuclei. The realistic N-N interaction is characterized by a strong tensor force component, a typical manifestation of which is the repulsive rearrangement effect on the single particle separation energy.

In terms of the effective interaction theory, B_Λ is obtained by diagonalizing the effective Hamiltonian H^{eff}_Λ in a chosen model space P_Λ for Λ, which is given by a series of diagrams;



$$H^{\mathrm{eff}}_\Lambda(\epsilon_\Lambda) = H^0_\Lambda + \cdots \qquad (1)$$

The diagram starting energy $\epsilon_\Lambda = -B_\Lambda$ is determined by solving the Bloch-Horowitz equation $P_\Lambda[H^{\mathrm{eff}}_\Lambda(\epsilon_\Lambda) - \epsilon_\Lambda]P_\Lambda\,\Phi_\Lambda = 0$. By taking only the above three terms in Eq.(1), an approximate H^{eff} is expressed as

$$H^{\mathrm{eff}}_\Lambda(\epsilon_\Lambda) = T_\Lambda + U_\Lambda(\epsilon_\Lambda) + U^R_\Lambda(\epsilon_\Lambda), \quad U_\Lambda(\epsilon_\Lambda) = \textstyle\sum_N G_{\Lambda N}(\omega = \epsilon_\Lambda + \epsilon_N),$$
$$U^R_\Lambda(\epsilon_\Lambda) = -\kappa_N\, U_\Lambda(\epsilon_\Lambda), \quad \kappa_N = -\textstyle\sum_{N'} \langle NN'|\partial G_{NN}(\omega)/\partial\omega|NN' - N'N\rangle_{\omega=\epsilon_N+\epsilon_{N'}}. \qquad (2)$$

κ_N is the famous wound-integral parameter for which the tensor force correlation is principally responsible. A simple consideration leads to the following qualitative features of U^R_Λ for ${}^{4}_{\Lambda}$He(${}^{4}_{\Lambda}$H) and ${}^{5}_{\Lambda}$He ; (i) $|U_\Lambda({}^{5}_{\Lambda}\mathrm{He})| > \frac{4}{3}|U_\Lambda({}^{4}_{\Lambda}\mathrm{He})|$, (ii) $\kappa_N({}^{5}_{\Lambda}\mathrm{He}) > \frac{3}{2}\kappa_N({}^{4}_{\Lambda}\mathrm{He})$, (iii) Size effect i.e. the ^{4}He core is more compact than the ^{3}He core. (i) and (ii) simply reflect a difference of bond numbers and the size effect of (iii). Thus $U^R_\Lambda({}^{5}_{\Lambda}\mathrm{He}) > 2\,U^R_\Lambda({}^{4}_{\Lambda}\mathrm{He}, {}^{4}_{\Lambda}\mathrm{H})$. A quantitative evaluation using the Reid-SC potential for v_{NN} and the softened D-H-T potential for $v_{\Lambda N}$, together with the model space P_Λ of {0s$\sim$3s} states, leads to the result in the table. The difference between U^R_Λ contributions to B_Λ for ${}^{4}_{\Lambda}$He(${}^{4}_{\Lambda}$H) and ${}^{5}_{\Lambda}$He amounts to an order of 1 MeV and is about one half of the overbinding magnitude found in previous calculations.

In conclusion, the rearrangement effect due to the strong N-N tensor force correlation is able to resolve a half of the overbinding difficulty of B_Λ in s-shell hypernuclei.

		${}^{4}_{\Lambda}$He (${}^{4}_{\Lambda}$H)	${}^{5}_{\Lambda}$He	
H.O. basis b_N		1.5	1.3	(fm)
$\langle 0s\|U_\Lambda\|0s\rangle$		-13.9	-19.9	(MeV)
κ_N		0.066	0.112	
$\langle 0s\|U^R_\Lambda\|0s\rangle$		0.92	2.23	(MeV)
B_Λ	no rearr.	2.8	5.9	
	with rearr.	2.1	4.2	(MeV)
	exp	2.2	3.1	

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SPIN-DEPENDENCE OF THE PHENOMENOLOGICAL EFFECTIVE ΛN INTERACTION

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Recently, Bouyssy[1] has analyzed the strangeness exchange reaction (K^-,π^-) data on some p- and s-d shell nuclei. Working within the single-particle shell model and invoking a residual spin-dependent lambda-nucleon (ΛN) interaction of zero range, he finds that ΛN force has very weak spin-dependence. On the contrary, Bedjidian et al[2] in their analysis of excited states of s-shell hypernuclei ($^4_\Lambda$H, $^4_\Lambda$He) find a strong spin-dependence in ΛN force. Recently, we had made an analysis[3] of p-shell hypernuclei binding energy (B_Λ) data in the shell-model framework. Our potential was strongly state-and spin-dependent. In the light of the above remarks we have carried out an analysis of the p-shell hypernuclei B_Λ data and Λ binding to nuclear matter to see if a potential with low spin-dependence could also fit the data.

The two-body ΛN potential was chosen to have the form

$$V_{i\Lambda} = V_s^t [1+\beta(\vec{\sigma}_i\cdot\vec{\sigma}_\Lambda - 3/4)]\, f(r_{i\Lambda}),$$

where parameter β is measure of the degree of spin-dependence. The interaction parameter in triplet state $V_t^t = (1-\beta)V_s^t$. For two choices of form factor $f(r_{i\Lambda})$ i.e. Skyrme type and gaussian, the data were analysed. Thus B_Λ of hypernucleus was expressed in term of four potential parameters; viz V_s^o, V_s^1, β and $a(=I_2/6\,I_1)$ or α(range) depending on whether shape function is Skyrme type or gaussian form.

Energy of Λ-particle in each hypernucleus was minimized with respect to size parameter of Λ-particle wave function taken as a single gaussian to search ΛN parameters. Even with as high as 25% spin-dependence the calculated binding energies were a good way off from the experimental values. A three body ΛNN potential of the form

$$V_3(r_{ij\Lambda}) = W_3\,(\vec{\sigma}_i\cdot\vec{\sigma}_j)\,(\vec{\tau}_i\cdot\vec{\tau}_j)\,\delta(\vec{r}_i-\vec{r}_\Lambda)\,\delta(\vec{r}_j-\vec{r}_\Lambda)$$

was added to the ΛN force to see if with low spin-dependence it could fit the data. Our results show that for Skyrme type interaction with as low as 10% spin-dependence the data are fitted. No fit could be found with as high as 25% spin-dependence for the gaussian form. Preliminary results for Yukawa and exponential shapes are also similar to those for the gaussian.

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INVESTIGATION OF THE LOW-ENERGY SPECTRUM OF Σ-HYPERNUCLEI

M. Dillig

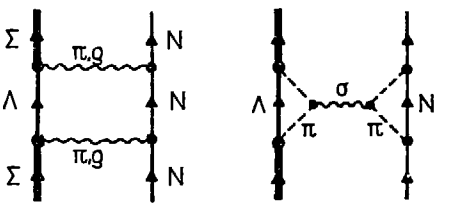
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Recently, with the (K,π) strangeness-exchange reaction on nuclei at medium energies a detailed study of the formation and the properties of Λ-hypernuclei became feasible. In the context of these investigations, first - through hitherto rather incomplete - results on the production of $\Sigma(1193)$-hypernuclei were reported[1]. Their spectra - if confirmed - reveal various interesting features:

- in corresponding orbits the Σ-hyperon seems to be slightly less bound than the Λ ;
- as for Λ-hypernuclei the spin-orbit splitting in Σ-hypernuclei seems to be very small;
- the width of the Σ (single particle) states, which are unstable against $\Sigma N \to \Lambda N$ conversion, is surprisingly small.

We investigate the Σ-spectrum for closed shell nuclei in a simple Hartree-Fock approach, with an elementary ΣN interaction formulated in terms of one and two-boson exchange contributions. Thereby the coupling to the ΛN absorption channel is incorporated via the (uncorrelated) 2π and $\pi\varrho$ exchange, which also adds, together with the corresponding correlated two-meson exchange contributions (supplemented by ω-exchange) to the spin-orbit interaction of the Σ-hyperon (see figure).

Within this model the lowest states of the Σ-spectrum are calculated under the assumption that the nucleonic core remains inert. The result qualitatively reproduces the features summarized above; in particular binding corrections and the Pauli-blocking reduce the widths of the lowest Σ-states below 15 MeV; furthermore the spin-orbit splitting found for Σ-hypernuclei is comparable (slightly larger) than for Λ hypernuclei (in disagreement with a prediction based on the quark structure of the Σ and Λ hyperon[2]).



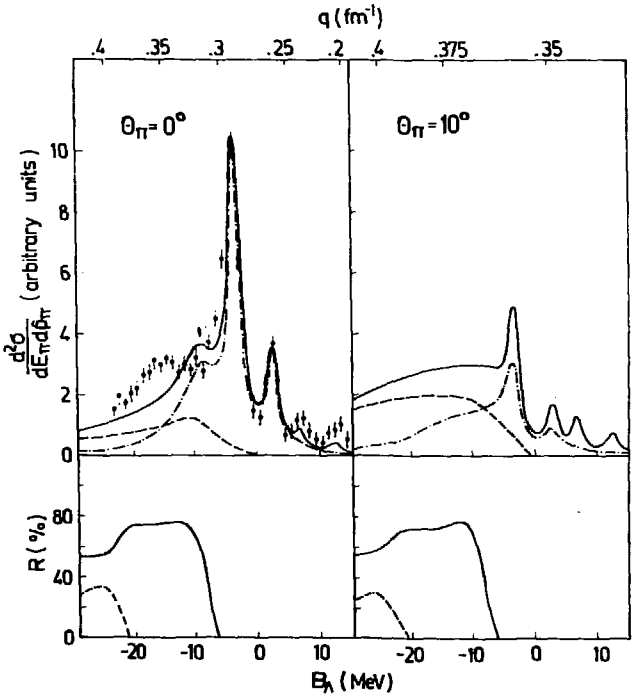
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CONTINUUM SHELL MODEL DESCRIPTION OF (K^-,π^-) REACTIONS

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Measurements of (K^-,π^-) reactions in noncollinear geometry are now in progress. We have investigated the $^{16}O(K^-,\pi^-)$ reaction at p_K = 715 MeV/c within the continuum shell model in DWIA using the eikonal approximation. With increasing π^- angle the ratio between the recoilles and the quasi-free Λ production is diminished as illustrated in the figure.



The upper part shows the calculated π^- spectra (full lines), their recoilless contributions (dash-dotted lines) and the contributions of the Λ particle continuum (broken lines) for Θ_π = 0° and 10°. The experimental data are taken from ref.[1]) The lower part gives the relative yields R of the $1p_{3/2}$ (full lines) and of the $1s_{1/2}$ (broken lines) hole states of the residual nucleus ^{15}O. The upper scale indicates the variation of the transferred momentum as a function of the binding energy B_Λ of the Λ hyperon.

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STRANGENESS ANALOG STATE AND MOLECULAR ORBITAL APPROACH TO $^{12}_{\Lambda}C$

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In $K^- + {}^{A}_{Z} \rightarrow \pi^- + {}^{A}_{\Lambda}Z$ reactions the resonances are interpreted as indications of hypernuclei produced in their excited or ground states. In a p-shell nucleus a simple replacement of a neutron by a Λ-particle would give rise to an excited hypernuclear state. Such a state has been called a Strangeness exchange resonance. They are also associated with "Strangeness Analog States" consisting of a coherent superposition of states obtained by replacing every neutron in the parent nuclear state in turn by a Λ. In shell model, the large energy difference between s and p shells ($\sim$10 Mev in ^{12}C) makes a coherent superposition untenable. The available data for ^{12}C and ^{16}O have been reasonably well explained [1] in the shell model as a neutron hole in the p-shell along with a Λ in the p-shell(excited state) or in the s-shell (ground state).

In this work I attempt an explanation of the data in the alpha particle modelfor ^{12}C. In this model the alpha particles are at the vertices of an equilateral triangle and possess D_3 symmetry. A nucleon of given spin and isospin at each vertex contributes an s-orbital. From the three s-orbitals we can form, by taking suitable linear combinations, molecular orbitals which belong to irreducible representation of one and two dimensions in the usual manner.[2] The one dimensional representation has the lower energy. The excited strangeness resonance state corresponds to having a neutron hole and a Λ in the states belonging to the two dimensional representation while the ground state corresponds to Λ being in the lower state with a neutron hole in the upper one.

In this way the alpha particle model is also able to explain the data equally well. This model, in addition, permits the idea of Strangeness analog state. As all neutrons are equivalent in the equilateral triangle configuration a coherent superposition obtained by replacing each one of them in turn by a Λ is quite feasible.

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STUDIES OF LIGHT HYPERNUCLEI

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Knowledge of the structure of hypernuclei is still in an incomplete and fragmentary state. Up to now targets used to study the (K,π) strangeness-exchange reaction have been primarily even-even with N=Z. Accordingly we have studied the (K,π) reaction on a series of light targets including ^{13}C and ^{18}O in order to compare adjacent hypernuclei differing by a single neutron or proton.

The experiments were performed using the hypernuclear spectrometer at the BNL AGS Low-Energy Separated Beam with kaon momentum of 800 MeV/c.[1] The resolution is 2.5 MeV FWHM for a 2 g/cm^2 target thickness. The spectrometer measures the energy difference between the incoming kaon and outgoing pion for angles from 0^o to 30^o.

The reaction $K^- + {}^A_Z \rightarrow {}^A_\Lambda Z + \pi^-$ is used to populate the hypernuclear states. Light systems offer the best opportunity for studying discrete states, since as A increases the reaction strength goes increasingly into quasi-free Λ production.

For targets with non-zero isospin, the hypernuclear states formed in the strangeness-exchange reaction can have $T=\pm 1/2$. The two observed states in ${}^9_\Lambda Be$ have been interpreted, in the framework of the Sakata SU(3), as representing isospin splitting.[2] The present data will help to test this interpretation for neighboring nuclei with N≠Z. Data on P-shell hypernuclei are provided in this experiment, and these data will further test the supposedly small value for the Λ-nucleus spin-orbit coupling observed by the Heidelberg-Saclay-Strasbourg collaborators.[3]

For our study of ^{13}C we have fabricated a scintillation counter consisting of benzene containing carbon enriched to 99% ^{13}C. The use of a scintillation counter in the target provides a strong background suppression by making use of the large signal produced by Λ hyperon decay in the target. A feasibility study of the observation of hypernuclear γ-rays following the strangeness-exchange reaction has also been carried out using a sodium iodide detector array.

Data on the hypernuclear levels and their systematics are currently being analyzed and will be presented.

† Research supported by the U.S. DOE under Contract DE-AC02-76CH00016.
†† Research supported by the U.S. DOE under Contract EG-77-5-02-4195.

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Λ- SPIN-ORBIT SPLITTING IN HYPERNUCLEI

A. Bouyssy

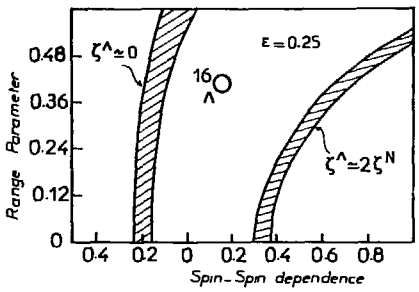
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Experimental data in $^{16}_{\Lambda}O$ *[1] show a clear evidence for two narrow peaks well separated by about 6 MeV, the ratio of intensity being about 3. In a simple model based on quasi-elastic configurations built on* $1p_{3/2}$ *and* $1p_{1/2}$ *orbitals [2] or using the concept of analogue and supersymmetric states [3], the diagonalization of the* ΛN^{-1} *energy matrix gives* ΔE *the energy shift and N the ratio of intensity of the peaks. Both quantities are functions of* $\Delta\zeta = -\frac{1}{3}(\zeta^{\Lambda} - \zeta^{N})$, *a parameter related to the spin-orbit depths of the Λ-particle and the neutron (known to be about 18 MeV), and of the* ΛN^{-1} *matrix elements. The latter are calculated with a Λ-N residual interaction chosen of the form*

$$V_{\Lambda N}(\vec{r}_{\Lambda}-\vec{r}_{N}) = -V_{o}/(\pi^{3/2}\mu^{3}).\exp\left[-|\vec{r}_{\Lambda}-\vec{r}_{N}|^{2}/\mu^{2}\right].(1-\varepsilon+\varepsilon P_{x})(1+\alpha.\vec{\sigma}_{\Lambda}.\vec{\sigma}_{N})$$

where P_x *is the space-exchange operator. The range* μ *of the interaction, the space-exchange parameter* ε *and the spin-spin dependence* α *are completely free parameters. The strength* V_o *is related to the Λ-nucleus central potential depth and is chosen as* $V_o = 260$ *MeV fm*^{3}. *The single-particle wave functions for the Λ-particle and the neutron are assumed to be those given by harmonic oscillator potentials, with* b_{Λ} *and* b_N *as harmonic oscillator parameters (see ref [2]).*

Assuming quite restrictive conditions for the experimental values of ΔE *and N (*$\Delta E = 6 \pm 0.5$ *MeV and* $N = 3 \pm 0.5$*) the comparison of the model calculation with the data gives results as shown in fig.1 by shaded areas. The case* $\varepsilon = 0.25$ *has been taken as a typical example. The quantity x is a dimensionless parameter related to the range of the interaction by* $x = \mu(b_N^2 + b_{\Lambda}^2)^{-1/2}$.



Two kinds of solutions are obtained : either a large spin-spin dependence associated with $\Delta\zeta = -6$ *MeV and corresponding to* $\zeta^{\Lambda} \simeq 2\,\zeta^{N}$, *or a small spin-spin dependence associated with* $\Delta\zeta = 6$ *MeV (and therefore* $\zeta^{\Lambda} \simeq 0$*), corresponding to the two different interpretations already known [2, 3]. For a value* $x = 0.36$ *which corresponds to a range* $\mu = 1.04$ *fm associated with a two-pion exchange, the spin dependence is* $\alpha = -0.15$ *for* $\zeta^{\Lambda} = 0$ *or* $\alpha = +0.60$ *for* $\zeta^{\Lambda} = 2\,\zeta^{N}$. *The second solution seems to be excluded by the knowledge of light hypernuclei and Λ-p elastic scattering [4], although we are working here with an effective interaction and not with the bare one which is believed to be stronger in singlet state than in triplet one.*

As a conclusion the result obtained here with a more refined Λ-N interaction confirms that the Λ- particle in a nucleus behaves as a "spinless neutron" [1].

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BETA DECAY OF ^{41,42,43}Cl

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The heavy chlorine isotopes up to A = 43 have been produced by fragmentation of an uranium carbide target with 600 MeV protons from the CERN synchrocyclotron. Mass analysis was performed with the ISOLDE isotope separator and selectivity for extracting halogens was obtained by the use of a negative ion source developed by Ravn et Vosicki[1]. The radioactivity of ^{41,42,43}Cl has been investigated by β multiscaling, γ-multispectrum analysis, β-γ and γ-γ coincidence measurements. The decay of ^{42}Cl and ^{43}Cl is reported for the first time.

For ^{41}Cl($T_{1/2}$ = 38.4 + 0.8 s) the strong β feeding of the $1/2^+$ state at 1.87 MeV, reported by Gurach et al.[2], has been confirmed. Furthermore, β branches to levels at 1.57, 2.36, 3.30, 3.57 and 3.92 MeV have been established. Most of these levels were not populated in previous (d,p) studies[3].

The ^{42}Cl decay ($T_{1/2}$ = 6.85 + 0.25 s) proceeds to hitherto unreported levels in ^{42}Ar at 4.04, 4.42, 4.61 and 4.93 MeV. Assuming a negative parity for the ^{42}Cl ground state and on the basis of the log ft values, the same parity may be inferred for the levels at 4.04 and 4.42 MeV. In this energy region $J^\pi=(2\text{-}5)^-$ states resulting from the $[(d_{3/2})^{-3}(f_{7/2})^5]_{J,T=3}$ configuration are expected.

The radioactivity of ^{43}Cl($T_{1/2}$ = 3.33 + 0.16 s) feeds predominantly a level at 1.79 MeV through an allowed transition (log ft ≈ 5.2). In addition weaker β branches to levels at 1.38, 1.44, 2.34, 2.39 and 4.25 MeV were observed. None of these states is reported in a previous (α,^{9}Be) study[4]. The 1.79 MeV level (π = +) which decays to the ^{43}Ar ground state by a cascade (1032 + 762 keV) has almost the same excitation energy as the $1/2^+$ level in ^{41}Ar (E_x = 1.87 MeV) strongly populated by the β decay of ^{41}Cl.

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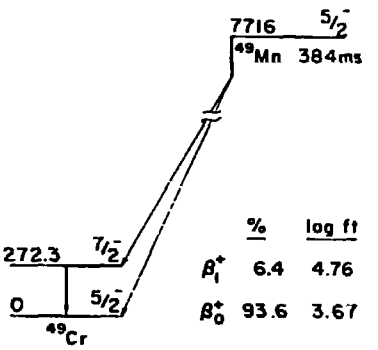
THE DECAY OF ^{49}Mn: FIRST RESULTS FROM THE CHALK RIVER ON-LINE ISOTOPE SEPARATOR

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The new Chalk River on-line isotope separator has been used to study the decay of neutron-deficient manganese isotopes. The activities were produced by bombarding a 2 mg/cm^2 target of natural magnesium with 95 MeV ^{28}Si ions from the Chalk River upgraded MP tandem. Reaction products recoiled from the target directly into a FEBIAD ion source, from which a 40 keV beam of ions was extracted into the isotope separator. Ions of a selected mass passed through a narrow slit on the separator image plane and thence through an electrostatic deflector and two quadrupole doublets into a shielded collection chamber. The mass-separated activities were collected on the tape of a small tape transport system and their decays studied with a Ge(Li) detector.

We wish to report here the first characterization of the decay of ^{49}Mn. The half-life of this nuclide, obtained from sequential measurements of the annihilation radiation, was determined to be 384 ± 17 ms. The major β-decay branch of ^{49}Mn (J^π,T = $5/2^-$,1/2) is the superallowed branch to its mirror, the $5/2^-$ ground state of ^{49}Cr. A weaker, (6.4 ± 2.6%) allowed branch was found to populate the $7/2^-$ state at 272 keV in ^{49}Cr. The log ft values for the superallowed and the allowed branches were determined to be 3.67 ± 0.02 and 4.76 ± 0.20 respectively. The deduced Gamow-Teller matrix elements agree very well with shell model calculations that employ a modified Kuo-Brown interaction.



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BETA DECAY OF ^{21}O

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Radioactive products from the bombardment of a 2-mg/cm^2 thick Be foil with 80-110 MeV ^{18}O ions at beam currents of up to 50 particle namp from the MP Tandem Van de Graaff were studied by using a helium gas transfer system. After the recoils were stopped in a glass target cell 13 cm long at a He pressure of ~1.5 atm. the activities were swept through a 1.6-mm i.d. plastic capillary to the counting area. Removal of non-gaseous products was accomplished by flowing the gas through a unit containing three pieces of 0.8-micron pore size 0.15-mm thick standard biological filter paper. This nearly eliminated ^{24}Na whose 2754-keV γ ray and consequent 1732-keV double-escape peak has been the chief background problem in various searches for ^{21}O at BNL since 1972. The gas then passed through a heated stainless-steel tube for removal of fluorine activities. A thin cell filled with silica gel thereafter collected the oxygen activities for study of the γ and β rays in Ge(Li) and plastic detectors. For half-life determinations the gas flow was periodically interrupted by solenoid valves and the decay of γ-ray lines in the spectrum was measured. In addition to the strong γ rays from ^{19}O decay and weaker ^{20}O γ rays, a line of 1730.4 ± 0.2 keV was observed to decay with a half-life of 4 ± 1 sec and to be in coincidence with β rays of $E_{\beta max}$ = 6.7 ± 0.7 MeV. (All results are preliminary).

Independent measurements were made of the energy of the $J^\pi = 3/2^+$ 1730-keV third excited state of ^{21}F by a new study of the $^{19}F(t,p)^{21}F$ reaction using a 3.5-MV Van de Graaff. An energy value of 1729.8 ± 0.4 keV was obtained for this state.

The 1730.4-keV γ ray in the Tandem experiment is assigned to the β decay of ^{21}O formed in the reaction $^9Be(^{18}O,2p\alpha)^{21}O$. The branch to the 1730-keV state of ^{21}F is consistent with the expected assignment of $J^\pi = 5/2^+$ to ^{21}O and the measured half-life compares with theoretical estimates of 1.2 sec by Lanford and Wildenthal[1] and 3 sec by Millener[2] based on the mass excess of 8.126 ± 0.051 MeV[3] for ^{21}O from measurements by Ball et al[4] and by Naulin et al[5]. An observed increase in ^{21}O yield with increasing ^{18}O beam energy from 80 to 110 MeV is in agreement with expectations based on fusion-evaporation calculations.

Preliminary evidence suggests other β-ray branches in ^{21}O decay but the results will depend on measurements in progress. We are indebted to Cary N. Davids for suggesting the filtering scheme. This research was supported by the Division of Basic Energy Sciences, Department of Energy, under contract No. DE-AC02-76CH00016.

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THE DECAY OF MASS-SEPARATED $^{99}Ag^{g,m}$

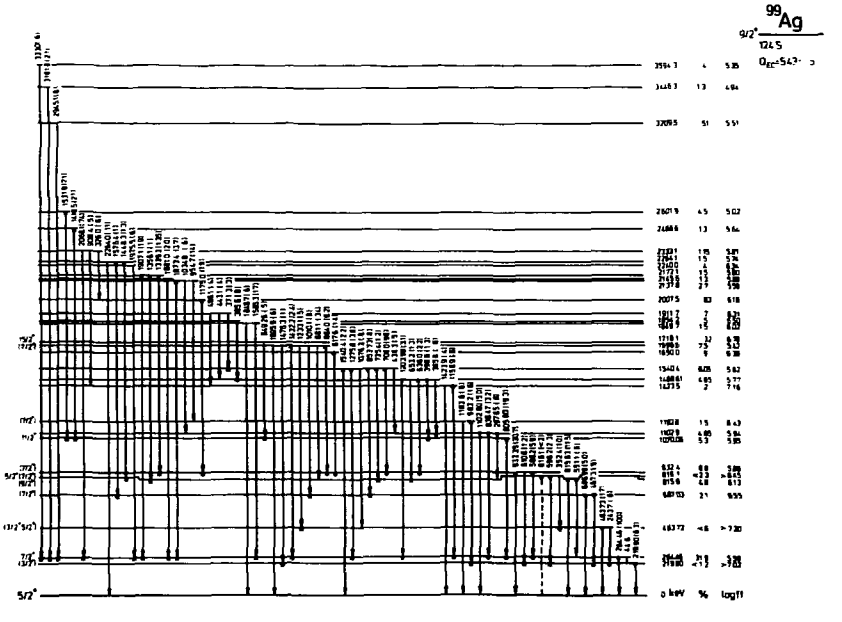
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The decay of hitherto unidentified 15 ± 2s $^{99}Ag^{m}$ and improperly identified 124 ± 3s $^{99}Ag^{g}$ nuclides have been investigated with the Leuven Isotope Separator On Line facility[1]. Sources were produced by the ^{92}Mo (^{14}N,2p5n) and ^{90}Zr (^{14}N,5n) reactions. Positron-, conversion electron-, x- and γ-ray singles spectra together with γ-γ coincidences measurements have been performed on mass-separated samples.

The $1/2^-$ isomeric level in ^{99}Ag decays with a 163.6 keV I.T to a $7/2^+$ level at 342.6 keV. The smooth trend of decreasing transition probability of the isomeric transition in the odd Ag nuclei with decreasing neutron number is interrupted in ^{99}Ag : the hindrance factor with respect to the Moszkowski single-particle estimate jumps from 68 in ^{101}Ag to 236 in ^{99}Ag.

In the proposed level scheme of ^{99}Pd, 92 % of the γ-intensity, observed in the β^+/EC decay of the ^{99}Ag groundstate, has been placed. We confirm the in-beam observations [2] of a decoupled band, built on the $7/2^+$ at 264.6 keV. A possible candidate for the first excited state of a similar band, built on the $5/2^+$ groundstate, is the $9/2^+$ state at 5.6 keV.



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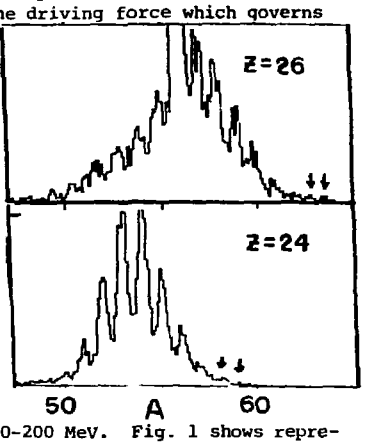
DETECTION OF NEW NUCLIDES WITH Z=20-26 IN DAMPED COLLISIONS*

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Studies of mass and charge distributions of products formed in damped heavy-ion collisions have demonstrated that the driving force which governs the nucleon-exchange process is strongly influenced by the N/Z ratio of the intermediate complex[1]. Consequently, in reactions between highly mass asymmetric projectile-target combinations, the N/Z ratio of the lighter reactant is enhanced, thus providing useful means of synthesizing new nuclides[2].



In studies of the ^{209}Bi + ^{56}Fe and ^{238}U + ^{56}Fe reactions at the LBL Super-HILAC, evidence has been obtained for new isotopes of the elements Ca through Fe. Self-supporting targets of ^{209}Bi and ^{238}U were bombarded with 8.3 MeV/u ^{56}Fe ions and the reaction products were detected with a ΔE-E time of flight detector telescope . This system yielded a resolution (FWHM) of less than 0.7 A units and 0.8 Z units for A>60 over an energy-loss range of 20-200 MeV. Fig. 1 shows representative mass spectra for Cr and Fe isotopes observed with this system; arrows indicate positions of previously unobserved nuclei. In order to minimize the possible contamination of the spectra from masses with Z±1, a gate of ±0.3 Z units about the charge centroid was used in deriving the mass spectra for each Z. The absence of effects due to slit-scattered ^{56}Fe ions in the A=56 peaks of the Mn and Co spectra and calculations based on the spectral shapes of the Z peaks confirm that contamination from other Z-values is less than 5 percent.

Nuclide	Counts	σ(mb)	Nuclide	Counts	σ(mb)	Nuclide	Counts	σ(mb)
(^{51}Ca)	9	0.3	(^{55}Ti)	31	1	^{58}Cr	106	3
^{52}Sc	47	2	(^{56}Ti)	25	0.7	^{59}Cr	38	1
^{53}Sc	23	0.8	^{56}V	139	4	^{61}Mn	20	0.7
^{54}Ti	106	3	(^{57}V)	49	2	^{63}Fe	14	0.4
						(^{64}Fe)	8	0.3

In Table I the new nuclides observed in these studies are listed along with the total number of events recorded and the approximate cross section for each. The criteria for identification were (1) number of observed counts N>10 and (2) spectral clarity. Parentheses indicate tentative assignments.

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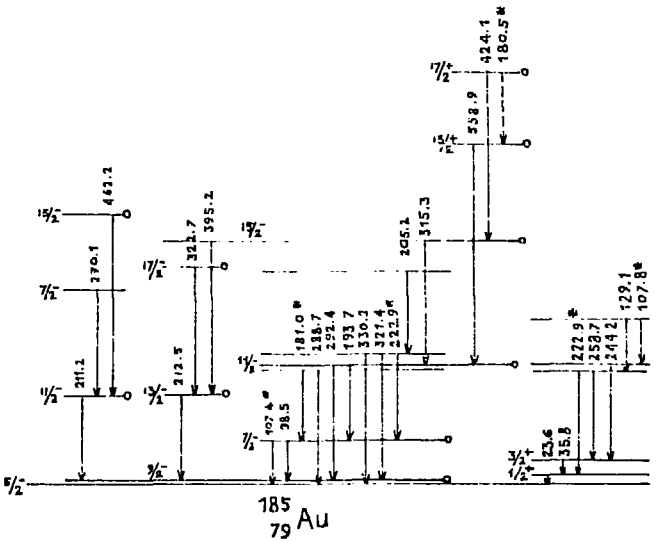
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NEW RESULTS ON ^{185}Au REVEALED BY DETECTION OF LOW-ENERGY ELECTRONS

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IPN et CSNSM, F-91406 ORSAY CEDEX

We have managed to build a level scheme including most of the numerous lines of the low lying states of ^{185}Au from the radioactive decay of ^{185}Hg ($t_{1/2} < 60$ s.) produced with the on-line separator ISOCELE II at Orsay. (On the figure, transitions placed twice are noted *, levels also populated by (HI, xnγ) reactions are noted o). The low energy spectrum has been recorded with a 2‰ resolution semi-circular spectrograph : The M2 23,6 keV transition enabled us to locate the positive parity low-spin levels with respect to the ground state. The 8,9 keV level has been deduced from coincidence data (γ−γ and X-γ). The electron spectrum obtained with a Gerholm type spectrometer with 10 kV preacceleration seems to be in rather good agreement with the existence of a 8,9 keV transition. Moreover the two 107.4 and 107.8 keV transitions can be clearly seen from the spectrograph data. Such measurements are very useful to locate the low-lying excited states and also to give an evidence of low-spin states which are not populated via (HI, xnγ) reactions [1]). Detailed calculations using the quasi particule + rotor model are in progress in order to obtain a full representation of all these states.



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DECAY OF ^{36}Ca: COMPLETION OF THE MASS 36 ISOSPIN QUINTET†

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Development of the on-line mass analysis system RAMA at the LBL 88-inch Cyclotron has led previously to the observation[1] of two new β^+-delayed proton emitters, ^{20}Mg and ^{24}Si. The decays of such 0+, T_z=-2 nuclides populate the 0+, T=2 states in their T_z=-1 daughters, frequently permitting completion of isospin quintets and providing sensitive tests of the isobaric multiplet mass equation (IMME).

We have recently utilized RAMA (an acronym for recoil atom mass analyzer) to search for the decay of ^{36}Ca, which would complete the heaviest isospin quintet possible with established techniques and stable targets. RAMA employs a helium jet to transport activity via skimmers to a hollow cathode ion source. Activity is extracted, mass-separated and then deposited on a thin carbon foil in the analyzer focal plane. Emitted protons following ^{36}Ca decay were detected using a semiconductor counter telescope. Monitoring of the overall operation of RAMA was accomplished by concomitantly observing the yield of β^+-delayed protons from the well-known nuclide ^{37}Ca, which was produced in much greater abundance.

The ^{40}Ca(^{3}He,α3n) reaction on natural calcium targets at 95 MeV was used to produce ^{36}Ca. Observation of $\sim$100 msec ^{36}Ca was difficult due to its low yield (<1μb for the observed decay mode) and to possible interference from the weak β^+-delayed proton decay of ^{36}K. Fortunately, a recent detailed study by Eskola et al.[2] of the β^+-delayed proton (and alpha) decay of the latter was available. We were able to duplicate their results for the decay of ^{36}K in the proton-energy region of interest and then, by elimination, to observe a new proton group at 2519$\pm$21 keV which we attribute to the β^+-decay of ^{36}Ca to the 0+, T=2 level in ^{36}K, followed by proton emission to the ground state of ^{35}Ar. The mass-excess of this lowest T=2 state in ^{36}K is -13168$\pm$22 keV.

Currently available results on isospin quintets provide tests of the IMME for seven isobars in which at least four members of the quintet are known and for four complete quintets. In heavier masses, good overall agreement with the predictions of the simple quadratic IMME is observed, as is also the case for the mass 36 quintet. Sufficient data are now available to permit systematic studies of the IMME in both its first-order and second-order forms, as has been done previously with the considerable data on complete isospin quartets.

†This work was supported by the Nuclear Physics and Nuclear Sciences Divisions of the U.S. Department of Energy.
††Present address: University of Jyvaskyla, Finland.

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KAON PHOTOPRODUCTION ON ^{12}C*

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This is the first of a series of studies of kaon photoproduction off nuclear targets. Our primary interest in such reactions is that they promise to be an exciting new probe of both Λ and Σ hypernuclei. It is of vital importance to estimate the size of the cross-sections to guide experiment, including the design of future electron accelerators. We calculate using a fairly straightforward approach. There are three main pieces in the analysis: the (γ, K^+) operator, the kaon nucleus interaction and the structure of the hypernuclear states. We employ a realistic model to describe (γ, K) on a nucleon. The K^+ nucleus interaction is well understood and is easily included using distorted waves. The hypernucleus is described in a shell model framework. We have calculated (γ, K^+) differential cross-sections on ^{12}C for a variety of different possible hypernuclear final states. We use our results to compare and contrast the exploration of hypernuclear states by (γ, K^+) with that by $(K^-, \pi^\pm)$.

*This work was supported in part through funds provided by the U.S. Department of Energy (DOE) under contract DE-AC02-76ERO-3069.

800 MeV PROTON INELASTIC SCATTERING TO THE ^{12}C 15.11 MeV STATE AT LARGE MOMENTUM TRANSFER: A SEARCH FOR CRITICAL OPALESCENCE†

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The differential cross section for the $^{12}C(p,p')^{12}C^*$(15.11 MeV, 1^+, T=1) reaction has been measured at 800 MeV with the High Resolution Spectrometer at LAMPF. The range of the angular distribution (6° to 17° LAB) corresponds to momentum transfers of 0.7 to 2.2 fm^{-1} and includes the secondary maximum observed in the electron scattering form factor.[1] Several authors have recently suggested that an enhanced (e,e') [2] or (p,p') [3] cross section at this maximum may be interpreted as evidence for critical opalescence, or pre-critical pion condensation.

An inelastic spectrum taken at 14°, the angle of the maximum predicted in Ref. 4, is shown in Fig. 1. The 15.11 MeV state is only weakly excited; the cross section is comparable to that for the 12.71 MeV, 1^+, T=0 state which is not expected to be enhanced. Preliminary absolute values of the cross section are below even the pure shell model predictions of Ref. 4. However, the two-nucleon potential used there is admittedly uncertain. Thus, while the present results are very suggestive, only when the potential parameters have been fixed by precise two-nucleon data can these results be interpreted as definitive evidence against critical opalescence.

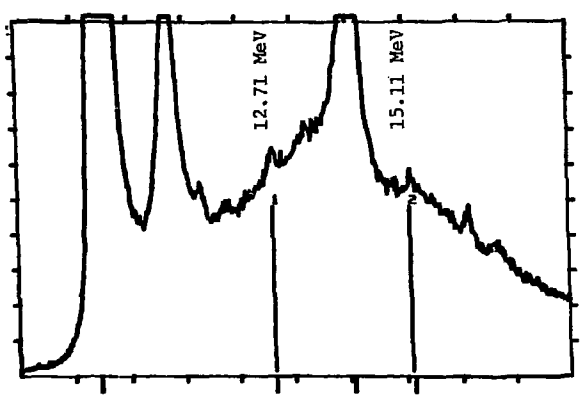


Fig. 1. Spectrum of ^{12}C at 14°. The two narrow states of interest are identified. They lie on a background of strong and broad natural parity excitations.

We are very grateful to M. Ericson and W. Weise for helpful correspondence.

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PRODUCTION OF ACTINIDE ELEMENTS IN THE ^{209}Bi + ^{56}Fe REACTION*

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In counter studies of strongly-damped collisions between ^{209}Bi and ^{56}Fe ions, the nucleon diffusion process has been shown to yield a net transfer of both charge and mass from the projectile to the target.[1]) Of related interest, Oganessian, et al.,[2]) have used similar reactions in the identification of new elements with Z = 104-107, all reported to be spontaneous fission (SF) activities. The possibility that the results of Ref. 2 can be explained at least in part by the formation of known SF activities in damped collisions is examined here.

The measurements involved bombardment of a self-supporting ^{209}Bi target of thickness 500 μg/cm^2 with 464-MeV ^{56}Fe ions from the LBL SuperHILAC. Projectile-like fragments were identified with a ΔE-E time-of-flight detector system which permitted discrete Z and A values to be determined; primary fragment yields were derived assuming $E^*_L/E^*_H = A_L/A_H$. Heavy fragment yields were then deduced from these values and the criterion that the damped collision process is binary in nature; i.e., $Z_H = 109-Z_L$ and $A_H = 265-A_L$.

The resultant heavy fragment primary yields indicate significant production of actinide elements in these reactions, ranging from 60 mb for Z = 90 to 4 mb for Z = 100. The Z = 104-107 SF activities reported in Ref. 2 fall into two groups of half-lives, (1) 1-10 msec, and (2) about 1 sec. Formation cross sections were of the order of 0.1 nanobarn.

Nuclide	$^{240}Fm_{Am}$	$^{242}Fm_{Am}$	$^{244}Fm_{Am}$	^{234}Cf	^{236}Cf	^{238}Cf	^{242}Fm	^{244}Fm	^{246}Fm
t_{SF}	0.9 ms	14 ms	1 ms	1 μs-200 ms	1 ms-100 s	2s-2h	0.8 ms	3 ms	1.2 s
Primary Yield (nb)	2×10^5	2×10^4	500	300	1×10^4	1×10^5	2×10^5	6×10^5	6×10^5
Final Yield (nb)	30[a]	20[a]	5[a]	0.02	0.1	0.3	0.05	0.1	0.05

a) Uncorrected for branching ratio to ground state.

Table I lists possible competing activities in the Z = 90-100 region, their half-lives, and calculated cross sections for both primary and final fragments. (The Cf half-lives were estimated from empirical systematics). Although the primary yields are seen to be strongly depleted by fission competition, calculated final cross sections are found to be of the order of 0.1 nb, comparable to those of Ref. 2.

These results suggest that the SF activities observed in similar reactions[2]) may be due at least in part to SF decay of known actinide elements and argue for a more unique atomic number identification of the products assigned to Z = 104-107.

*Research supported by U. S. Department of Energy.

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THE SYNTHESIS OF NEUTRON RICH NUCLIDES WITH HEAVY ION BEAMS ; OBSERVATION OF ^{54}Ti,^{56}V,^{58}Cr,^{59}Cr,^{61}Mn,^{63}Fe,^{64}Fe IN THE 8.5 MeV/u $^{40}Ar+^{238}U$ INTERACTION.

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Two strategies are now considered in the search for new neutron rich nuclides with heavy ions beams.

At very high bombarding energies (200 MeV/u), the reaction products labelled as spectators in the fire ball model exhibit, for a given element, a broad isotopic distribution extending far off the beta stability line. Thus, the choice of an already neutron rich projectile such as ^{48}Ca has recently allowed the formation of new neutron rich nuclides for elements below the projectile[1]). At high energy, the neutron richness of the projectile seems to be the most important parameter insuring the success of these synthesis (the target nucleus playing the role of a chopper).

At energies close to the interaction barrier, in the so-called deep inelastic collisions the reaction mechanism is quite different. It has been shown that the isospin degree of freedom reaches equilibrium very rapidly in the composite system[2]). Thus, one can take advantage of a target with a large N/Z in order to enrich with neutrons the interacting projectile or projectile-like nucleus. The bombarding energy must be carefully chosen in order to optimize the result of two counteracting effects : the production of the primary products and their deexcitation. Fig.1 shows some of the isotopic distributions where the seven nuclides ^{54}Ti,^{56}V,^{58}Cr,^{59}Cr,^{61}Mn,^{63}Fe,^{64}Fe were first observed in the 340 MeV $^{40}Ar+^{238}U$.

Furthermore, the influence of bombarding energy, and interaction time were investigated by comparing the isotopic distributions at different angles for 265 MeV and 340 MeV Ar beams.

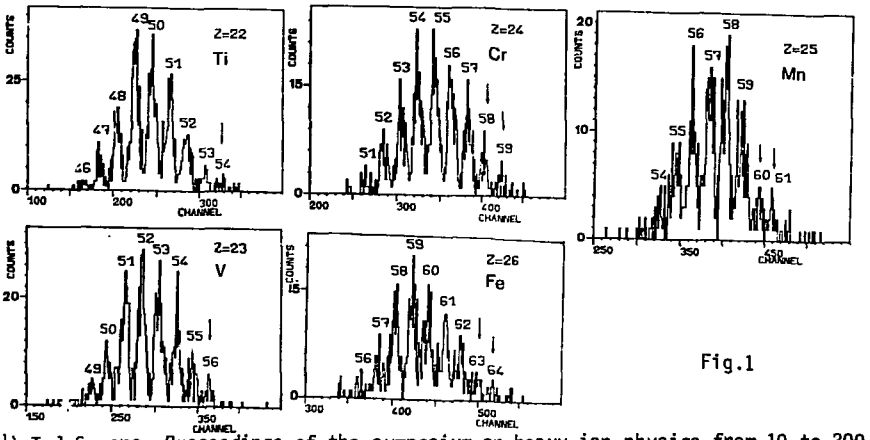


Fig.1

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PRODUCTION OF NEW, NEUTRON-RICH ISOTOPES IN 210 MeV/A ^{48}Ca + Be COLLISIONS[†]

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Fragmentation of relativistic nuclei has proven to be a powerful new technique[1]) for production of very neutron-rich nuclei. The fragments are typically emitted within about 1° of the original beam direction and very close to the beam velocity. By running this "beam" of projectile fragments through a magnetic spectrometer, rare neutron-rich isotopes may be isolated and analyzed.

Using the zero-degree spectrometer at the LBL Bevalac, we have measured cross sections for the production of extremely neutron-rich isotopes of C, N, O, F and Ne is projectile-fragmentation reactions of 210 MeV/A ^{48}Ca + Be. Fragments transmitted through the spectrometer are brought to rest in a large stack of Lexan detectors. Charge, mass and energy are determined from the track etch rate, magnetic deflection and range. Preliminary results indicate that at least one new isotope, ^{20}C, has been found and many other isotopes reported in ref. 1 have been confirmed. Final results on possible new isotopes and production cross sections will be reported.

[†]This work was supported by the Nuclear Science Division of the U.S. Department of Energy.

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OFF-SHELL EFFECTS IN KAON-NUCLEUS SCATTERING†

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The importance of the off-energy-shell kaon-nucleon (KN) interaction in kaon-nucleus elastic scattering is investigated. Paralleling previous pion studies[1]), different prescriptions (models) for the KN off-shell behavior are calculated and compared for K^{+}-^{12}C elastic scattering: 1) Kisslinger; 2) local Laplacian; 3) non-local, separable representation from inverse scattering theory. To fully assess the off-shell effects calculations will be performed at several energies for different sets of KN amplitudes which reproduce empirical KN scattering cross sections.

†Supported in part by the U. S. Department of Energy

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$\bar{K}$-NUCLEUS SCATTERING AND THE DYNAMICS OF THE $\Lambda(1520)$[†]

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The nuclear interactions of hadron resonances can be studied in meson-nucleus scattering. Most attention has centered on the lowest πN resonance, the $\Delta(1232)$, which has a free-space width of 120 MeV, and theoretical analysis has developed to the stage where quantitative information has been extracted from π-nucleus data. The lowest $\bar{K}N$ resonance is the $\Lambda(1520)$ which has a width of 16 MeV, by far the smallest of all πN or $\bar{K}N$ resonances. Because the width of the resonance sets the scale of sensitivity to the nuclear dynamics, $\Lambda(1520)$ formation and propagation are governed by the interplay between hadronic and nuclear degrees of freedom.

To analyze the physics of the $\Lambda(1520)$ in the nucleus, we use a microscopic isobar-hole approach. Both the D-wave nature of the resonance and coupling to the inelastic $\pi\Sigma$ channel are included. The parameters of the model are determined by fitting $K^- p$ scattering data, and the model includes binding and Pauli modifications in the nucleus. Non-resonant $\bar{K}N$ scattering is included in a first-order optical potential.

We have used the model to calculate K^--^{4}He scattering and investigate the role of a collective "doorway" state. The $\pi\Sigma$ channel is of particular importance in providing a mechanism for true $\bar{K}$ absorption on a single nucleon.

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[††]Dr. Chaim Weizmann Postdoctoral Fellow.

Y_0^* (1405) DYNAMICS IN KAONIC ATOMS

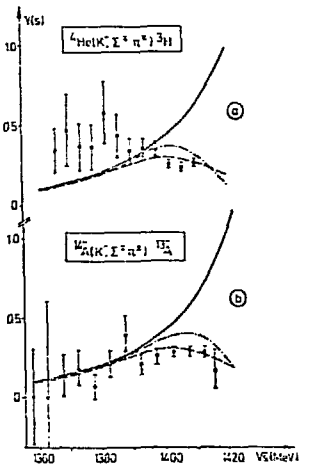
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It is well understood that the strange s-wave baryon-resonance Y_0^* (1405, $I = 0$, $J = 1/2^-$) - which is just 27 MeV below the free KN threshold - plays the dominant role in K^- absorption at rest on nuclei. Unfortunately, information on the Y_0^* dynamics in nuclei from an optical model analysis of the widths and shifts of kaonic atoms is scarce due to the strong influence of the $I = 1$ K^-N isospin channel. However, a quantity sensitive to the Y_0^* selfenergy is the ratio $f(s) = N(\Sigma^-\pi^+)/N(\Sigma^+\pi^-)$ of $\Sigma\pi$ pairs, emitted with the invariant $\Sigma\pi$ energy $\sqrt{s}$ after K^- absorption due to the opposite interference of the Y_0^* dominated $I = 0$ and the $I = 1$ background amplitude. Assuming a quasi-free production mechanism, the ratio for the nuclear production of $\Sigma^*\pi^*$ pairs is explicitly given by

$$f(s) = \left| \frac{t^0_{\bar{K}N}(s) + \sqrt{\frac{3}{2}}\, t^1_{\bar{K}N}(s)}{t^0_{\bar{K}N}(s) - \sqrt{\frac{3}{2}}\, t^1_{\bar{K}N}(s)} \right|^2$$

where, in this simple model, medium corrections enter only into the elementary K^-N isospin amplitudes, $t^I_{\bar{K}N}(s)$. If we parametrize the Y_0^* dominated part by a Breit-Wigner form, then a repulsive, energy dependent self energy for the Y_0^* of around 20 MeV (at the KN threshold) is needed to account for the data[1] (in the figure enclosed the dashed and the full line give $f(s)$ without or including a self energy correction for the Y_0^*).



In a microscopic meson exchange model various sources for such a repulsive shift - including K and π induced rescattering contributions and, as the leading agency, the Pauli-blocked $Y_0^* \rightarrow$ KN decay - are discussed.

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RADIATIVE CAPTURE OF KAONS ON HYDROGEN AT REST

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The reactions $K^-p \to \Lambda\gamma$ and $K^-p \to \Sigma^0\gamma$ at rest have been studied by searching for gammas from K^- stopping in a liquid hydrogen target. Gammas were detected in a 25 × 30 cm NaI detector surrounded by particle veto counters and Pb shielding. The experiment was carried out at the Cern PS. The spectra are being analysed to identify contributions from known sources, which are mainly π^0 decays. The experiment is a continuation, with improved sensitivity of the experiment carried out at Nimrod[1].

The implications of the results for the NYK coupling constant and the K^-p amplitudes at threshold will be discussed.

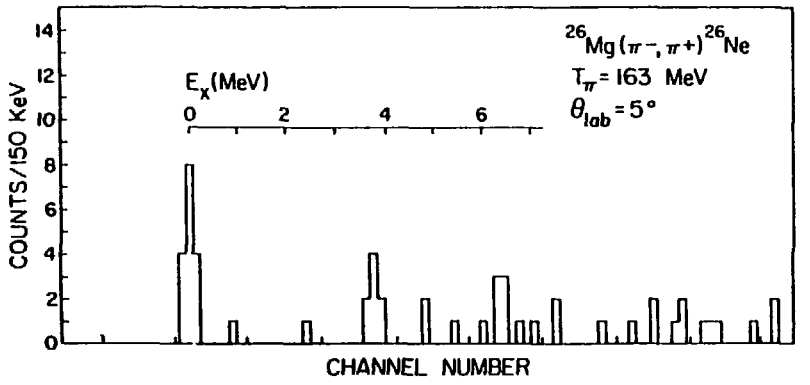
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MASS OF ^{26}Ne BY THE ^{26}Mg(π^-,π^+) REACTION*

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The mass of ^{26}Ne has been measured by the double charge exchange reaction ^{26}Mg(π^-,π^+)^{26}Ne at T_π = 162.75 MeV using the EPICS facility at LAMPF. The reaction ^{12}C(π^-,π^+)^{12}Be, with known Q_0 = -26.100 ± 0.015 MeV, was used for calibration to obtain Q_0 = -17.65 ± 0.08 MeV for the ^{26}Mg(π^-,π^+)^{26}Ne reaction. This Q-value corresponds to a mass excess of 0.42 ± 0.08 MeV for ^{26}Ne. This is to be compared with theoretical predictions of +0.30 MeV (Thibault and Klapisch, +0.17 MeV (Jelly), -0.27 MeV (Jelly), +0.13 MeV (Groote), +0.19 MeV (Janecke) and -0.06 MeV (Garvey-Kelson relations).



*Supported in part by the U.S. Department of Energy.
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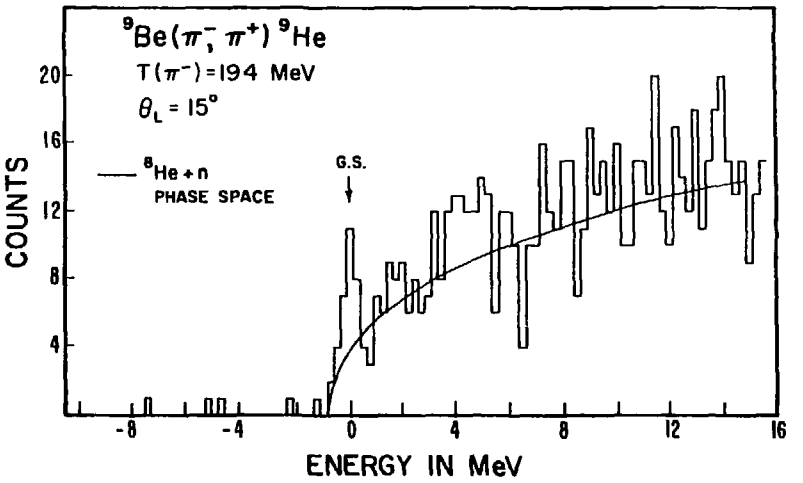
IDENTIFICATION AND MASS DETERMINATION OF ^{9}He

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The reaction ^{9}Be(π^-,π^+)^{9}He has been studied at the EPICS facility at LAMPF at T(π^-) = 194 MeV. A clear enhancement over ^{8}He + n phase space is observed at Q = -30.65 MeV and is interpreted as corresponding to the ^{9}He (g.s.). From this measurement it is concluded that ^{9}He(g.s.) is unstable to ^{8}He + n decay by 1.31 ± 0.20 MeV. This should be compared with predictions of B(n) = -2.36 MeV (Janecke), -2.94 MeV (Jelly), -3.82 MeV (Jelly), -3.08 MeV (Thibault and Klapisch).

Using the measured mass excess of ^{9}He in the transverse Garvey-Kelson relations, the mass excess of ^{10}He is predicted to be 49.40 MeV, i.e. it is predicted to be unbound with respect to two neutron decay by only 1.66 MeV.



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ANOMALOUS ENERGY SHIFTS IN MUONIC LEVELS OF ^{208}Pb*

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In light of recent work [1], we have reexamined the nuclear polarization (NP) correction for muonic Pb-208. All known states up to 8 MeV, including the near-resonant 6-8 MeV 1-, 2+ and 3- states that have recently been observed in (α,α'), (p,p'), (e,e') and (γ,γ') experiments, were included in the NP calculation, as were the giant resonances. Despite the use of various giant resonance parameters and widely differing transition charge densities, the calculations still display the following anomalies: 1) both 3d muonic levels are bound deeper by 150 eV than indicated by experiment [2], 2) the 2p levels are bound approximately 400 eV deeper than indicated by experiment, 3) the Δ2p splitting is larger by 200 eV than indicated by experiment. From a theoretical viewpoint, explanations of these discrepancies might be found in the reference spectrum method used in the NP calculation, in the Lamb shift correction, or in the vacuum polarization correction. However, calculations of the latter two corrections are in essential agreement with experiment in other levels of Pb-208 and in other nuclei [3]. The transverse interaction (defined in the Coulomb gauge), which was mentioned in ref. 1. as a possible explanation of the Δ2p discrepancy, has been investigated and found to have negligible influence. From an experimental viewpoint, it appears desirable to remeasure the values of the 4f-3d and 3d-2p transition energies. The table below shows the results of a typical calculation in which the Fermi charge distribution parameters have been adjusted to best fit the experimental energies [2,3]. The anomalies mentioned above are evident.

Transition	Experiment (MeV)	Calculation (MeV)	Transition	Experiment (MeV)	Calculation (MeV)
2p3/2-1s1/2	5.962770(420)	5.962804	4f5/2-3d3/2	0.971850(60)	0.972000
2p1/2-1s1/2	5.777910(400)	5.777750	4f7/2-3d5/2	0.937980(60)	0.938112
3d3/2-2p1/2	2.642110(60)	2.642195	5g7/2-4f5/2	0.437748(12)	0.437754
3d5/2-2p3/2	2.500330(60)	2.500227	5g9/2-4f7/2	0.431360(11)	0.431340

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* supported by U.S. Department of Energy
+ supported in part by Purdue University

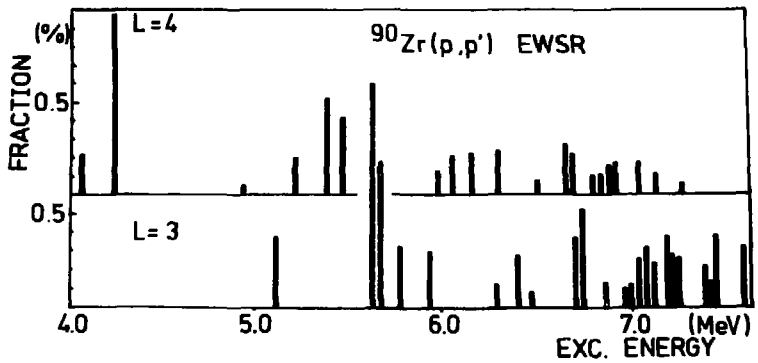
THE L=4 STATES IN LOW-ENERGY OCTUPOLE RESONANCE REGION OF ^{90}Zr

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Around an excitation energy of 30 $A^{-1/3}$, the so called low energy octupole resonance (LEOR) exhausting 20-30 % of the strength allowed by the energy-weighted sum rule (EWSR) has been observed in many nuclei using the (α, α') experiment[1-3]. A recent (p, p') experiment[4] has confirmed almost the same result in ^{90}Zr but as a result of the improved resolution (~80 keV), some structured nature of the LEOR has been suggested.

In this article we report on a high resolution ^{90}Zr(p, p') experiment for the lower half (E_{ex}=4~7.6 MeV) of the LEOR region. An isotopically enriched (~98%) ^{90}Zr foil of 490 $\mu g/cm^2$ was bombarded with 65 MeV protons from the RCNP AVF-cyclotron. The inelastically scattered protons were detected with a 1-m long position sensitive resistive-wire proportional counter at the focal plane of the spectrograph "RAIDEN". Data were taken at fourteen angles from θ_{lab}=10° to 63°. Over-all energy resolution was 15 keV. With this high resolution, many discrete individual levels were observed instead of the structure of a broad bump on the continuum. As a result of analysis, many discrete states of L=4 character were found in addition to the levels of L=3 character. The strength was derived for each level. The figure shows the distribution of EWSR fraction for the L=4 and L=3 states. The L=4 states found in the experiment exhaust 4.7% of the EWSR limit for the hexadecapole strength and the L=3 states 7.6% of the octupole strength. The concentration of L=4 states in this energy region is suggestive of a presence of the isoscalar hexadecapole resonence as is expected to exist from the RPA calculation[5].



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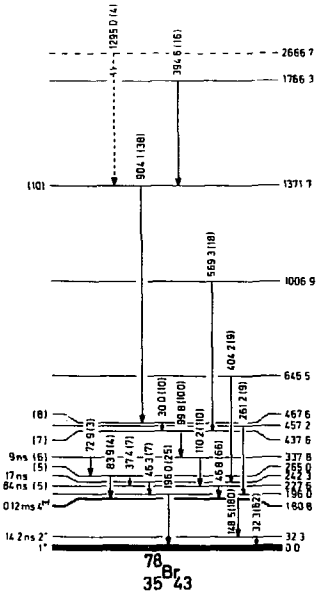
$\pi g_{9/2} \otimes \nu g_{9/2}$ STRUCTURE IN ^{78}Br

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Following the succesful description[1] of the correspondence found[2] between positive parity bands of $g_{9/2}$ parentage in ^{76}Br and ^{77}Kr, it is of interest to search for the same excitations in ^{78}Br and to study to which extent they are related to levels in ^{79}Kr.

The existence of a $\pi g_{9/2} \otimes \nu g_{9/2}$ band structure built on the known 4^+ isomer in ^{78}Br was recently investigated[3,4] and it is likely that some of the observed[4] levels correspond to the lowest multiplet expected from this system. In order to gain more information on this band structure a search for higher states in ^{78}Br was performed. The ^{77}Se(α,2np) reaction produced with the 30 to 55 MeV α-beam of the BA Synchrocyclotron was used in conjunction with conventional on-line γ-ray spectroscopy techniques. The level scheme in the figure summarizes the results. The levels up to 467.6 keV have already been reported[4,5]. Of particular interest is the 904.1 keV transition which exhibits quadrupole character and compares well with the $(11/2^+)$ to $7/2^+$ spacing in ^{79}Kr. In order to check the assumption that the sequence of levels with $I = 4, (5), \ldots (8)$ and (10) in ^{78}Br corresponds to a $\pi g_{9/2} \otimes \nu g_{9/2}$ rotational like structure a calculation, similar to that performed for ^{76}Br (Ref. 1), has been carried out. The model involves a non-interacting quasi-proton and neutron coupled to a rigid rotor. The neutron parameters were determined by fitting the positive parity band in ^{79}Kr. The deformation was taken as a mean value from that of the neighboring even-even cores. The main results of the calculation are: a) the 4^+, 5^+,... 8^+ members of the lowest multiplet, corresponding to almost vanishing rotation, lie within 300 keV (in contrast to 600 keV in ^{76}Br owing to the smaller deformation); b) the 9^+ state is pushed up about 0.5 MeV above the 8^+ state; c) the predicted spacing between the 10^+ and 8^+ state is 0.9 MeV. These results are fully consistent with the data and hence provide evidence for the validity of the present interpretation.



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HIGH-LYING EXCITATIONS IN ^{16}O WITH 1p-1h-STRUCTURE

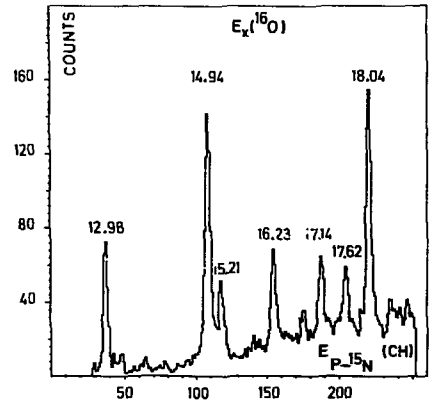
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In a kinematically complete experiment we have measured the reaction $^{14}N(^3He, p)\ ^{16}O^* \rightarrow p + ^{15}N^{gs}$ at the projectile energy $E_{^3He} = 13$ MeV. This reaction proceeds in two steps, the first of which is governed by a direct reaction mechanism. Since the target nucleus ^{14}N can be described in good approximation as a 2-hole structure relative to the closed shell nucleus ^{16}O mainly 1p-1h and 2p-2h states in ^{16}O are excited. With the subsequent decay into $^{15}N^{gs} + p$ a high selectivity for 1p-1h-structure in the intermediate ^{16}O system is expected for the whole reaction process. In the figure a projection of the phase space corrected Dalitz Matrix onto the $p - ^{15}N^{gs}$ relative energy axis is given, showing only a few prominent excited states in the intermediate nucleus. The ^{16}O excitation energies at the peaks are extracted from our experiment with an uncertainty of 30 keV.

For most of the observed intermediate states decay angular distributions have been measured in the reaction plane of the first step. The primarily emitted proton was detected at $\theta_{Lab} = 37.5^o$. The analysis of the angular correlation in terms of a series of modified Legendre polynomials leads to restrictions for the spin assignments of the decaying states. The order of the highest polynomial needed for the description of an angular distribution is limited by the value of the spin J of the decaying state or the orbital angular momentum ℓp of the decay proton whatever value is lower. The conclusions drawn from the fits agree with spin quantum numbers and structure assumptions as far as they are known from literature. Our results are: $J, \ell p \geq 1$ for the states at $E_x(^{16}O) = 12.98$, 16.23 and 17.14 MeV, and $J, \ell p \geq 2$ for the 17.62 MeV state.

For the two most prominently occuring states (14.94 and 18.04 MeV) the fit leads to the lower limits $J, \ell p \geq 3$. This implies for the structure of these states that the dominant component seen in this experiment has to be a particle in the $f_{7/2}$-shell and a hole in the $p_{1/2}$-shell. Thus we are forced by the results of our experiment to take into account 1p-1h states in ^{16}O with $2\hbar\omega$ excitations below commonly used estimations.



NEUTRON PARTICLE-HOLE STATES IN ^{132}Sn

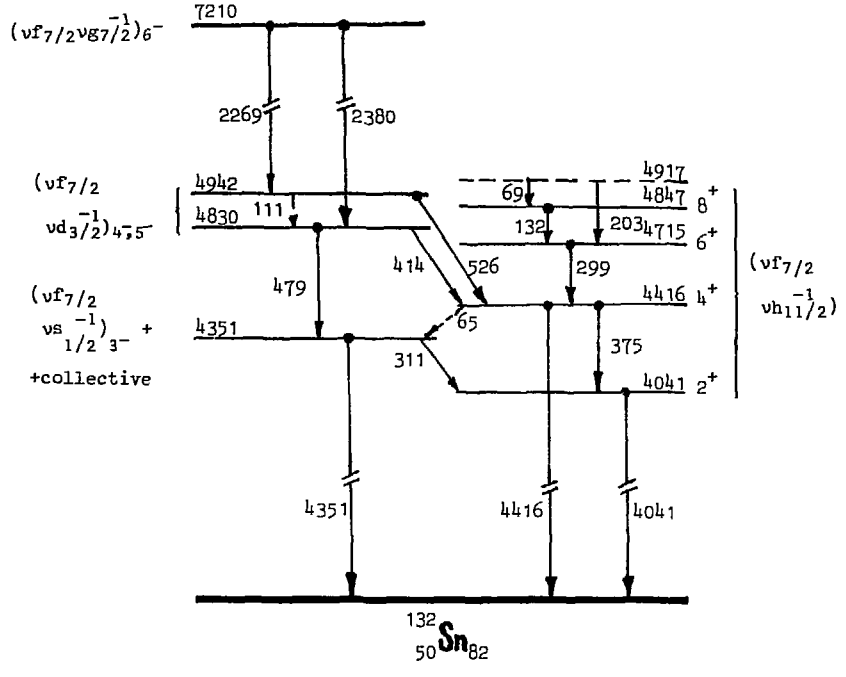
T.Björnstad, J.Blomqvist, G.T.Ewan, P.G.Hansen, B.Jonson, K.Kawade, A.Kerek, S.Mattsson and K.Sistemich (ISOLDE Collaboration)

The large energy from the ground state of the ^{132}Sn nucleus to its first excited state (4041 keV) indicates an unexpectedly high stabiligy of the Z=50, N=82 core. This doubly closed shell nucleus - the least investigated out of the seven existing - is only accessible through the fission process.

The present contribution reports preliminary results on excited states in ^{132}Sn and their interpretation. The experiments have been performed at the ISOLDE isotope separator by studying the β-decay of ^{132}In. The preliminary level scheme in the figure is based on singles and coincidence gamma ray and conversion electron measurements.

Excited states in a doubly closed shell nucleus are most easily formed by promoting one nucleon from an occupied shell to an empty shell. In ^{132}Sn the energy gap between the highest occupied shell and the lowest empty shell is around 5 MeV for neutrons and around 6 MeV for protons. The excited states should consist of a set of a particle-hole multiplets at the excitation energies of the single nucleon.

According to the shell model the beta-decaying ground state of ^{132}In has the configuration $(\nu 2f_{7/2}, \pi 1g_{9/2}^{-1})7^-$. The main decay should proceed by a Gamow-Teller transition transforming the $1g_{9/2}$ proton hole to a $1g_{7/2}$ neutron hole, analogous to the ^{131}In → ^{131}Sn decay. In ^{131}Sn the neutron hole then jumps from $1g_{7/2}$ to $2d_{3/2}$ with the emission of a 2429 keV E2 gamma ray. The 2380 and 2269 keV gamma rays in ^{132}Sn are candidates for similar transitions.



SEARCH FOR GAMOW-TELLER GIANT RESONANCE IN ^{90}Nb BY THE ^{90}Zr(^{3}He,t)^{90}Nb REACTION AT 90 MeV

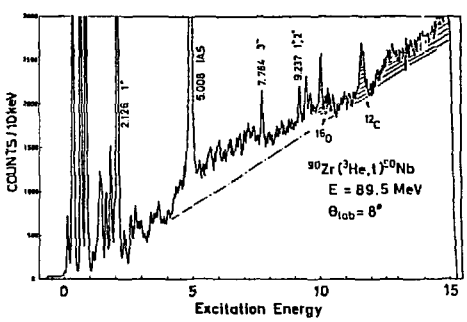
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Possible evidences for Gamow-Teller giant resonance have been obtained in the (p,n) and (^{3}He,t) charge exchange reactions on several nuclei[1,2,3]. However, considerable discrepancies still exist among the reported results[4,5] for the shape and energy, showing a necessity for a further detailed investigation.

We studied the ^{90}Zr(^{3}He,t)^{90}Nb reaction with a 90 MeV ^{3}He beam from the 230 cm AVF cyclotron at RCNP, Osaka University. The tritons were momentum analyzed by the high resolution spectrograph RAIDEN, and detected by a 1.5 m position sensitive proportional counter. The overall resolution was about 60 keV, which was limited by the thickness of the target used (2 mg/cm^2). Data were taken at scattering angles up to 30° including the beam direction.

The figure shows a typical triton spectrum obtained at θ_{lab}=8°. It may be clear that there appears a broad bump near the intense IAS 0$^+$ peak, covering the energy range of 4.5∿10 MeV. This is in at least qualitative agreement with the previous results. In the present data, however, the bump is seen to be composed of many discrete levels. From the energies and angular distributions, some of the distinct levels were identified as excited analog states of the parent ^{90}Zr. Examples are 7.237 MeV (2$^+$), 7.764 MeV (3$^-$) and 9.237 MeV (1$^+$ or 2$^+$) states. The most of the other weak levels in this region were observed to show an angular distribution consistent with that of the 2.126 MeV 1$^+$ state. Although there still is a possibility that a small fraction of the levels may not have a same J^π, the intensities of the weak peaks (not including analogs) were summed up to give a measure of the cross section of the GT giant resonance. This yielded a value roughly in agreement with the theoretical prediction. These results strongly suggest that the weak states around 0$^+$ IAS actually form a GT giant resonance, with the strength being concentrated in the energy region of E_x=4.5∿7.5 MeV in ^{90}Nb. It is of interest to note that the 9.237 MeV analog state might make a candidate for the $T_>$ component of the GT resonance. The relative yield of this state to the area under the bump is about 0.1, which, indeed, is very close to the expected ratio of $1/(2T_0-1)$. The detailed (p,p') experiment to search for the 1$^+$ state in ^{90}Zr would be valuable in confirming the situation.



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DROPLET MODEL FOR GIANT 2^{λ}-ELECTRIC RESONANCE

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The droplet model applied to the giant resonance[1] was succesful for explaining the A-dependence of resonance energies and the form factor of inelastic electron scattering experiments[2]. Here we generalize the treatment for Eλ resonances, including corrections due to the Coulomb, surface and higher order terms of droplet parameters, which improve slightly for the dipole resonance. The nuclear density distribution is parametryzed in order to represent the Steinwedel-Jensen and Goldhaber-Teller modes, as

$$\rho^{\lambda}_{N,Z}(r,\theta,\phi,t) = \rho^{o}_{N,Z}\left[1+N_{\lambda}b_{\lambda\mu}(t)j_{\lambda}(kr)Y_{\lambda\mu}(\theta,\phi)\right]\Theta\left[r-R_{N,Z}(\theta,\phi,t)\right]$$

$$R^{\lambda}_{N,Z}(\theta,\phi,t) = R^{o}_{N,Z}\left[1+a_{\lambda\mu}(t)Y_{\lambda\mu}(\theta,\phi)\right]$$

where N_{λ} is the normalization factor chosen to give the same 2^{λ}-multipole moment for the same displacement of a_{λ} and b_{λ}. For isovector resonances, the elements of inertia and stiffness matrices are given by:

$$B_{11}=B_o S(1+2\varepsilon)/\lambda \quad ; \quad B_{12}=B_{21}= B_o S(1+2\varepsilon-1\eta)/\lambda \quad ; \quad B_{22}=B_o S g_{\lambda}(1+2\varepsilon-2I\eta)/2$$

$$C_{11}= \frac{2}{3} HA^{4/3}(1+4\varepsilon) + 2E_c\left(\frac{N}{A}\right)^2 \frac{(1-\lambda)}{(2\lambda+1)}\left(1-\varepsilon+3\frac{N}{A}\eta\right)$$

$$C_{12}=C_{21}= \frac{4}{3} PAS\ \alpha_{\lambda}^2(1+3\varepsilon+3I\eta) + \frac{2}{3} a_2 A^{2/3}.$$
$$\alpha_{\lambda}^2 \frac{S}{\lambda}\left(1+2\varepsilon+2\frac{N^2-2Z^2}{A^2}\eta\right) + E_c\left(\frac{N}{A}\right)^2 q_{\lambda}.$$
$$\left(1-\varepsilon+\frac{N+A}{A}\eta\right)/2$$

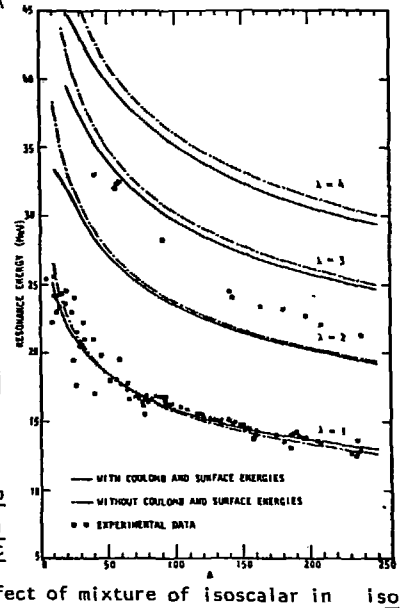
$$C_{22}= 4JAS^2\alpha_{\lambda}^2 g_{\lambda}(1+3\varepsilon+6I\eta) - \frac{8}{3}GA^{2/3}S^2.$$
$$\alpha_{\lambda}^4/\lambda^2.(1+2\varepsilon+6I\eta) + \frac{3}{2}E_c g_{\lambda}\left(\frac{N}{A}\right)^2.$$
$$\left(1-\varepsilon+\frac{Z+A}{A}\eta\right)$$

where, $S=NZ/A^2$, $I=(N-Z)/A$, $\eta=t/R_o$

$g_{\lambda}=[\alpha_{\lambda}^2-\lambda(\lambda+1)]/\lambda^2$, $q_{\lambda}=[15(3\lambda+1)-2(2\lambda+1)\alpha_{\lambda}^2]$

$/[5\lambda(2\lambda+1)]$, $E_c=Z^2e^2/(r_o A^{1/3})$,

$B_o= m_{eff} r_o^2 A^{5/3}$ and t,ε,P,H,J,G are the droplet parameters. The resonance energy is calculated as in ref.1) (see figure). The effective mass seems to assume a smaller value for quadrupole than the dipole case. The effect of mixture of isoscalar in isovector modes is found to be very small.



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$Z^{-1/3}$ LAW FOR ENERGIES OF THE GIANT RESONANCES IN NUCLEI

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It is well known that the experimental data of the giant resonance systematically deviates from the $A^{-1/3}$ law. Motivated by the superior $Z^{-1/3}$ law than the $A^{-1/3}$ law for the nuclear charge radius[1], we have found that for the energies of the isoscalar (monopole and quadrupole) giant resonances the agreement with the experiment is excellent if

$$E = 49\ Z^{-1/3}\ \text{Mev}\ (GQR, \Delta T = 0) \tag{1}$$

$$E = 60\ Z^{-1/3}\ \text{Mev}\ (GMR, \Delta T = 0) \tag{2}$$

The situation is not so simple for the energies of the isovector giant resonances, since they are related also with the symmetry energy as well. For the isovector giant dipole resonance (GDR, $\Delta T=1$), we start with the Steinwedel-Jensen mode, in which the resonance energy can be expressed as

$$E = \frac{2.08\ \hbar c}{R} \sqrt{\frac{a_{sym}}{2M}}\ A^{(1-\alpha)/2} \tag{3}$$

if the symmetry term in the nuclear mass formula is written as $a_{sym}\frac{T^2}{A^{\alpha}}$. For $\alpha=1$, we obtain the conventional formula, which gave the $A^{-1/3}$ dependence. According to the mass formula we have presented[2], the best fit between the experimental mass data and the formula can be obtained if $\alpha = 0.9$ and $a_{sym}=45.86$ Mev. While we take $R = r_0 Z^{-1/3}$ ($r_0 = 1.64$ fm) as in the isoscalar case, we obtain

$$E = C\ Z^{-1/3}\ A^{0.05} \tag{4}$$

which is in excellent agreement with the experiment if $C = 45$ Mev. This value can be calculated by Eq.(3) when we regard M as the effect mass instead of the real mass of the nucleon m, and $M = 0.75\ m$ as suggested by Myers and Swiatecki.

For the other isovector giant resonance, up to now, only some experimental data exist for GQR($\Delta T=1$). In a similar manner we can get $E = C'\ Z^{-1/3}\ A^{0.05}$ with $C' = 74$ Mev. Again, it is much superior than the $A^{-1/3}$ law.

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LEVELS OF ^{26}Al EXCITED THROUGH THE ^{27}Al(^{3}He,α) REACTION

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The ^{26}Al nucleus represents an interesting case being in the transition region of deformed light nuclei; the nature of its states is not yet completely understood. The ^{27}Al(^{3}He,α) reaction has been used to investigate the level scheme of ^{26}Al in the less known region of higher excitation energies.

Energy and angular distributions of α-particles were measured with a ΔE - E telescope and a Goulding identification scheme, in 3° steps over the angular range 17° - 80°, for a bombarding energy of 30 MeV. Measured spectra present a continuous part due to the preequilibrium emission, on which some peaks are superposed. The peak energy location is in agreement with the existing data for the case of lower excitation energies [1].

New states of ^{26}Al located at higher than 5.0 MeV excitation energies were found in the present measurements namely : 6.21 MeV; 8.64 MeV; 9.77 MeV; 10.04 MeV; 10.80 MeV; 11.69 MeV; 12.57 MeV; 13.46 MeV; 14.74 MeV and 15.59 MeV. Some of them (10.04 MeV; 10.80 MeV and 11.69 MeV) were identified as isobaric analogues to states in the ^{26}Mg nucleus [1]. This statement is supported on one side by the energy location of the involved states leading to values of the Coulomb displacement energy in agreement with the theoretical value and also with the one obtained for the first four analog states of the ^{26}Al - ^{26}Mg isobaric pair. [2] On the other hand spin assignments and spectroscopic factors obtained from a DWBA analysis confirm the identification of the above mentioned states as isobaric analogs. Another interesting result is the identification of a new low - lying negative parity state at 6.21 MeV.

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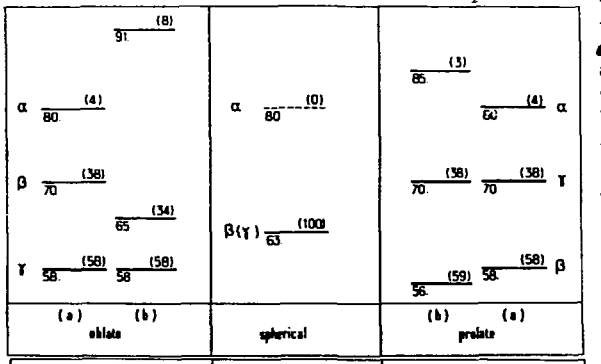
ON THE FRAGMENTATION OF THE ISOSCALAR STRENGTHS IN DEFORMED NUCLEI

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In a previous work (Phys.Rev.Lett.39 (1977) 922) we have performed a complete study of the monopole (α), axial (β) and non-axial (γ) quadrupole vibrations using the generator coordinate theory and the scaling assumption. We have thus shown that in light deformed nuclei the deformation has a predominant influence in the fragmentation of the quadrupole strength and that a realistic treatment must consider the coupling between the various modes of vibrations. These detailed calculations which are extremely lengthy cannot be extended to medium and heavy nuclei. We have thus consider a simplified treatment of the coupled vibrations based on the cranking method which allows to explain clearly the mechanism of the fragmentation of the giant monopole and quadrupole resonances in deformed nuclei. We were thus able to derive in a fairly interaction independent way general expressions for the positions of the GMR and GQR peaks as well as the fragmentation of the respective sum rules (figs. 1 and 2).

Fig. 1. Fragmentation of the giant quadrupole resonance in axial nuclei(equilibrium deformation taken to be $|\beta_{eq}| = 0.3$). Results obtained in the cranking model a) the three vibrations α, β, γ, uncoupled b) all three vibrations coupled. The excitation energies are in units $A^{-1/3}$ MeV. The isoscalar E2 strengths are shown in parentheses (in percent of the EWSR).



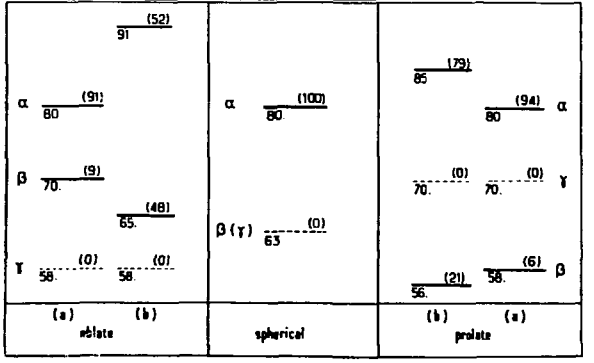


Fig. 2. Fragmentation of the isoscalar monopole strength.

ENERGY SYSTEMATICS OF M1 and E1 ISOVECTOR GIANT RESONANCES OBSERVED[†] IN (p,n) REACTIONS

W. Sterrenburg, S. Austin, R. DeVito, and A. Galonsky

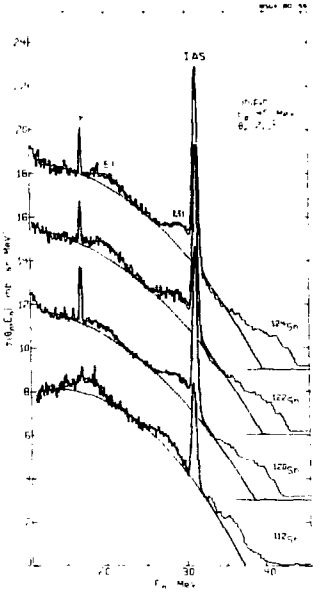
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Neutron spectra resulting from bombardment with45-MeV protons were measured at a forward angle on 17 targets between ^{90}Zr and ^{208}Pb. Spectra from targets of four Sn isotopes are shown in the figure.

Three features are common to the spectra: (1) a sharp peak representing the isobaric analog of the target ground state (IAS), (2) a broad peak, FWHM=3-4 MeV, at slightly higher, but target-dependent, excitation energy (M1), and (3) a similarly broad peak ~10 MeV higher than (2)(E1). The dependence of these energies on (N-Z)/A shows that the broad peaks are related to states in the target not as analogs but, more likely, as $T_<$ or anti-analogs of target states. Proposed parents for (2) and (3) are the giant M1 (or Gamow-Teller)[1]) and giant E1 states. If the E1 assignment is correct, the T, T-1 splitting is experimentally determined for the first time. E_T is obtained by Coulomb displacement of the giant dipole resonance (GDR) from the parent nucleus. E_{T-1} is the energy of the observed neutron group above the IAS. The resulting values, $\Delta E = E_T - E_{T-1}$, are given in the table.

Target	ΔE (MeV)
^{90}Zr	2.2
^{91}Zr	2.0
^{92}Zr	1.7
^{94}Zr	2.0
^{96}Zr	2.1
^{93}Nb	2.0
^{94}Mo	1.7
^{96}Mo	2.5
^{97}Mo	2.2
^{98}Mo	2.4
^{100}Mo	
^{112}Sn	2.7
^{116}Sn	2.5
^{120}Sn	3.6
^{122}Sn	4.3
^{124}Sn	4.6
^{208}Pb	4.5

Isospin Splitting of the GDR



[†]This work was supported by the National Science Foundation.

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ISOVECTOR GIANT RESONANCES IN ^{90,92,94}Zr(p,n) AT 80, 120, and 160 MeV[†]

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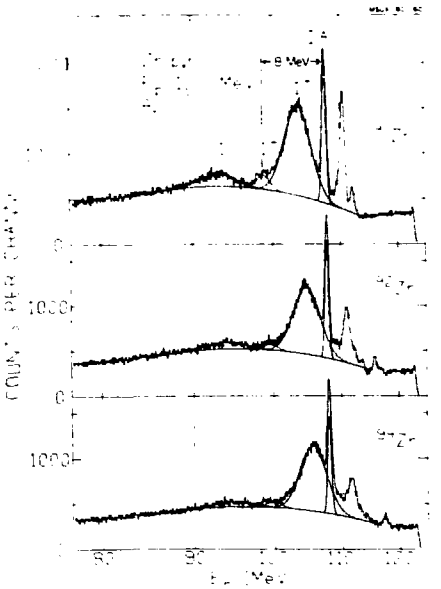
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Spectra for the above reaction were obtained with the beam-swinger, time-of-flight system at Indiana U. The 0° spectra obtained at 120 MeV are shown in the figure. The two sizeable broad peaks, labeled 1^+ and 1^-, were previously observed with 45-MeV protons,[1] but they are more prominent at 120 MeV. The angular distributions of the peaks are very different from each other. The lower peak has the ℓ=0 shape of the IAS, whereas the upper peak has an ℓ=1 shape; hence, the tentative J^π assignments. These peaks may represent the T-1 components (or antianalogs) of the giant M1 and E1 resonances. As at 45 MeV, the peaks move to lower excitation energies as N-Z increases.



The smaller peak labeled 1^+ corresponds, in this interpretation, to the analog, having isospin T, of the giant M1 state in ^{90,92,94}Zr. Isospin vector geometry greatly gavors the (p,n) transition to the T-1 component over the T component. If the interpretation is correct, we have a direct measurement of the M1 isospin splitting in three Nb isotopes. The splitting is then about 4.5 MeV in ^{90}Nb (topmost spectrum) and can be seen to increase slightly as N-Z increases. This behavior favors the interpretation given.

[†]Supported by the National Science Foundation and the Department of Energy.

1. W. Sterrenburg, S. Austin, R. DeVito, and A. Galonsky, contribution to this Conference.

RADIATIVE CAPTURE OF POLARIZED NEUTRONS BY ^{3}He

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We have measured the 90° cross section for the ^{3}He(n,γ)^{4}He reaction for neutron energies of 6.0 to 14.5 MeV, corresponding to excitation energies (E_x) of 25.1 to 31.5 MeV in ^{4}He. A pulsed fast neutron beam was produced with a chopped and bunched deuteron beam incident on a deuterium gas cell. The gaseous ^{3}He target consisted of a 1/16" thick stainless steel container filled to a pressure of 118 ATM. A seven angle angular distribution was obtained at $E_n(E_x)$=9.0(27.3) MeV. A preliminary analysis indicates a surprisingly large a_1 coefficient of $\sim$-0.2, comparable in magnitude with that observed at $E_p \sim 9.0$ MeV in the T(p,γ)^{4}He reaction.[1)]

Data have also been obtained using a polarized neutron beam produced via the D($\vec{d}$,n)^{3}He reaction. Analyzing powers obtained at E_n=9.0 MeV at 55°, 90° and 125° indicate the presence of a small b_2 coefficient similar in magnitude to that observed in the T($\vec{p}$,γ)^{4}He experiment[1)]. These data will be used to estimate the strength of the triplet (S=1) E1 transition matrix element.

+Work partially supported by the U.S.D.O.E.
++Physics Department, University of Saskatchewan, Saskatoon, Saskatchewan
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ISOVECTOR GIANT MONOPOLE RESONANCES: A SUM RULE APPROACH

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Probably the most sophisticated way to describe the isovector giant monopole resonance (IVGMR) consists in a consistent HF+RPA calculation in the coordinate space. Although these calculations are feasible, they are technically difficult and hence often poorly approximated. The advantage of sum rule techniques consists in the fact that certain moments $m_k(Q) = \Sigma\, (\hbar\Omega_\alpha)^k\, |\langle\alpha|Q|0\rangle|^2$ of the RPA strength distribution can rather be evaluated by simple HF- and adiabatic time dependent HF means. If one takes[1]) for the IVGMR the $Q = \Sigma\, r_i^2 \tau_{zi}$, one obtains $m_{-1}(Q)$ and $m_{-3}(Q)$ by performing a CHF calculation, $\delta\langle\lambda|H-\lambda Q|\lambda\rangle = 0$ and by evaluating the polarizability, $m_{-1} = 1/2\ \partial/\partial\lambda\langle\lambda|Q|\lambda\rangle$, and the ATDHF-mass, $m_{-3}(Q) = 1/2\ M(\lambda)$. Together with values of Auerbach et al.[2]) for $m_1(Q)$ and $m_3(Q)$ one can determine the even moments $m_{-2}(Q)$, $m_0(Q)$, $m_2(Q)$ by determinantal inequalities of refs. 4,5.

The calculations are performed in the coordinate space of (equivalently) in a basis of >25 harmonic oscillator shells using the Skyrme-3 interaction, which has a reasonable symmetry energy of 28.1 MeV. The inequalities determine m_{-2} and m_{+2} up to 8 % and m_0 up to 2 % accuracy. The final results[4]) concerning the centroid energy, $\hbar\Omega_0$, and various candidates for the peak energies, $\hbar\Omega_k$, are given in table 1. The $\hbar\Omega_k$ differ very much from each other

		^{16}O	^{40}Ca	^{90}Zr	^{208}Pb
$\hbar\Omega_0 = m_1^{RPA}/m_0^{RPA}$	[MeV]	33.2±0.8	32.7±0.8	32.6±0.5	27.6±0.4
$\hbar\Omega_{-1} = (m_{-1}^{RPA}/m_{-3}^{RPA})^{1/2}$	[MeV]	25.1	25.0	26.7	19.3
$\hbar\Omega_1 = (m_1^{RPA}/m_{-1}^{RPA})^{1/2}$	[MeV]	32.1	31.8	32.1	26.8
$\hbar\Omega_3 = (m_3^{RPA}/m_1^{RPA})^{1/2}$	[MeV]	40.6	38.6	35.8	30.5
$\hbar\Omega_p$	[MeV]	32.8	32.0	31.8	26.1
σ	[MeV]	12.3	10.6	7.9	7.1

since the variance σ of the distribution is very large corresponding to a FWHM of $\sim$2.35 σ. The $\hbar\Omega_p$ is the average over the above energies and is close to the peak energy. With an error of ±2 MeV it can be approximated by $\hbar\Omega_p \simeq 46\ A^{-1/3}$. Apparently the IVGMR lies highly in the continuum with a FWHM of more than 16 MeV. Hence it will be difficult to establish a direct evidence for its existence.

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Surface Symmetry Energy and The Dipole Giant Resonance.

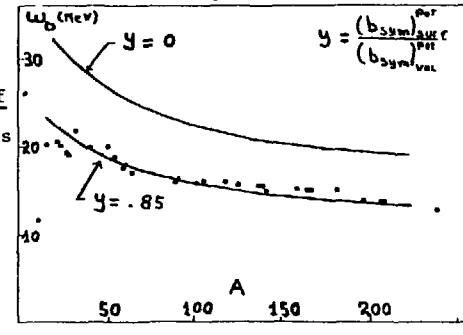
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In this work we discuss the role of the symmetry energy in the giant dipole resonance [1], with particular emphasis to surface effects. We use a microscopic approach for the collective motion and we assume scaling deformations for the isovector density $\rho_1 = \rho_n - \rho_p$: $\delta\rho_1 = \text{const}\ \frac{\partial \rho}{\partial z}$. Starting from a very general energy functional we derive the following formula for the mean excitation energy:

$$\omega_D = \sqrt{\frac{1+K_D}{3mA}\left[\frac{m}{m^*}\int \nabla^2 V\, \rho\, d\vec{r} + \int v_{sym}\, |\vec{\nabla}\rho|^2 d\vec{r}\right]}$$

where K_D is the enhancement factor of the TRK sum rule, m^* is the effective mass, V is the average 1-body potential and v_{sym} enters in the symmetry energy potential $U_{sym} = \frac{1}{2}\int v_{sym}\, \rho_1^2\, d\vec{r}$. The first term (V) results from the one-particle excitation energies, while the second term (v_{sym}) gives the effect of the interaction. In the figure we have plotted ω_D by assuming Woods-Saxon shapes for V and ρ , for two different choices of v_{sym} : 1) $v_{sym} = \frac{1}{4}\frac{V_1}{\rho}$ 2) $v_{sym} = \frac{1}{4}\frac{W_1}{\rho} + b_1$. Choice 1) reproduces the volume term in the semi-empirical mass formula and does not give surface terms; choice 2) gives either volume and surface contributions to the symmetry energy $E^{pot}_{sym} = \frac{1}{2}\frac{(N-Z)^2}{A}\left[(b_{sym})^{pot}_{vol} - \frac{1}{A^{1/3}}(b_{sym})^{pot}_{surf.}\right]$. The fig. clearly shows that the surface symmetry energy, though scarcely affecting the total binding energy, is crucial to reproduce correctly the energy of the dipole mode in the whole nuclear table.



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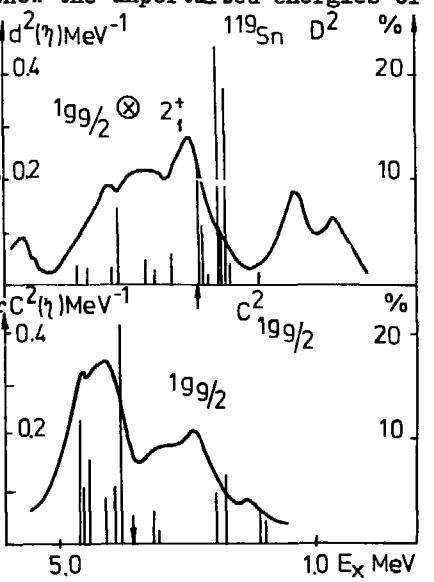
STRENGTH DISTRIBUTION OF THE $1g_{9/2}$ -HOLE STATE AND $1g_{9/2}\otimes 2^+_1$ CONFIGURATION IN ^{119}Sn

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Strength dictribution of quasiparticle (α^+) and quasiparticle+phonon components has been studied within the quasiparticle-phonon model[1]. The wave function of excited states includes α^+ , α^+Q^+ , $\alpha^+Q^+_1Q^+_2$ components.

The vertical lines in the figures show the strength distribution of the $1g_{9/2}$ neutron hole state and $1g_{9/2}\otimes 2^+_1$ configuration in the case when the $\alpha^+Q^+_1Q^+_2$ components are not included in the wave function of the excited states. The curves show the influence of these components on the $1g_{9/2}$ ($C^2(\eta)$) and $1g_{9/2}\otimes 2^+_1$ ($d^2(\eta)$) strength distribution. The strength function $C^2(\eta)$ is related to the spectroscopic factor S_j : $S_j = (2j+1)\int_{\Delta E} C^2(\eta)\,d\eta$. The arrows show the unperturbed energies of the $1g_{9/2}$ state and $1g_{9/2}\otimes 2^+_1$ configuration.



As has been mentioned earlier[2] swiching on of the $\alpha^+Q^+_1Q^+_2$ components in the wave function of the ^{119}Sn excited states results in the redistribution of the $1g_{9/2}$ strength. In the energy region 6.5-8.5 MeV the second peak exists and 33% of the $1g_{9/2}$ strength is concentrated in this region. The influence of the $\alpha^+Q^+_1Q^+_1$ components is more important for the distribution of the $1g_{9/2}\otimes 2^+_1$ strength. At energies higher than 9 MeV more than 20% of the full strength of this configuration is shifted. The low-energy part of the spectrum is also changed considerably.

The calculation of the distribution of strength of the α^+Q^+ components of the wave function gives a possibility to calculate microscopically the γ -transitions from the neutron binding energy region to the ground state and also the widths of the giant resonances in the odd spherical nuclei.

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THE EFFECTS OF CORE POLARIZATION

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We use nuclear field theory (NFT) to treat the self-energy correction of single particle and phonon given by diagrams in Fig.1 and Fig.2 and their exchange diagrams.

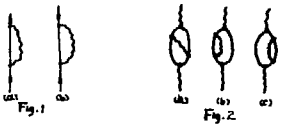


Fig.1

Fig.2

For ^{208}Pb, in performing RPA calculation, the single particle levels near fermi surface (one major shell above and one below) are taken from experiment and the other levels are constructed with a standard spherical harmonic oscillator (10 major shells for proton and 11 major shells for neutron). the coupling constants are determined by self-consistancy condition given by Bohr and Mottelson. The phonons for $\lambda \leq 6$ are calculated.

The energy corrections of single particle level shown in Fig.1 and of phonon($\lambda=2$) shown in Fig.2 are calculated with the elementary modes mentioned above. The results show that, for single particle state, the average distance between the two major shells is greatly reduced: 2.1 MeV for neutron and 3.7 MeV for proton; for the phonon($\lambda=2$), the diagrams (b) and (c) in Fig.2 give more contribution (-1.03 MeV), but the contribution from diagram (a) in Fig.2 is nearly neglegible (-0.09 MeV). However, since the experimental single particle levels near the fermi serface are taken, so the diagrams (b) and (c) in Fig.2 should disappear in the renormalized NFT. In this case, the correction of RPA phonon is rather small.

We have also solved the secular equations obtained from Dyson equation (partial summation) when only single particle levels near fermi serface are considered. The results show that the contributions from high order diagrams are unimportant in the region of ^{208}Pb.

FEW-QUASIPARTICLE COMPONENTS OF THE WAVE FUNCTIONS AT LOW, INTERMEDIATE AND HIGH EXCITATION ENERGIES

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To comprehend the structure of atomic nuclei it is useful to represent the wave functions of excited states as an expansion over a number of quasiparticles and phonons. The square of each coefficient of this expansion determines a fraction of time of the nucleus in a certain configuration. The fraction of time of the nucleus in the one-quasiparticle or one-phonon configuration decreases exponentially with increasing excitation energy. The quasiparticle-phonon nuclear model[1] allows the calculation of the fragmentation of a few-quasiparticle states at different excitation energies.

Based on the calculations and the corresponding experimental data, the following conclusions about the behaviour of a few-quasiparticle components of the wave functions can be made:

1) The wave functions of the low-lying states contain one dominating component which is studied experimentally and well described.

2) With increasing excitation energy the fragmentation of these components becomes stronger, and at 5-8 MeV they appear as substructures in the one-nucleon transfer reactions. A good description of the experimental data on the fragmentation of deep-hole states in spherical nuclei has been obtained in ref.[2]

3) The one-quasiparticle components in the wave functions of the neutron resonances comprise 10^{-4}-10^{-6}. The neutron and some partial radiative strength functions are determined by the one-quasiparticle or one-phonon components. They are well described within the quasiparticle-phonon nuclear model[3].

4) At the excitation energies higher than the neutron resonances the fragmentation appears as substructures in the reaction cross sections[4].

5) The position and widths of the giant resonances are determined by the fragmentation of one-phonon states[5].

The most reliable nuclear properties are determined by the behaviour of a few-quasiparticle components of their wave functions. The information on many-quasiparticle components, except for the high-spin states, is very scarce. A subsequent step is to study the main regularities of the fragmentation of many-quasiparticle components of the excited state wave functions.

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THE SPREADING WIDTHS OF GIANT RESONANCES

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The giant resonances are quite broad, showing a full width half maximum Γ of 2-10 MeV [1]. To lowest order, the giant modes can be described in the Random Phase Approximation, that is as a linear combination of 1 particle-1 hole (1p-1h) excitations on a correlated ground state. In these RPA calculations the continuous spectrum can be included, to study the particle escape widths of the giant resonances. To obtain the spreading width, we have to include the coupling of the RPA state to the (2p-2h) excitations. We are [2] mainly considering one type of (2p-2h) states, allowing one (1p-1h) to be all RPA collective and non-collective roots associated with the isoscalar normal parity vibrations of different multipolarity. In this scheme, we are calculating the strength functions of the giant resonances in different nuclei, that is in ^{208}Pb, ^{120}Sn, ^{90}Zr, ^{40}Ca and ^{16}O. For each nucleus, we start from a Hartree--Fock single-particle field obtained with the Skyrme 3 force and then we determine the properties of the low-lying collective states and of the giant resonances in the RPA. The strength of the residual (1p-1h) separable interaction we use, is chosen to bring the isoscalar dipole state at zero energy [2]. Three leading terms contribute to the square of the matrix elements coupling the RPA giant vibrations to the above discussed (2p-2h) excitations. Two terms represent the processes in which either the particle or the hole of the (1p-1h) components of the giant modes is damped by bouncing inelastically off the nuclear surface, exciting a surface vibration. They are related to the spreading widths of the particle and of the hole, but they have to be calculated with the appropriate energy-dependence. The third term describes the exchange of a vibration between the particle and the hole. In the case of the exchange of an isoscalar normal parity vibration of multipolarity λ this term tends to reduce the coupling [2]. In fact, the intermediate phonon samples the λ-multipole moment of the particle and of the hole. For collective states like the giant resonances, they are opposite in sign, the resulting static value being small. The centroids and the standard deviations σ of the calculated strength functionscan be compared with the experimental data for the excitation energy and Γ. Actually, it is not obvious how to compare σ with Γ, only for a gaussian shape being Γ=2.36 σ.The calculated value in MeV of σ for the giant quadrupole resonances are equal to 1.16 (^{208}Pb),1.7 (^{120}Sn), 2.08 (^{90}Zr), 1.95 (^{40}Ca), 2.8 (^{16}O), the experimental values of Γ being respectively 3.6, 4.0, 4,0, 3.5 and 7.5 (±0.5) MeV. For the giant monopole states, the values of σ are 0.7 in ^{208}Pb and 1.4 in ^{90}Zr, the experimental widths being of the order of 3 MeV. For the giant octupole in ^{208}Pb, we obtained σ=2.14 MeV. The calculations for the giant dipole states are in progress. The calculated values for the centroids will be discussed in [2]. Owing to the strong coupling associated with the low-lying collective excitations like the octupole states, a structure seems to be present in the strength functions, which should have consequences in the relative population of final states after particle emission.

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DYNAMICAL THEORY OF VIBRATION*

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A dynamical theory of vibration has been proposed[1] which points out the coupling of particles to vibrations and the coupling of vibrations to vibrations leads to ω-dependent effects which are extremely important for understanding of vibrations. These ω-dependent effects directly imply that the single particle strengths will be split up leaving the spectroscopic factors of states substantially less than unity, which is easy to see from the relations

$$Z_\nu = \{ 1 - \frac{\partial \Sigma_{\nu\nu}(\omega)}{\partial \omega} \Big|_{\omega = E_\nu} \}^{-1} ,$$

$$\text{and } - \frac{\partial \Sigma_{\nu\nu}(\omega)}{\partial \omega} = \sum_{\nu'\mu} \{ |(1-n_{\nu'}) \frac{\gamma^{\mu}_{\nu\nu'}}{\omega - E_{\nu'} - \varepsilon_\mu}|^2 + |n_{\nu'} \frac{\gamma^{\mu}_{\nu'\nu}}{\omega - E_{\nu'} + \varepsilon_\mu}|^2 \} .$$

In this work we calculate the spectroscopic factors of ^{208}Pb ± 1 nuclei. In addition to a zero-range interaction of the type used in Fermi-liquid theory, we employ the one-pion and one-rho meson exchange potential. The former is to take care of the long-range part of the effective interaction, and the latter is for convenience, since it cuts off the pion-exchange potential. We calculate the contributions from $0^+,1^-,1^+,2^-,2^+,3^-,4^-,4^+,5^-,6^+,7^-,8^+$ states, respectively. The results of RPA calculations are in good agreement with empirical energies, also the transition strengths. The correction for double counting is considered. The spectroscopic factors of the states near Fermi surface in average are 0.66 for protons, 0.72 for neutrons. This indicates that the states near Fermi surface are far from pure single particle states. We compare the contributions from collective and non-collective states. The results show that the low lying collective states play much important role than non-collective states in reducing spectroscopic factors. The effect of meson exchange part in interaction is discussed also. Our results are roughly in agreement with the experimental results on spectroscopic factors.

Table. The spectroscopic factors

proton	$3P_{1/2}$	$3P_{3/2}$	$2f_{5/2}$	$1i_{13/2}$	$2f_{7/2}$	$1h_{9/2}$	
	.31	.45	.50	.59	.68	.81	
	$3S_{1/2}$	$2d_{3/2}$	$1h_{11/2}$	$2d_{5/2}$	$1g_{7/2}$		
	.84	.85	.68	.69	.65		
neutron	$3d_{3/2}$	$2g_{7/2}$	$4S_{1/2}$	$3d_{5/2}$	$1j_{15/2}$	$1i_{11/2}$	$2g_{9/2}$
	·80	·73	·87	·86	·61	·77	·81
	$3P_{1/2}$	$2f_{5/2}$	$3P_{3/2}$	$1i_{13/2}$	$2f_{7/2}$	$1h_{9/2}$	
	·88	·81	·83	·71	.62	.63	

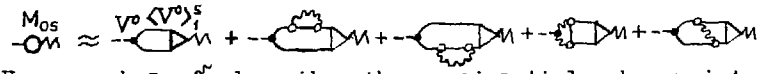
*Supported in part by USDOE Contract No. DE-AC02-76 ER13001
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ON THE QUASIPARTICLE-PHONON INTERACTION EFFECT UPON M1 RESONANCE PROBABILITY AND QUASIPARTICLE EFFECTIVE MASS. ESTIMATES FOR ^{208}Pb

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If we restrict ourselves to taking into account the second order effects in quasiparticle-phonon interaction the amplitude M_{os} of the ground into excited state transition induced by the external field V^0 is

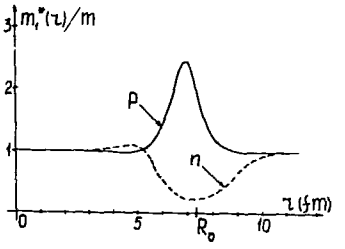


(1)

Here graph g describes the quasiparticle-phonon interaction, the triangle is the amplitude of the transition of 1p1h pair into the excited state s, which is considered in our approximation within the framework of the Migdal theory [2]. The first term $\langle V^0\rangle_1^s$ corresponds to the usual RPA but the lines in eq. (1) correspond to the single-particle Green function G_1 without taking into account coupling to the phonons. The quasiparticle effective mass which is contained in G_1 and particularly in the MGR formulae is [1]

$$(m/m^*)_1 = (a_1/a)\cdot(m/m^*) - a_1\cdot 2m\cdot\partial M/\partial \vec{p}^{\,2} \qquad (2)$$

where $a = (1-\partial\Sigma/\partial\varepsilon_F)^{-1}$, $a_1^{-1} = a^{-1} + \partial M/\partial\varepsilon_F$ and $m^*/m \approx 1$ is the "old" empirical effective mass. We take the mass operator M as $M = g\,g$. The important role of the effective mass for MGR was pointed out in [3].



We have approximately calculated the relative $0^+ \longrightarrow 1^+$ transition amplitude $\alpha(\omega) \equiv M_{os}/\langle V^0\rangle_1^s$ at the energies ω = 8.3 and 7.4 MeV corresponding to 1p1h levels [2]. The result is a strong redistribution of M1 strength as compared with the usual RPA. E.g. for the most collectivized 1^+ level $\alpha(8.3) = 0.4$.

The results for $m_1^*(r)/m$ are shown in the figure (we assumed here $a_1 = 1$, $m^*/m = 1$ in eq.(2)). The calculated difference between $m_1^*(r)/m$ and $m^*/m \approx 1$ may have a significant effect on MGRs.

Our rough estimates seem to signify that taking into account the particle-vibration coupling is important for the considered effects. More consistent calculation should be made according to [1].

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THE ASYMPTOTIC STRUCTURE OF GIANT MONOPOLE VIBRATIONS†

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Highly collective nuclear states, such as the giant monopole vibration, give information on the properties of nuclear matter which cannot be obtained directly from the static properties of finite nuclei. Such states are often described in fluid dynamical terms. It is also possible to cast microscopic calculations in forms which give meaning to many classical continuum variables. The liquid drop description is commonly thought to be correct for such macroscopic variables, at least in the limit of large nuclei. However, a simple radial scaling of the wavefunctions also seems to give good results for the monopole in heavy nuclei. These two models yield quite different forms for the velocity field of the collective motion, especially near the surface. Detailed microscopic calculations of the monopole vibration in ^{208}Pb give a velocity field of an intermediate form[1]. A clear determination of the motion in the large A limit, with no assumptions on the form of the exciting field, is important if monopole vibrations are to be used to specify properties of nuclear matter.

We have shown that the velocity field for monopole vibrations of large spherical nuclear systems is neither liquid drop nor simple scaling. Using the RPA theory for a coherent collective state, we have made variational calculations of the monopole velocity fields in both Fermi and Bose systems. The motion of the bulk of the particles is well described by the classical equations for the vibrations of an elastic medium. In the Fermi system, shear terms give results which differ distinctly from normal fluid values.

There also remains the question of whether ^{208}Pb is large enough to exhibit this asymptotic behavior. In the surface the velocity field becomes an increasing exponential. This can be expressed in terms of the binding energies of the ground and excited states. For ^{208}Pb, this surface boundary condition masks the bulk behavior, giving an average behavior over the nucleus close to simple scaling. Thus, at least for monopole vibrations, ^{208}Pb is a "small" nucleus.

†Supported in part by the NSF, grant no. PHY-7620097.

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NUCLEAR DIPOLE STATES IN THE TRANSLATIONALLY INVARIANT MODEL INCLUDING CONTINUUM

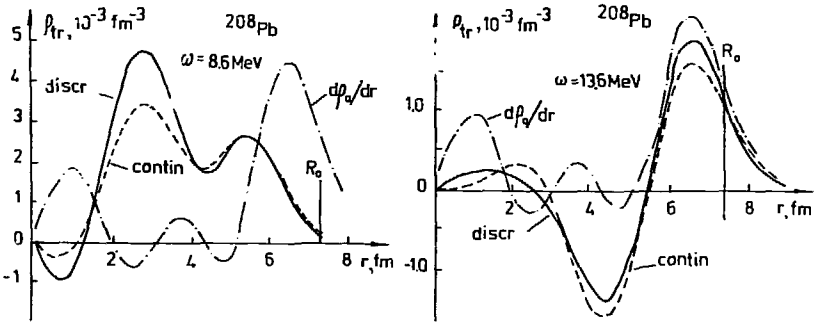
S. N. Ershov, S. A. Fayans, F. A. Gareev, N. I. Pyatov, D. I. Salamov

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The properties of 1^- excited states are investigated in the framework of the translationally invariant self-consistent model[1] with separable effective forces. The one-particle continuum was included by the method[2], whereas in ref.[1] it was substituted by the quasi-discrete states. The energies, transition charge densities, and escape-widths of narrow resonances above the nucleon threshold are calculated. In ^{208}Pb the calculated neutron escape-widths of 1^- states above the neutron threshold (see table) agree qualitatively with the experimental data[3].

E, MeV	7.45	7.55	7.66	7.87	8.02	8.12	8.63	8.79
γ_n, keV	0.1	0.1	0.01	0.1	1.8	0.07	4.4	0.08

A correct inclusion of the continuum decreases slightly the resonance energies and leads to some modification of the transition charge densities as compared with that in ref.[4] (see figs.). Our calculations confirm the change of the shape of ρ_{tr} with increasing the excitation energy that has been found in ref.[4]. Thus, the use of the same ρ_{tr} (for instance, of the type $\partial\rho_0/\partial r$) for different parts of the excitation spectrum may lead to essential errors in calculating the form factors for the inelastic electron scattering.



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STRUCTURE STUDY OF HIGHLY EXCITED STATES IN ^{24}Mg BY MICROSCOPIC ^{12}C + ^{12}C MODEL

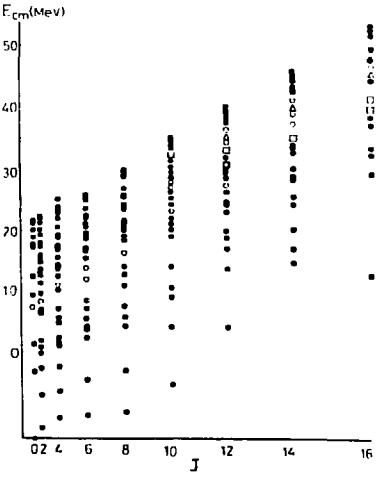
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The purpose of this study is to see how a microscopic ^{12}C + ^{12}C cluster model leads to a natural understanding of the molecular resonant structures in ^{12}C + ^{12}C reactions[1].

By using a microscopic ^{12}C + ^{12}C model, we calculate energy spectra of ^{24}Mg and analyze the structure of the levels in the highly excited energy region. In this model, the wave functions of the ^{12}C clusters are taken as $(\lambda,\mu)I^{\pi} = (0,4)0^+,2^+,4^+$ states and the relative wave function between the ^{12}C clusters are expanded on the Pauli allowed states which have non-zero eigen values of the ^{12}C + ^{12}C norm kernel[2]. We solve cluster dynamics by employing the coupled channel orthogonality condition model[3]. For the interaction between the ^{12}C clusters, we adopt the folding potential[4] obtained by using an effective two-nucleon force[5], of which we adjust the strength so as to reproduce the ^{24}Mg binding energy as measured from the ^{12}C + ^{12}C threshold.

Calculated energy spectra are shown in Fig. 1, where we mark the states in which spectroscopic factors and reduced width amplitudes are large for elastic, aligned single 2^+ excited and aligned mutual 2^+ excited channels, with circles, triangles and squares, respectively. i) Energy levels which are dominated by the elastic component appear to follow the J(J+1) rule. The moment-of-inertia is small compared to the experimental one. ii) At high spins (J ∿ 12), the locus of the levels which contain a strong component of the elastic channel crosses that of the levels which contain a strong component of the aligned inelastic channel. This feature corresponds to the result of the band crossing model[6].



In conclusion, ^{12}C + ^{12}C molecular states are obtained by the microscopic ^{12}C + ^{12}C model at the highly excited states in ^{24}Mg.

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GIANT RESONANCES IN HEAVY NUCLEI WITH THE FOURIER-BESSEL-RPA

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The Fourier-Bessel-RPA proposed by Heisenberg and Krewald[1], extended to embody the continuum, is employed to the analysis of the giant resonances.

In this method we Fourier-Bessel expand the transition density, just like in the model independent analysis of electron scattering[2], and set up the equations only in terms of the expansion coefficients (which are the form factors).

The swiftness of the method allows to treat very large model spaces even for heavy nuclei, always casting the RPA-equations in a 60-dimension system (to be compared with the 300x300 matrices of the usual diagonalization procedures), no matter how large we take our model space.

We are then able to analyze the influence of the extent of the model space on the final results, and take it large enough to eliminate this dependence, like for instance one sees in the mass density for the 0^+ transition in ^{208}Pb, which becomes smoother for larger model spaces, approaching the Tassie result.

With this exact treatment of continuum states, being able to obtain the decay widths of giant resonant states, we present transition densities for various magic nuclei, comparing with existent results.

[+] Also: Instituto de Fisica, Universidade Federal do Rio de Janeiro, Brazil

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MAGNETIC DIPOLE STATES IN ^{52}Cr

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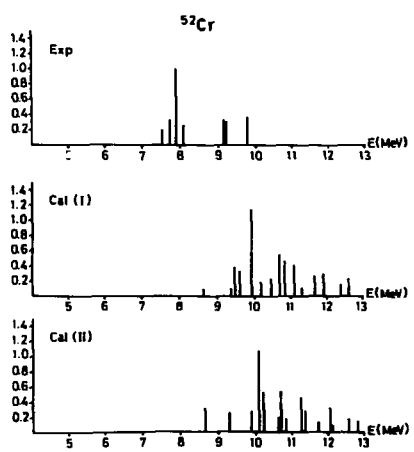
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Strong M1 excitation leading to 1^+ state is expected in doubly even fp-shell nuclei, because of the following two points. In these nuclei, the $f_{7/2}$ shell is almost or completely filled and the $f_{5/2}$ shell completely or almost empty, then the $f_{7/2} \rightarrow f_{5/2}$ spin-flip transition can be realized easily. Further, since both protons and neutrons should participate in the spin-flip transition, they might correlate strongly to produce a "collective M1 state". Recently, (γ,γ) experiment was made and successfully located several 1^+ states in ^{52}Cr[ref. 1)], showing clustering of M1 strengths in the excitation energy region of 7-10 MeV.

It is therefore quite interesting to carry out shell-model calculation in order to interpret the newly observed phenomena. Since the spin-flip transition plays an important role, we assume the $(f_{7/2})^{12} + (f_{7/2})^{11}(p_{3/2},p_{1/2},f_{5/2})^1$ configuration for ^{52}Cr. For the $|(f_{7/2})^{11}\alpha_1 T_1 J_1, j; TJ\rangle$ basis functions, both $T_1 = 5/2$ and 3/2 ones are included, where $T = 2$. Effective interactions used here are based upon the previous work[2] with some extension. The figure compares our calculated $B(M1;1^+ \rightarrow 0^+)$ in $(n.m.)^2$ with the experimental one as a function of excitation energies. Although the excitation energies turn out to be shifted up by about 2 MeV, the distribution of the M1 strengths is nicely reproduced. It is found that the spin-flip components are strongly fragmented among the levels in this energy region and are no longer pure. No collectiveness for the M1 states comes up theoretically.



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INELASTIC ELECTRON SCATTERING FROM 4^+ STATES IN THE fp-SHELL NUCLEI

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Inelastic electron scattering measurements made recently by the Sendai group[1] have indicated two different shapes for the C4 form factors of the $0^+ \rightarrow 4^+$ transitions in nuclei around A=56. One is the smooth inversed-U shape as shown in Figs. 1 and 3, and the other is rather complex, as shown in Fig. 2 for ^{56}Fe, having a dip near q_{eff}=1.4 fm^{-1}. The experimental results suggest that there might exist essential differences in the structure of the 0^+_{gnd} and 4^+_1 states in these nuclei.

We have, therefore, carried out shell-model calculations by assuming the $\pi(f_{7/2})^p$ configurations for the N=28 isotones, the $\nu(p_{3/2},p_{1/2},f_{5/2})^n$ for Ni isotopes and the $\pi(f_{7/2})^p \times \nu(p_{3/2}, p_{1/2},f_{5/2})^2$ for the N=30 isotones. Harmonic oscillator wave functions and constant effective charges e_p = 1.3e and e_n = 1.2e are used to evaluate the single-particle matrix elements. The solid curve in the figures is obtained by this assumption, and the broken curve with e_n =1.4e instead of 1.2e, emphasizing the sensitivity of the effective charges on the form factors. It is shown that the pairing scheme wave functions are responsible for the smooth inversed-U shape, while the unusual shape for the $0^+ \rightarrow 4^+$ transition in ^{56}Fe can be attributed to the enhanced collectivity due to the strong correlation between protons and neutrons in the shell-model wave functions.

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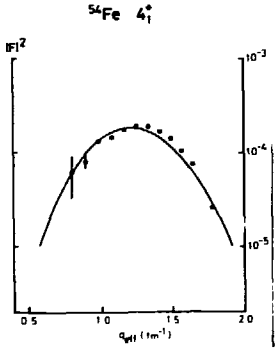


Fig. 1

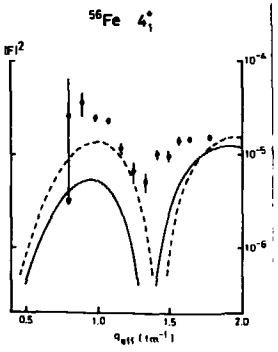


Fig. 2

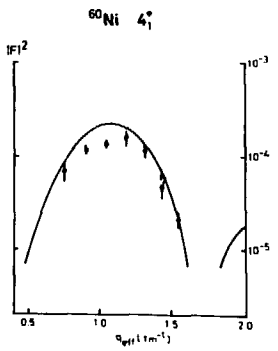


Fig. 3

ISOVECTOR GIANT RESONANCE STATES IN LARGE NUCLEUS LIMIT

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A variational study is worked out with the aim of understanding IVGR states in the large A limit on the basis of the TDHF-theory. We follow the approach given by Bertsch et al.[1] to construct a time-dependent wave function ϕ from the static one $\phi^{(0)}$ as

$$\phi(\vec{r},t)=\exp(im\xi(\vec{r},t)\tau_z)\exp((\lambda(t)/2)(\vec{u}\cdot\vec{\nabla}+\vec{\nabla}\cdot\vec{u})\tau_z)\phi^{(0)}(\vec{r}) \qquad (1)$$

and then obtain the vibrational frequency ω by applying the variational principle. The 'velocity field' $\vec{u}$ is restricted to the form; $\vec{u}=\vec{\nabla}(j_L(qr)Y_{L0}(\hat{r}))$ (L=0∿2) with q treated as a variational parameter. The choice q∿0 yields the Tassie-type transition density, while the choice $j_L(z)'=0$ (z=qR, R; nuclear radius) the hydrodynamical (HD)-one. In the large A limit the latter choice completely eliminates the surface effect to give a motion of volume character, $\omega\sim A^{-1/3}$, and thus is favoured. Note, however, that the dynamics underlying the present approach is very different from the usual hydrodynamics whose basic concept is subject to a serious doubt in the application to nuclear GR's.[2]

By using a zero-range density-dependent force, we can explicitly show that the variational solution for ω converges, in the large A limit, as:

$$(\omega/\Omega)^2 \to ((1+F_0')/3+C_L(z))z^2 \qquad (2)$$

with z given by the HD-model, where $C_0(z)=4/15$, $C_1(z)=4/15-8/5z^2(z^2-2)$, $C_2(z)=4/15-24/5z^2(z^2-6)$, $\Omega^2=2\langle T\rangle/mA\langle r^2\rangle$ (Ω;'HO-frequency') and F_0' is the isospin-dependnet Landau parameter in the standard convention. In terms of the RPA-moment $m_k(F)$,[3] this ω^2 can be understood as $m_3(F)/m_1(F)$ with $F=j_L(zr/R)Y_{L0}(\hat{r})\tau_z$. The rhs of Eq.(2) differs from the HD-formula, $(\omega_{HD}/\Omega)^2=((1+F_0')/3)z^2$, by the contribution $C_L(z)z^2$ originating from the quadrupole distortion of the local Fermi-surface[2] introduced in $\phi(\vec{r},t)$. Eq.(2) can be generalized to include the effect of finite-range exchange-forces by incorporating the Landau parameters of higher ranks as

$$(\omega/\Omega)^2 \to (1+\kappa)(m/m^*)((1+F_0')/3+C_L(z)(1+F_2'/5))z^2 \ , \qquad (3)$$

where $1+\kappa=(m/m^*)(1+F_1'/3)$ and m^* is the s.p. effective mass $m^*/m=1+F_1/3$. This is our asymptotic formula for IVGR frequencies. Much effort, however, remains to be done in linking this formula with IVGR states in a 'small' nucleus such as ^{208}Pb where the bulk behavior is still tangled by the surface effect.[4]

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SYSTEMATICS OF THE GIANT MONOPOLE RESONANCE AND NUCLEAR INCOMPRESSIBILITY*

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Utilizing small angle inelastic alpha particle scattering, we have identified the giant monopole resonance (GMR) in eleven nuclei over the mass range $64 \leq A \leq 208$. The GMR was not observed in ^{40}Ca. The parameters obtained are summarized in ref. 1. The energy of the GMR can be related directly to the nuclear incompressibility K_A as follows

$$E = \frac{\hbar}{r_0}\sqrt{\frac{K_A}{m}} \qquad (1)$$

where r_0 is the root-mean-square nuclear radius and m is the nucleon mass; K_A can be related to the incompressibility of infinite nuclear matter using the semiempirical mass formula

$$K_A = K_{nm} + K_{surf}/A^{1/3} + K_{sym}\left(\frac{N-Z}{A}\right)^2 + K_{Coul} \quad . \qquad (2)$$

The coefficients in equation (2) can be viewed as second derivatives with respect to r of corresponding coefficients in the mass equation. Unfortunately, the derivatives of the coefficients in the mass equation cannot be evaluated with sufficient accuracy to obtain meaningful estimates of K_{surf}, K_{sym} and K_{nm}.

The incompressibility of infinite nuclear matter and the surface and symmetry contributions to the incompressibility were determined from eq. (2) with a least-squares fit to the experimentally obtained values of K_A. In the present calculation we used twelve experimental values of K_A for nuclei ranging from ^{64}Zn to ^{208}Pb: two from the work of Buenerd et al.[2]) and ten from Texas A&M. Values obtained for deformed nuclei were excluded from the fit. The resulting coefficients are listed in the table. If only a few data points are available, very different K_{surf} and K_{sym} values can be obtained. Using random-phase-approximation (RPA) calculations, Blaizot et al.[3]) have extracted monopole energies and nuclear incompressibilities for five different effective interactions. The incompressibility coefficients obtained with three of the interactions are shown in the table. The values obtained using the interactions B1 of Brink and Boeker and D1 of Gogny agree with the experimental data within the errors, although K_{sym} is at the upper limit of the experimental error, while K_{sym} obtained with the Ska interaction is substantially higher than the experimental value. Data will be required over a wider range of nuclei to determine the coefficients more accurately.

Coefficients of the incompressibility (MeV)

	Exp	B1	D1	Ska
K_{nm}	222± 32	190	228	263
K_{surf}	-403±130	-300	-315	-394
K_{sym}	-224±265	-500	-500	-610

*Supported in part by the National Science Foundation and the Robert A. Welch Foundation.

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TWO HOLE STATE IN THE CADMIUM ISOTOPES†

G.M. Crawley, S. Gales,†† D. Weber and B. Zwieglinski

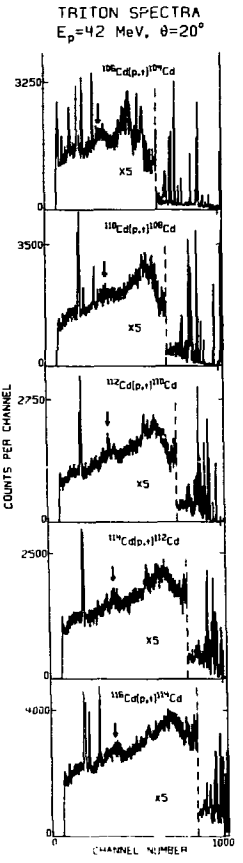
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A broad peak observed in (p,t) reactions on the tin isotopes has been tentatively identified as arising from either the pickup of two neutrons from deep orbits or the pickup of a valence neutron and a deep orbit neutron[1,2]). To investigate this phenomenon further, the (p,t) reaction was studied on a series of cadmium isotopes; ^{106}Cd, ^{110}Cd, ^{112}Cd, ^{114}Cd and ^{116}Cd at 42 MeV bombarding energy using the MSU K50 cyclotron. The experimental method was similar to that described in a previous publication[1]).

Spectra from the five isotopes are shown in Fig. 1. A broad peak was observed in all cases at an excitation energy which changed systematically with A from 6.3 MeV in ^{104}Cd to 7.7 MeV in ^{114}Cd. In the two cases for which the same mass nuclei could be studied in both cadmium and tin, the excitation energy of the broad peak was very similar. In addition, the slope of the excitation energy versus A line was very similar for these two isotope chains.

However, in the cadmium isotopes a second broad feature (marked with an arrow in Fig. 1) was observed at a higher excitation energy. The strength of this bump is weaker than the lower energy one, and it moves to higher excitation energy as the A increases much more rapidly than does the lower energy bump. For example, the separation of the two features is only 2.1 MeV in ^{104}Cd but is 4.4 MeV in ^{116}Cd. This result is not consistent with predictions of the spacing of deep orbits nor of their predicted variation with mass[3]).

The ^{106}Cd(p,t)^{104}Cd case is particularly interesting since the broad features are at low enough excitation energy that substructures which possibly correspond to single levels or to small numbers of individual levels are observed. Indications of 0^+ strength in some of these substructures add support to the argument that at least some of the strength in the first broad bump arises from pickup of two particles from deep orbits.



† This work was supported by the U.S. National Science Foundation.
†† Permanent address: IPN, BP No1-91406 Orsay, France.

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STRUCTURE OF EXCITED 0^+ STATES OF ^{16}O INVESTIGATED WITH FOUR ALPHA-PARTICLE BOSON MODEL

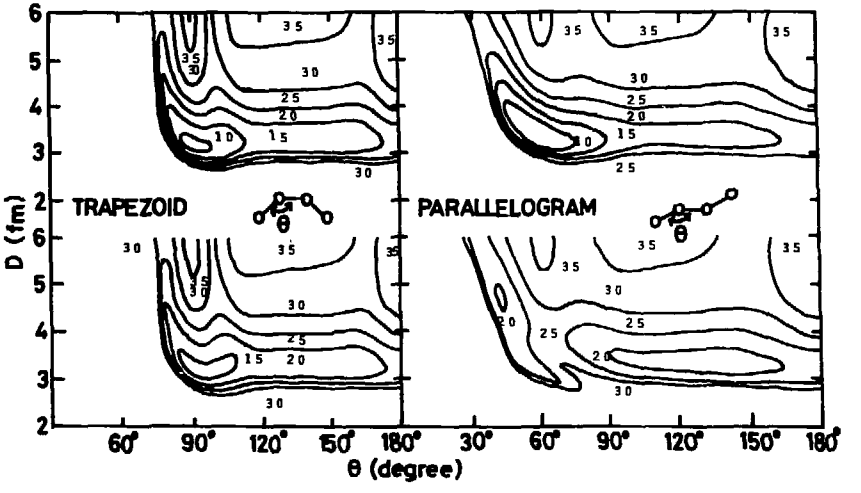
Y. Suzuki

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We have investigated structure of excited 0^+ states of ^{16}O with four α-particle boson model. This work is based on the theoretical results[1] that the ground and the excited 0^+ states at 6.05 and 12.05 MeV are remarkably well understood by the ^{12}C +αcluster model and that the structure of ^{12}C is well described by the microscopic 3 α-particle model. We therefore expect that an interacting four α-particle model is valid in some region above 15 MeV in excitation energy. This is also of interest in connection with a problem on whether the linear chain structure of 4 α-particles is realized.

The figure shows the 0^+ energy surfaces of the trapezoid and the parallelogram configurations with the distance of the adjacent α-particles fixed to a common length D (the energy is measured from the 4 α-decay threshold). The α-α potential used is the Ali-Bodmer e-type. The lower parts of the figure correspond to the energy maps of the excited states which are obtained by imposing the orthogonality of the assumed configurations to the low-lying four 0^+ states described with the tetrahedral and ^{12}C(regular triangle)+α configurations.

We find a local minimum around the square configuration with D≈3.2 fm. In addition the trapezoid and parallelogram structures are almost degenerate in a wide configuration space ($110° \lesssim \theta \lesssim 165°$). This suggests the strong coupling between both the configurations and a possible existence of prolonged structure which is not specified by a fixed geometrical shape.



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LINE BROADENING AND COULOMB-ENERGY SHIFTS OF THE HIGH-LYING HOLE-STATE ANALOGS

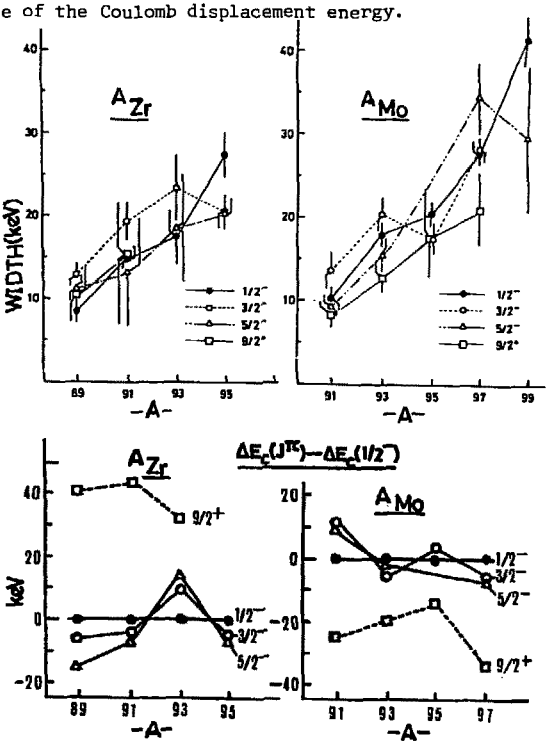
H. Ikegami, T. Yamazaki, S. Morinobu, I. Katayama, M. Fujiwara, Y. Fujita
H. Taketani,† M. Adachi,† T. Matsuzaki†
N. Koori,†† and M. Matoba††

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Widths and excitation energies of the high-lying hole-state analogs have been measured accurately for the residual nuclei ^{49,51,53}Cr, ^{57,59,61,63}Ni, ^{89,91,93,95}Zr, ^{91,93,95,97,99}Mo, and ^{111,113,115,117,119,121,123}Sn in order to study the isospin mixing of the $T_>$ state with the surrounding $T_<$ states and to study the orbit dependence of the Coulomb displacement energy.

Using 50 or 55 MeV protons from the RCNP AVF cyclotron, deuterons from the (p,d) reaction were analyzed with the QDMDQ type spectrograph "RAIDEN". The over-all energy resolution ranges from 10 to 30 keV, depending mainly on the target thickness.

At excitation energies corresponding to the hole-state analogs, fine structures were observed for the lighter isotopes of Cr and Ni and single broadened line-shapes were observed for the Zr, Mo, and Sn isotopes. As an example, the results for Zr and Mo isotopes are shown in the figures. Our analysis shows that the observed intrinsic widths shown in the upper figures consist of almost A-independent "spreading width" through mixing with the isovector monopole state and additional "escape width" for the heavier isotopes. Another interesting point of the present data is the major-shell dependence of the Coulomb displacement energy ΔE_c. For example, the plots of $\Delta E_c(J^\pi) - \Delta E_c(1/2^-)$ shown in the lower figures indicate distinct difference of ΔE_c between fp and 1 g shell. The Coulomb displacement energies for the 2 $p_{1/2}$, 2 $p_{3/2}$, and 1 $f_{5/2}$ orbits are nearly equal but are different from those for the 1 $g_{9/2}$ orbit by 20 ~ 40 keV. It is interesting to note that the sign of this difference for Zr isotopes is opposite to those for Mo and Sn isotopes.[1)]



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MOMENT INVERSION FOR TRITON PHOTOEFFECT†

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The cross section for the triton photoeffect, $\sigma(E_\gamma)$, is calculated[1,2] using a final state wave function $|f\rangle$ for a spin-independent Volkov potential with no exchange character. The energy weighted moments are defined by $\sigma_p \equiv \int_0^\infty \sigma(E_\gamma) E_\gamma^p dE$. The formalism of hyperspherical harmonics (h.h.) is used[1,3] to evaluate σ_{-1}, ... σ_3 from sum rules and the triton's ground state $|i\rangle$.

We improve the accuracy of Maleki's calculation[3] of σ_2 and σ_3 by considering a second term in the h.h. expansions of $|i\rangle$ and of the Volkov potential. We outline a moment inversion technique[4] by assuming the cross section can be written as a series expansion of Laguerre polynomials multiplied by a decreasing exponential. Various model cross sections, such as $SI(x) = x^2\exp(-Cx)$, are examined by comparing the inverted curve SO with the assumed cross section SI. Figure 1 shows that, for C = 1, good convergence is attained for 5 terms in the Laguerre series. We apply the inversion formula to the triton moments to obtain the cross section curve in Fig. 2. We compare with Fang's calculations[2] and find that our inversion technique has difficulties with such a sharp-peaked curve.

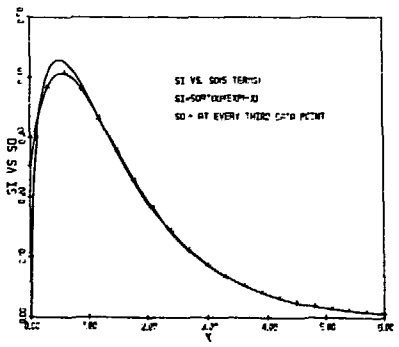


FIGURE 1

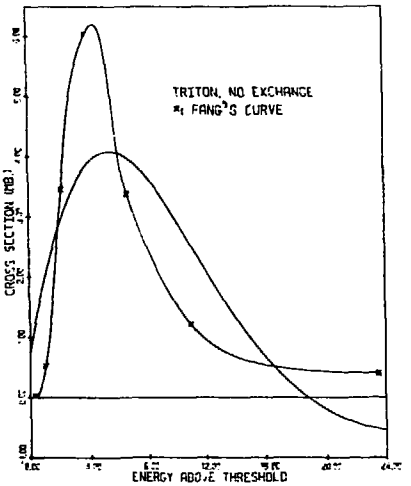


FIGURE 2

†Supported in part by the National Science Foundation.

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MASS AND ENERGY DEPENDENCE OF RADIATIVE STRENGTH NEAR NEUTRON TRHESHOLD

J. Kopecky

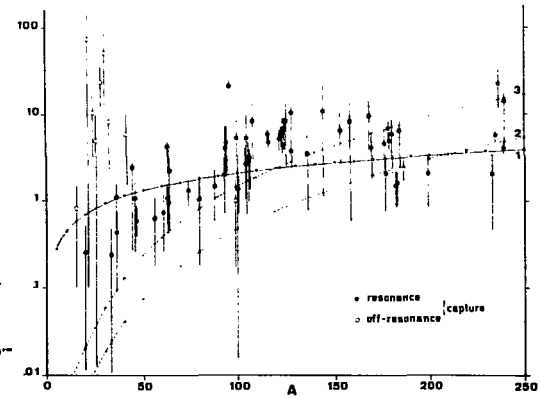
Netherlands Energy Research Foundation
1755 ZG Petten, The Netherlands

The overall behaviour of the dipole radiative strength near the neutron threshold has been a subject to many studies since 1960. Two available theoretical models, i.e. the single particle (SP) and the giant-resonance models (GR), explicitely differ in the energy and mass dependence, usually expressed as $\Gamma_\gamma = CE^k A^l D$ with empirically adjusted constant C.

Recent study [1] resulted in the currently most accurate values of C for different models, but they obviously suffer from fitting only one model for the whole mass range and moreover the structural effects, fluctuations or some insufficient data make a conclusion about the particular model difficult.

Another approach in which the ratio of E1 and M1 reduced strengths ($B = I_\gamma E_\gamma^{-3}$) is studied, seems to be more sensitive to differentiate between the considered models. Presented analysis (fig. 1) is primarily based on the resonance [1] and the available thermal data, and is further divided into a resonance (thermal data with strongly involved resonances are also included) and off-resonance capture ($\sigma_\gamma < 0.7$ b). Errors are derived from the Porter-Thomas distribution and only the data points with $\Delta < 100\%$ are considered.

Three curves reveal the expected values as derived for (SP(E1,M1) being 0.097 $A^{2/3}$ (1), while the other two represent GR(E1)/SP(M1) with $1.4.10^{-7} A^{8/3}$ plotted for $E_\gamma = 4$ and 7 Mev (2)(3), respectively (based on constants from ref. [1]).



Resonance data for $A < 100$ reasonably follow the SP estimate, which is perhaps slightly overestimated. Large deviations for the off-resonance data can be attributed to the enhanced strength of the E1-direct capture, which manifests itself by large (n,γ)(d,p) correlations for these nuclei. Data points for masses $90 < A < 170$ are significantly higher than SP.

Compared to the GR(E1)/SP(M1) prediction, the data points have an excess only for $90 < A < 120$, for which an enhancement of the E1 strength due to the valence capture may be responsible. From $A > 130$ both curves (3)(4) satisfactorily represent the data and since we have some extra indication elsewhere, that GR(E1) is dominant there, the largest uncertainty to improve the fit remains in a better knowledge of the M1-strenght properties and the location of the M1-giant resonance.

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STRUCTURE OF STRONG M1 EXCITATIONS AT 15.106 MeV IN ^{13}C AND 11.24 MeV IN ^{20}Ne INVESTIGATED THROUGH ANALOG TRANSITIONS $^{13}C(\pi^-,\gamma)\,^{13}B$ (G.S.) AND $^{20}Ne(\pi^-,\gamma)^{20}F$ (1.06 MeV)

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Branching ratios for (π^-,γ) measured recently at Los Alamos have been combined with published inelastic electron scattering and β decay data to give rather model independent information on the structure of the giant M1 transitions in A=13 and A=20.

The Gamow-Teller matrix element and the transition radius extracted from the pion capture and β decay data are in good agreement with the electron scattering data, assuming that the orbital terms in the M1 amplitude are unimportant.

The structure of the A=20 transition is shown to be quite different. Comparison with the inelastic electron scattering data (the analog β decay has not been observed) shows that the M1 amplitude is only (40 ± 12)% spin flip. The remainder results from orbital recoupling of the $d_{5/2}$ nucleons. These results are in agreement with detailed theoretical calculations.[1]

The presently available energy resolution (850 KeV) and statistics of radiative pion capture spectra make this reaction a useful probe of spin flip transition strength in nuclei.

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†††Present Address: University of Tokyo, Tokyo, Japan

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VERIFICATION OF THE AXEL-BRINK HYPOTHESIS IN DEFORMED NUCLEI

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Joint Institute for Nuclear Research, Dubna, 101000, Moscow, P.O.Box 79

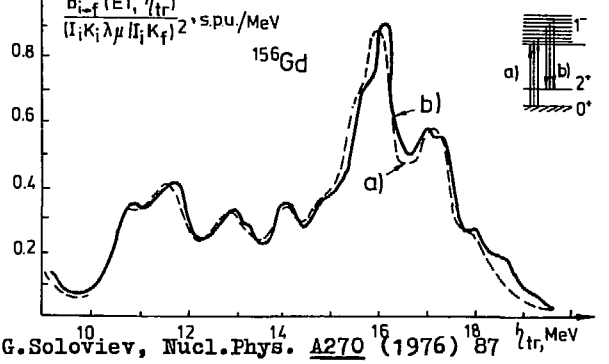
The highly excited states of deformed doubly even nuclei are investigated within the quasiparticle-phonon model taking into account complex configurations. The proposed treatment allows a direct verification of the Axel-Brink hypothesis[1] on the structure and position of giant resonances on the excited nuclear states.

The strength function of the reduced probability of $E\lambda$ - transitions from the highly excited $(I^\pi K)_i$ to the low-lying state $(I^\pi K)_f$ is

$$\frac{b_{i\to f}(E\lambda,\eta_{tr})}{(I_iK_i\lambda\mu\,|\,I_fK_f)^2}=\frac{1}{\pi}\,\mathrm{Im}\,\frac{\begin{Vmatrix}\sum_G \frac{V_G^2}{\omega_G-z} & -\sum_G \frac{V_G U_{Gg}}{\omega_G-z}\\ -\sum_G \frac{V_G U_{Gg}}{\omega_G-z} & (\omega_g-z)\delta_{gg'}-K_{gg'}\end{Vmatrix}}{\|(\omega_g-z)\delta_{gg'}-K_{gg'}\|} \qquad (1)$$

Here ω_g and ω_G are the energies of one-phonon g and two-phonon G poles; V_G, U_{Gg} and $K_{gg'}$ are the matrix elements determining the quasiparticle-phonon interaction; $z=\eta_{tr}+i\Delta/2$, where η_{tr} is the transition energy and Δ is the averaging interval[2]. The numerator of (1) is the determinant of the matrix with the rank larger by unity than the rank g of the denominator matrix.

The calculations for the giant electric dipole resonance in the rare-earth nuclei have shown that if the final state f is similar (in structure) to the one-phonon state, the Axel-Brink hypothesis is justified with high accuracy. In the figure for ^{156}Gd the value (1) of the strength function of E1-transitions from the states $(I^\pi)_i=1^-$, $K_i=0$ and 1 to the final 2^+2 state (thick curve) is compared with the strength function of the E1-resonance reduced probability $b_{0^+\to 1^-}(E1,\eta)$ calculated taking into account anharmonicity (dashed line). The energy of the finite state $\approx$1.2 MeV; the main contribution to its wave function (~90%) is given by the lowest quadrupole phonon. It is seen that the electromagnetic transition wave function depends on the transition energy η_{tr} only and is independent of the nuclear excitation energy.



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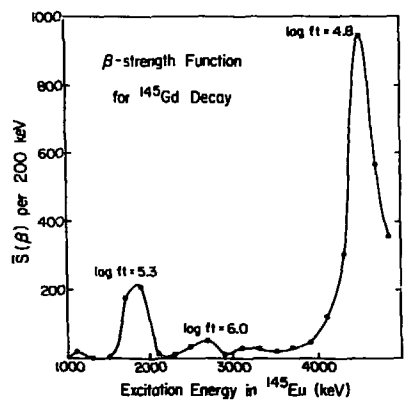
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OBSERVATION OF LARGE RESONANCES IN THE ß-DECAY OF $^{145}_{64}Gd_{81}$

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The ß-decay of nuclei far from stability is not yet well understood. An unusally complex ß-decay scheme for ^{145}Gd to 135 levels below 5 MeV in ^{145}Eu was recently measured[1]. Sufficient ß-decay intensity was placed (>98%) to allow a precise evaluation of the ß-strength distribution S_β=ß-intensity/ft which is plotted below in 0.2 MeV summed intervals to enhance the macroscopic decay structures. Strong resonances are observed at 1.8, 2.6, and 4.5 MeV. The lower resonances can be described by weak coupling of the odd $d_{5/2}$ proton to the 2_1^+ and 2_2^+ ^{144}Sm core states. This is supported by the excitation energy, γ-ray decay, microscopic structure, and the total ß-transition rate to these resonances. Also, the five $1/2^+$-$9/2^+$ couplings of the $\pi d_{5/2} \times 2_1^+$ configuration tentatively have been identified. The large resonance at 4.5 MeV represents 72% of the total ß-decay strength. A shell model calculation was performed indicating that the N>82 neutron shell opens at 3.9 MeV in ^{145}Eu. This strong 4.5 MeV resonance may result from the fast $\pi h_{11/2} \rightarrow \nu h_{9/2}$ ß-decay across the shell closure.



These results differ markedly from Hardy et al's suggestion[2] that ^{145}Gd should have a constant average ß-strength with only broad fluctuations. Duke et al[3] failed to observed ß-decay resonances near Z=82 however they did see a substantial change in the average ß-strength near N=126. More recently Kratz et al[4] found evidence for distinct resonances in ß-delayed neutron decay near Z=50. The analysis of the ^{145}Gd decay data shows clearly that the ß-strength is dominated by strong, easily understood, resonance structures.

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GIANT RESONANCES AND ℓ-DEPENDENT OPTICAL POTENTIALS+

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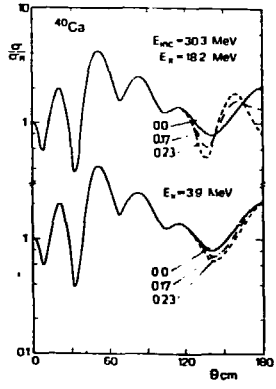
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Microscopic optical potentials are related to the mass operator or generalized optical model. Two approximation schemes have been followed to calculate the mass operator. One uses the many body Green's function equation, the other uses the perturbation expansion in terms of the free NN interaction and is known as Brückner Hartree-Fock approach. In BHF the particle ladder diagram summation is essential in generating the complex energy and density dependent effective interaction or reaction matrix. The nonlocal OMP is the result of an antisymmetrized folding procedure with the diagonal and non diagonal single particle density of the target g.s. The imaginary OMP is representative for loss of flux into a homogeneous excitation spectrum. The nuclear structure approach emphasises the importance of collective states and incorporates the resummation of bubble diagrams with intermediate states described by the RPA[1].

Recent systematic measurements together with standard phenomenological OMP analyses gave evidence for inadequacies in medium mass nuclei. They consists in enhancements in differential cross sections above 120° and projectile energies below 50 MeV[2]. These experiments support certain features of the nuclear structure approach of the OMP.

The kind of effects and alterations can also be deduced from the phenomenological ℓ-dependent OMP.

In the present study the nuclear structure effects are identified with the strong channel coupling to known giant resonances (GR). Contrary to a low-lying collective state does channel coupling with GR severely change differential cross sections at large angles. These highly excited inelastic states are nearly closed, bear no loss of flux but redistribute elastic scattering events. In the figure we display a comparison for the coupling of GQR in ^{40}Ca, when exhausting 0%, 40% and 75% of the linear EWSR. Coupling to the low-lying quadrupole state (E_x = 3.9 MeV) yields changes which can also be accounted for by slightly modified OMP. Detailed analyses to the experiments give a full account of the mass and energy dependence when using known GMR informations, such as centroid energies, widths and splittings together with smoothly varying BHF OMP. This establishes further the need for an unification of the BHF and the nuclear structure approach in microscopic OMP.



+Supported by BMFT 06 HH 706

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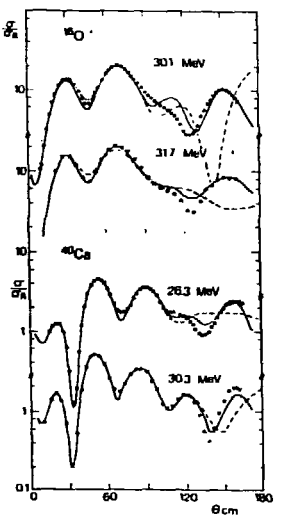
GIANT RESONANCE EFFECTS IN PROTON ELASTIC SCATTERING

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In the last year a large amount of data on proton elastic scattering on light nuclei have been collected to see shell effects and peculiar deviations from average potential results. An enhancement in elastic cross sections for closed shell nuclei has been evidenced both at forward and backward angles; the backward effect being relatively much larger[1]. With best fit optical potentials (OP) cross section and polarization data for scattering angles below 120° may be well reproduced together with total reaction cross sections. The reproduction power of the OP, however, fails very often above 120°.

In the present analysis we accumulate evidence of strong coupling effects between giant multipole resonances and the ground state. This feature can only be properly accounted for in coupled channel calculations with ingredients known from other sources. In its assumptions this analysis is free from newly fitted parameters. The GR informations (centroid energy, strength and splitting) have been taken from hadron scattering experiments. The essence of the here sketched treatment rests on coupling nearly closed channels with little loss of flux, at incident energies below 40 MeV, yielding marked back-angle alterations. The figure shows exemplaric changes from pure OP calculations (dashed lines) to coupled channel calculations (full lines) at various incident energies and for two nuclei. Averrage OM potentials [1,2] were used with therefrom derived macroscopic transition form factors to the inelastic channels.



These selected examples together with analyses of other nuclei in wide energy ranges lend strong support to the inadequacies of standard local optical model description of nucleon scattering from light to medium nuclei.

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STUDY OF GIANT RESONANCE REGION BY INELASTIC SCATTERING OF INTERMEDIATE ENERGY POLARIZED PROTONS†

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Differential cross sections $\sigma(\theta)$ and analyzing powers $A(\theta)$ have been measured for transitions leading to the giant resonance (GR) region and low-lying bound states of ^{92}Zr and ^{120}Sn through inelastic proton scattering using the 104 MeV polarized proton beam from IUCF. It was expected that a simultaneous measurement of $\sigma(\theta)$ and $A(\theta)$ allows one to determine more reliably the strengths of L=0 and L=2 transitions and put more stringent limits on the presence of higher multipoles. The scattered protons were detected using a ΔE-E telescope consisting of intrinsic Ge detectors. The data were measured in 2^{o} steps from 10^{o} to 30^{o} for ^{92}Zr target. For ^{120}Sn, the measurements covered the angular range 14^{o} to 26^{o} in 3^{o} steps. The cross sections and analyzing powers for the GR in both the cases have been extracted following the conventional procedure of subtracting out a smooth underlying continuum background. Standard DWBA calculations using the Oak Ridge form of deformed spin orbit coupling have been carried out to determine the sum rules for the various L values exhausted in the GR region. We have assumed 100% GDR and have extracted the %EWSR for other L values by simultaneously fitting $\sigma(\theta)$ and $A(\theta)$. The results for Zr are tabulated below and are compared with other measurements.

Reaction	E (MeV)	L=0	2	4	Reference
(α,α')	129	90	66	-	1)
(p,p')	60	60	60	-	2)
$(\vec{p},p')$	58	-	18	16	3)
$(\vec{p},p')$	104	80	16	6	present work

It is found that for Zr target, the present work agrees well with refs. [1)2)] for L=0 strength and is in good accord with ref. [3)] for L=2 and 4 strengths. For ^{120}Sn, our preliminary results agree with ref. [2)] for L=0 strength. The L=2 strength extracted is small, in agreement with ref. [4)]. Some evidence for presence of a few percent of L=4 strength was observed. In view of the known dissimilarities in radial behaviors of the exact hadronic transition operator and the equivalent electromagnetic transition operator used in DWBA calculations, the present result and the differences observed can be considered reasonable.

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†Work supported in part by the National Science Foundation

GIANT RESONANCE STUDIES WITH 800 MEV PROTONS†

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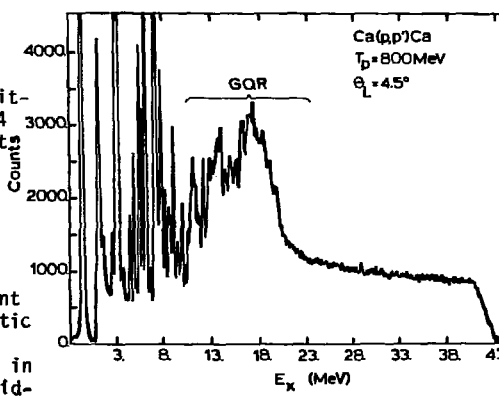
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We have studied the excitation of isoscalar ℓ = 0, 2 and 3 resonances in ^{16}O, ^{40}Ca, ^{116}Sn and ^{208}Pb with 800 MeV protons using the High Resolution Spectrometer at LAMPF. The measurements covered the lab angular range from $\theta_L \simeq 2.5^o$ to $\theta_L \simeq 9.5^o$, which includes the first maxima for multipole excitations with ℓ = 2 through ℓ = 4 for all targets employed except ^{16}O. Near the first maximum of the giant quadrupole resonance (GQR) we observed an excellent 2:1 peak-to-continuum ratio (See figure). Also, the continuum shape for all targets appears to be consistent with a dominance of quasi-elastic nucleon knockout.



The appearance of the GQR in 800 MeV proton spectra is considerably different from that obtained with 100-150 MeV alpha particles. E.g., in $^{40}Ca(\alpha,\alpha')$ the peak at 18 MeV of excitation has been interpreted as the GQR. The 800 MeV $^{40}Ca(p,p')$ data, on the other hand, suggest a much broader and rather more fragmented distribution of ℓ = 2 strength.

The very favorable peak-to-continuum ratio that we observed encouraged us to search for the elusive high-energy octupole resonance (HEOR); this resonance has been predicted to contain about 75% of the E3 energy-weighted sum rule. Preliminary analysis of the (p,p') excitation spectra indicates a broad structure with ℓ = 3 centered at approximately $110A^{-1/3}$ MeV and roughly 8-10 MeV wide for ^{116}Sn and 5-6 MeV wide for ^{208}Pb. Because of its large excitation energy and consequent large width it is unlikely that such a resonance would be observable with 100-150 MeV alpha particles.

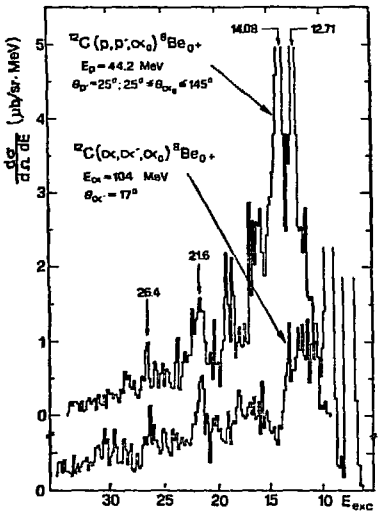
†Work supported in part by U.S. DOE and U.S. Nat'l. Science Foundation.

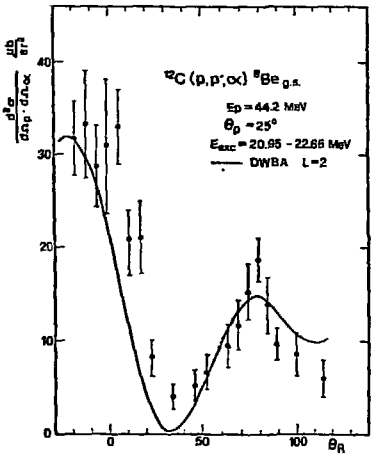
EXCITATION OF E=2 STRENGHT IN ^{12}C VIA THE $^{12}C(pp',\alpha)^{8}Be$ REACTION

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Widely differing amounts of E2 strenght have been reported from various experiments on ^{12}C in the 20–30 MeV energy range; a particularly low value has been found in a $(\alpha\alpha',\alpha)$ correlation experiment[1]. This last result and the strenght found in proton inelastic data[2] support the conjecture that protons excite predominantly isovector resonances in contrast with recent experimental evidence[3] for other light nuclei. We have carried out a correlation experiment measuring the decay alpha particles from groups excited in proton inelastic scattering at 44.2 MeV. No background has been subtracted since quasifree processes are neglegible in our kinematic conditions. Practically all the isoscalar strenght is detected since alpha decay is predominant in light nuclei. A remarkable correspondence is found between the structures observed above 20 MeV excitation in $(\alpha\alpha',\alpha)$ and the present (pp',α) spectra while other peaks are present at lower energies. Angular correlation fits for the main high energy groups show an L=2 character, while cross sections are an order of magnitude lower than for alpha excitation.





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GIANT RESONANCES OBSERVED IN THE ^{112,124}Sn(p,n)^{112,124}Sb REACTIONS

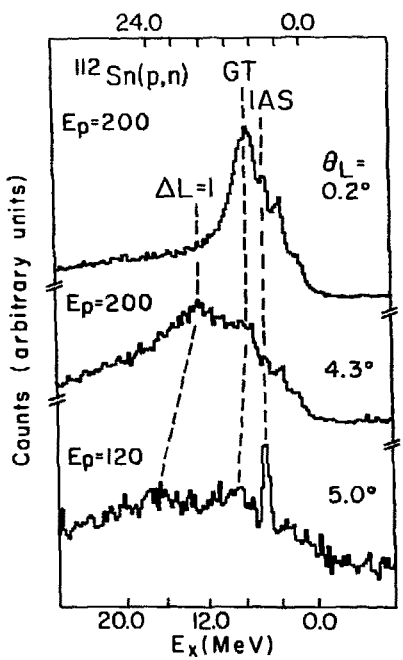
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The (p,n) reaction at E_p>100 MeV is increasingly sensitive to the spin-isospin terms in the effective interaction. As such it is an excellent tool for distinguishing between Gamow-Teller (GT) and Fermi transitions. The ^{112,124}Sn(p,n)^{112,124}Sb reactions have therefore been studied at E_p=120 and 200 MeV. Data were obtained with the IUCF beam swinger facility using 60 to 70 m neutron flight paths.

The forward angle spectra at E_p=120 MeV are characterized by two $\Delta\ell$=0 transitions. The strength and excitation energy of the lower level identify it as the Fermi transition to the g.s. IAS. The peak 3 (1) MeV above the IAS in ^{112}Sb (^{124}Sb) is a GT resonance with Γ(FWHM)=4.5 MeV. The figure shows that at E_p=200 MeV the GT dominates the 0° spectra. Indeed the ratio of the 0° cross sections for this peak relative to that for the IAS increases by a factor of 4.0±0.6 from 120 to 200 MeV, in qualitative agreement with the GT predictions of Love[1]).

A striking feature of the 200 MeV data is the presence of a giant resonance (Γ=13 MeV) centered about 10.1 (7.3) MeV above the g.s. IAS in ^{112}Sb (^{124}Sb). Its angular distribution appears to be sharply peaked near 5°, suggestive of a $\Delta\ell$=1 transition. Although populated weakly at 120 MeV, this resonance is enhanced at higher E_p and thus, as in the case of the GT, probably involves a spin-flip. This $\Delta\ell$=1, ΔS=1 resonance could have a spin ranging from 0$^-$ to 2$^-$, but we suggest that it is a 1$^-$, T_o-1 resonance. At present this tentative spin assignment is only supported by energetics. Using a ΔT splitting of 50(N-Z)/A, the observed excitation energies are within 1 MeV of the expected values for a T_o-1 member of an isospin multiplet based on the GDR in the Sn targets. Details of this calculation are presented in another contribution to this conference.



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FISSION DECAY OF THE GIANT QUADRUPOLE RESONANCE (GQR) in ^{238}U

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We have measured the fission probability of ^{238}U excited by 152 MeV α-particle inelastic scattering. The excitation region studied extended from threshold to 30 MeV. Alpha particles scattered from an 800 μg/cm^2 ^{238}U foil at 11.5° lab [a maximum in the giant quadrupole resonance (GQR) angular distribution] and at 17.5° lab [a GQR minimum] were detected in ΔE(3500μ), E(5000μ)Si surface barrier telescopes. Both telescopes subtended angles of 1° horizontally and 2° vertically. Coincident fission fragments were detected in position-sensitive gas proportional counters. One fragment detector was centered on the ^{238}U recoil direction [74° lab for α-particles scattered at 11.5° lab] and subtended 25° horizontally and 1° vertically. The second fission fragment detector was located anti-parallel to the ^{238}U recoil direction and subtended a 25% larger solid angle.

Triple coincidences between two fission fragments and inelastically scattered α-particles were recorded simultaneously with pre-scaled α-particle singles. A giant resonance peak appeared in the 11.5° lab α-singles spectrum located at 11.0 MeV with a width of ∿ 5 MeV (FWHM) which we attribute to the GQR. The GQR was unobserved in the 17.5° α-singles data. In the triple coincidence α spectrum at 11.5°, we observe an enhancement of the fission probability at 10.4 MeV with a width of ∿ 1.5 MeV (FWHM) while no such enhancement is evident in the 17.5° triple coincidence data.

According to DWBA calculations, our coincidence measurements were primarily sensitive to the K=0 component of the GQR in the deformed ^{238}U. Assuming we have located the K=0 component, we can construct the entire GQR structure using the prescription of Suzuki and Rowe.[1] With a value $\beta_2 \approx 0.25$ for the static quadrupole deformation of ^{238}U, we can then account for the shape and location of the GQR observed in α-singles from the shape and location of the identified K=0 component. Accounting for the non-observed K=1 and K=2 components in this manner,[1] we find a fission branch for the GQR in ^{238}U of ∿ 20%.

*Operated by Union Carbide Corporation under contract W-7405-eng-26 with the U. S. Department of Energy.
+Work supported in part by NSF.

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NONSTATISTICAL FEATURES OF M1 TRANSITIONS NEAR NEUTRON THRESHOLD

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Recently the interest in M1-neutron capture has grown, because beside larger transition strength than predicted also (n,γ) (d,p) correlations have been observed. Since the direct s-s(d) capture is forbidden, Clement et al.[1] attributed the correlation to a semidirect process, in which two conditions have to be fulfilled for a large effect: the target nucleus has a collective M1-giant resonance with energy $\hbar\omega_1$ and in the product nucleus bound states (l_p=0) are available at excitations E_x, such that $B_n - E_x \approx \hbar\omega_1$. These conditions eliminate closed-shell nuclei and mass ranges 40-80 or 130-220 (s-orbits are filled).

In order to provide more experimental information on correlations for s-s transitions, a systematic study has been made for A < 130 (see fig. 1) and the following conclusions can be drawn: (i) Significant correlation is concentrated in 5 odd targets with $25 \leq A \leq 35$, the only exception is ^{92}Mo (perhaps ^{102}Ru too). (ii) The abrupt cut-offs of the correlation at A=25, 35 can be well understood. For A < 25 the M1-matrix element falls to zero, as $A \to {}^{16}$O ($1d_{5/2}$ orbit is empty), while for A > 35 the $2s_{\frac{1}{2}}$-final orbit is fully occupied, i.e. not available and the M1-matrix element falls again to zero, as $A \to {}^{40}$Ca ($1d_{3/2}$ orbit is full). (iii) Large correlation found for ^{35}Cl and ^{92}Mo, where resonances are strongly involved, was however difficult to explain with the semidirect model only and valence components had to be considered too [1]. (iv) The correlation is almost absent in the mass range 80 < A < 130, which is surprising, because the facts are similar to those in $25 \leq A \leq 35$.

Very recently some evidence occurred, which may help us to understand the last two riddles. Lane[2] pointed out, that strong initial correlations can in fact arise from the semidirect process as well and this is just important to preserve the effect in nuclei, where resonances are involved.

Another vital information has been given in the dynamical theory of GDR[3], which predicts a spreading of the M1 strength to substantially higher excitations than previously foreseen for nuclei heavier than Ni isotopes. This may break the condition of the energy match for masses 80 < A < 130.

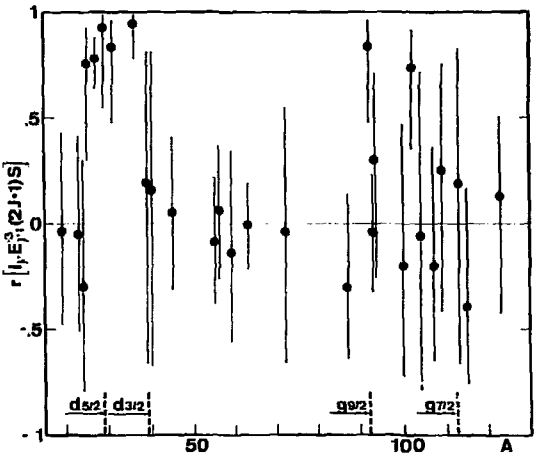


Fig. 1. Linear correlation coefficient r vs A. Error bars represent rms errors based on Fisher's transfotmation.

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ELASTIC SCATTERING $\vec{p}$-NUCLEUS IN THE GIANT RESONANCE ENERGY REGION†

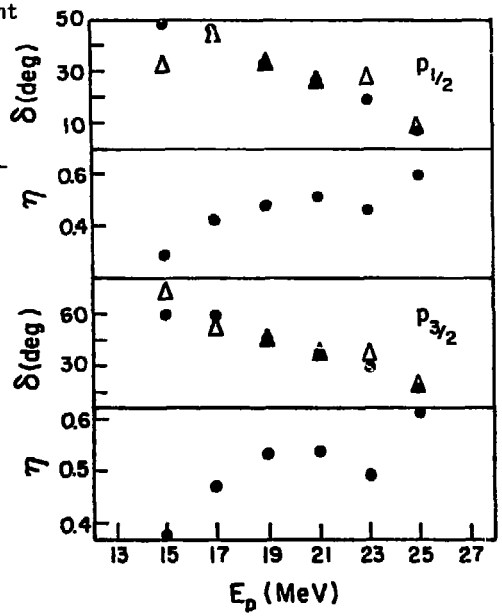
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Optical model analysis has been completed on the elastic scattering data of polarized protons on three nuclei, ^{24}Mg, ^{27}Al and ^{32}S, between 13 and 27 MeV incident energy by 2 MeV steps. The aim was to investigate for possible strong energy variations in the spin-orbit strength, like those observed for the $\vec{p}$ + ^{28}Si system in the giant dipole resonance energy region[1].

Similar energy variations have been observed in the present analysis. Moreover, a phase shift analysis has been performed on differential cross section and analysing power data. Starting values for the phase shifts were provided, at the lowest energy by the optical model analysis code[2]. One or more partial waves were searched simultaneously. As it is shown on the figure for ^{32}S, there are only small differences between the phase-shift analysis results (Δ) and the optical model analysis values (•). In general, no particular energy variations allowing resonance-like behaviour is obtained in phase shifts, reaching the conclusions of the $\vec{p}$ + ^{28}Si analysis[3], at variance with those from work[4] on ^{14}C and ^{56}Fe nuclei[4].



†Work supported in part by the USERDA, by the NSERC of Canada and by Ministère de l'Education, Québec.

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DETERMINATION OF THE SPIN OF DEEP HOLE STATES OBSERVED IN (p,d) REACTIONS†

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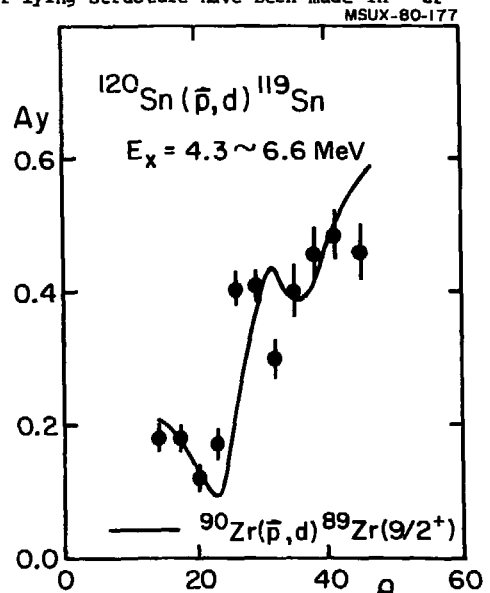
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Studies of deep hole states by single nucleon transfer reactions are limited by the fact that the angular distributions in general determine only the ℓ of the transferred particle but not the J. However Distorted Wave calculations of the analysing power in (p,d) reactions using polarized protons imply that these analysing powers should be a very good signature of the J of the final state. Measurements of the (p,d) reaction at 90 MeV on a series of Sn isotopes showed that the deep hole states near 5 and 8 MeV excitation energy, were strongly excited[1]).

The analyzing power has therefore been measured for the (p,d) reaction on targets of ^{90}Zr, ^{120}Sn and ^{208}Pb using the 90 MeV polarized proton beam from the Indiana University Cyclotron. The spin direction was flipped automatically every minute during the data taking runs. Two detector telescopes were used each consisting of a Si and Ge detector.

Measurements of the analyzing power (Ay) versus angle for a number of low lying states and for the higher lying structure have been made in ^{89}Zr and ^{119}Sn. These measurements show clearly that the Ay's are out of phase for the two low lying ℓ=1 states in ^{89}Zr, one of $J^{\pi}=1/2^{-}$ (0.595 MeV) and the other with $J^{\pi}=3/2^{-}$ (1.1 MeV). Most of the measured Ay's are positive with the exception of the 1.46 MeV $5/2^{-}$ state in ^{89}Zr where Ay is negative for angles forward of 20°. A plot of Ay for the broad structure near 5 MeV excitation energy in ^{119}Sn is shown in Fig. 1 together with a solid line which represents the shape of the empirical Ay observed for the ground state of ^{89}Zr with a known J^{π} of $9/2^{+}$. The agreement of the two measurements provides the first experimental evidence for the J of the deep hole state observed in ^{119}Sn.



†This work was supported by the U.S. National Science Foundation.

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CORRELATION OF NEUTRON MULTIPLICITY AND PROTONS FOLLOWING INTERACTION OF 110 MEV α PARTICLES WITH HEAVY NUCLEI

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Highly excited nuclei produced by medium energy (~100 MeV) light ion bombardment deexcite to a large extent by emitting protons and neutrons at the pre-equilibrium (PEQ) stage. The neutron multiplicity is a sensitive probe for the PEQ deexcitation process[1]. We studied the pre-equilibrium process of the (α, pxnγ) reaction by measuring the neutron multiplicity distribution $M_n(x)$ in coincidence with the decaying protons. Typical deformed ^{165}Ho nuclei were bombarded by 109 MeV alphas. The M_n for the (α, pxnγ) reaction was obtained by measuring discrete γ-rays of $^{168-x}$Er nuclei in coincidence with the decaying protons. The M_n gated by the forward protons does extend much toward to the low multiplicity (pre-equilibrium side) than those by the backward protons with the same excitation energy. (see Fig.). This is explained in terms the exciton number as follows. The forward protons from the (α,p) reaction are emitted at an early stage of the door way after a few collision, leaving highly excited nuclei with a few excitons. This decays by emitting fast neutrons at the pre-equilibrium stage, and contribute to the low neutron multiplicity process. The backward proton emission from the (α,p) reaction follows many nucleon-nucleon collision and results in the large number of excitons. Then it is likely to get equilibrium and decays by evaporating many slow neutrons (high multiplicity). These features are illustrated by the exciton model fit (Fig.).

In short the neutron multiplicity for the (α, pxnγ) reaction measured by the discrete γ-proton coincidence provides a useful probe for studying the property of the highly excited pre-equilibrium stage which does depend on the proton angles.

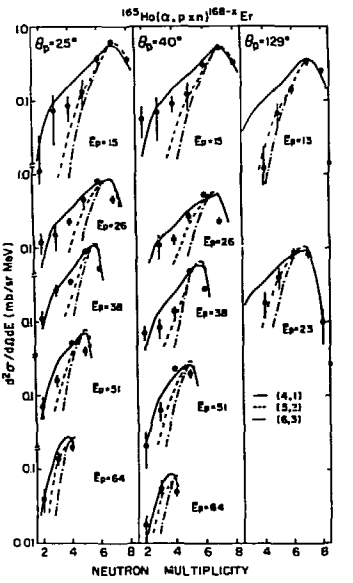


Fig. Neutron multiplicity distributions obtained in coincidence with protons with average energy $\bar{E}_p$. Solid, dashed, and dotted lines are calculations based on the exciton model with initial excitons (4,1 : 4-particle, 1 hole), (5,2), and (6,3), respectively.

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ISOBARIC ANALOG RESONANCE EFFECTS IN POLARIZED PROTON RADIATIVE CAPTURE

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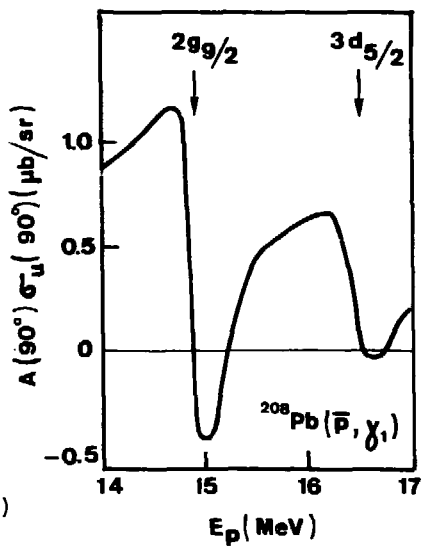
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The direct-semidirect model so far formulated is unable to provide a detailed description of the observed (p,γ) excitation functions in the energy region where the isobaric analog resonances (IAR) are located. To remove this difficulty, the model is developed [1,2] to include the IAR as intermediate states in proton E1 radiative capture. Calculations are performed for the $^{208}Pb(p,\gamma_1)^{209}Bi$ reaction in and above the giant dipole resonance (GDR) where the excitation of the single-neutron $2g_{9/2}$, $3d_{5/2}$ and $2g_{7/2}$ IAR takes place. Some first results [2] show satisfactory agreement with the 90° excitation function observed in high-resolution measurements [3].

Here we present the results provided by the model for the additional IAR effects on the 90° differential cross section when the incident proton is polarized. Expanding in Legendre polynomials, these effects can be simply expressed by

$$A(90°)\ \sigma_u(90°) = \frac{\sigma}{4\pi}\left(b_1 - \frac{3}{2}\,b_3\right) \quad ,$$

where $A(\theta)$ is the analyzing power; σ and $\sigma_u(\theta)$ are the integrated and unpolarized differential cross sections, respectively; b_1 and b_3 are coefficients related to the interference between radiations of opposite parity involved in the reaction process. The figure shows the result achieved when the E1 (direct + semidirect via GDR and IAR) and E2 (direct + isoscalar and isovector semidirect) capture processes are taken into account. From the figure we learn that a sign inversion in the spin up - spin down asymmetry at 14.92 MeV is ascribable to the presence of a remarkable $2g_{9/2}$ IAR excitation effect. Moreover, the zero value of the curve at 16.50 MeV suggests that the 90° differential cross section, owing to excitation of the $3d_{5/2}$ IAR, should not show traces of polarization effects.



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PHOTONEUTRON SPECTRA IN THE REGION OF GIANT DIPOLE RESONANCE

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The analysis of experimental data on energy spectra of photoneutrons emitted from medium and heavy nuclei shows that each spectrum consists of two components: a steeply varying part corresponding to low-energy neutrons and a slowly dropping part for high energy neutrons[1]. The values of statistical theory parameters α and T obtained from the low-energy part of spectra are close to those calculated using the neutron spectra from the reactions with heavy particles whose energy is small enough to consider the compound nucleus formation predominant.

The comparison of neutron spectra from $^{209}Bi(\gamma,n)^{208}Bi$, $^{209}Bi(n,n')^{209}Bi$ and $^{209}Bi(p,n)^{209}Po$ reactions indicates much higher contribution of the doorway state decay to the continuum in the case of a photoneutron reaction (Fig.I).

The dependence of photoneutron spectrum shape on the excitation energy is quite different for heavy nuclei and for several nuclei in the region of A~60. An estimation of the non-evaporated neutron fraction (ρ) has been performed for several values of the bremsstrahlung maximum energy $E_{\gamma m}$. For heavy nuclei Bi, Au and Ta the curve $\rho(E_{\gamma m})$ has a maximum near $E_{\gamma m}$=19-20 MeV(Fig.2). For medium nuclei ^{54}Fe, ^{56}Fe and ^{64}Zn the contribution of direct neutrons increases smoothly up to $E_{\gamma m}$=25-26 MeV. The value of ρ for these nuclei is lower than for heavy nuclei. It may be concluded that the cross section for direct photoneutron emission is shifted to a higher γ-quanta energy with respect to the GDR. The other feature of the photoneutron energy spectra from medium nuclei is the pronounced structure in the high energy part of spectra, at least for nuclei with closed or nearly closed neutron and proton $1f_{1/2}$ shells. /I/B.S.Ratner. INR USSR Academy of Sciences preprint (1980).

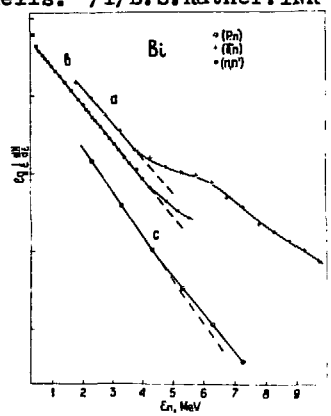


Fig.I

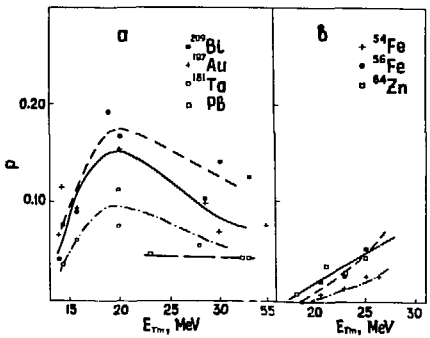


Fig.2

ON THE DESCRIPTION OF EI GIANT RESONANCE WIDTH

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As a result of systematic investigations of the electric dipole giant resonance (DGR) in the total photoabsorption cross section performed in various laboratories, an extensive experimental material is now available which allows one to follow an evolution of DGR parameters in a wide nuclear mass range.

One of the main characteristics of DGR is its width Γ. Theoretical description of DGR widths and their evolution with the change of A have been connected with considerable difficulties which possibly could explain the attempts to describe Γ in the framework of a semi- phenomenological approach. The relationship describing DGR widths for the nuclei with vibrational-type spectra of low-energy excitations in $100 < A < 150$ range was obtained in ref. [1]. An analysis of the experimental data was based on an assumption that $\Gamma = \Gamma' + \Delta\Gamma$, where damping width Γ' is connected with a coupling of the simple IpIh states with the states of more complicated nature (2p2h, 3p3h, etc.) and $\Delta\Gamma$ takes into account a coupling between the dipole oscillations and the motions of nuclear surface.

Available experimental data on DGR made it possible to perform a semi-phenomenological analysis of DGR width evolution for nuclei with $A > 150$ including deformed ones. The following expression describing DGR widths in $A > 150$ range was obtained as a result of an analysis of the experimental data:

$$\Gamma = (0.019 \pm 0.005)E_d^2 + (10.0 \pm 0.16)\beta + (0.44 \pm 0.04)(E_\beta^{0+})^{-2} \quad (\text{MeV}).$$

In this expression E_β^{0+} is an energy of 0^+-level of the β - vibrational band, β is a nuclear deformation parameter, E_d is a DGR maximum energy. Since the experimental values of E_d obtained by various groups for the same nuclei show a marked difference the energy E_d in the above expression was calculated using formula [2]

$$E_d = C_1 A^{-1/3}(1 - e^{-A/A_0}) + C_2 A^{-1/6} e^{-A/A_0},$$

where $C_1 = 77.9$ MeV, $C_2 = 34.5$ MeV and $A_0 = 238$.

It should be pointed out that if we assume that damping width Γ' does not depend on energy, the following simple expression could be obtained which describe quite well the behaviour of experimental DGR widths [1-4] in a very wide A range (at least from $A \sim 100$ up to ~ 200):

$$\Gamma = (3.74 \pm 0.06) + (10.0 \pm 0.16)\beta + (0.48 \pm 0.04)(E_\beta^{0+})^{-2} \quad (\text{MeV}).$$

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NUCLEAR STRUCTURE IN PHOTON ABSORPTION CROSS SECTIONS

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Total absorption cross sections σ_{abs} of Al, Ta, and Bi have been measured with 42 MeV bremsstrahlung and a liquid deuterium (LD_2) target viewed by a photoneutron time of flight (TOF) detector. The giant dipole resonance (GDR) in each nuclear cross section σ_N was observed superimposed on the atomic cross section σ_Z. Values of σ_Z calculated by Hubbell, Gimm, and Overbo fit our data at energies below and above the GDR where σ_N is negligible. We obtain σ_N experimentally from ($\sigma_{abs} - \sigma_Z$). As reported earlier[1], σ_N(Ta) displays the double-humped GDR of a prolate nucleus agreeing with estimates ($\sigma_n \simeq \sigma_N$) from the total photoneutron cross section σ_n(Ta) measured by Bramblett et al. and by Bergère et al. The GDR of Al agrees with σ_{abs} measurements by Ahrens et al., showing somewhat more structure. The GDR of Bi agrees with measurements of σ_n(Bi) by Young and by Harvey et al. At energies below the GDR where our LD_2-TOF spectrometer has very good energy resolution (30 keV at 6 MeV), considerable structure appears in σ_{abs}(Bi). The peaks labelled with photon energy in Figure 1 could be random clumps of sharp absorbing states whose spacings are comparable to their widths. Many weak states in ^{209}Bi have been observed by Chapuran and Moreh in photon resonance scattering. Stronger peaks which correlate in energy but not in relative strengths with ours were reported by Laszewski and Axel in γ-scattering with poorer resolution. Can the peaks in σ_{abs}(Bi) be individual excited states of ^{209}Bi? There is structure in the ^{208}Pb(γ,n) cross section[2] in the same range of photon energy, with features large enough that they might be seen in absorption. Excitation of closed neutron shells common to both nuclei may cause the structure in σ_{abs}(Bi) as well as the dipole states in the ^{208}Pb(γ,n) reaction.

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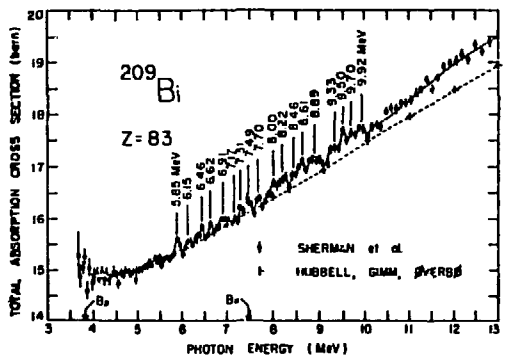


Figure 1. Meaaured photon absorption cross section of ^{209}Bi (dots), compared to the calculated atomic cross section (crosses). The photon and neutron separation energies B_p and B_n are indicated. The nuclear absorption is the area between the solid and dashed curves.

INTERFERENCE EFFECTS BETWEEN E1,E2 RESONANCES IN THE $^{206,207}Pb(\gamma,n)$ REACTION

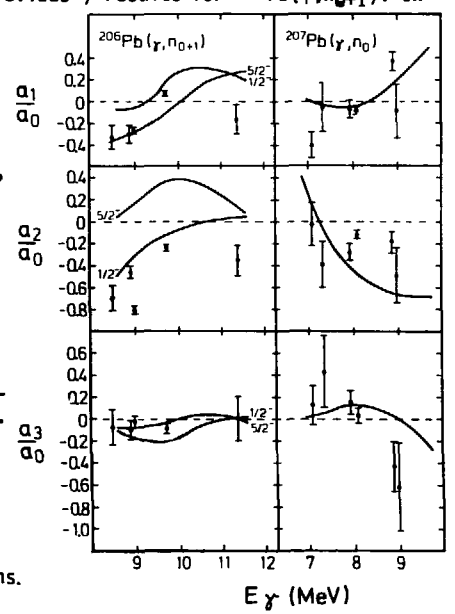
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A systematic study of the (γ,n) reaction in lead isotopes is currently under progress at our laboratory. In a previous work[1] we have presented experimental evidence for the existence of E1-E2 interference in the $^{206}Pb(\gamma,n)$ reaction. This evidence was inferred from the asymmetry around 90 of the angular distribution of the photoneutrons. The purpose of this study is to present results for the $^{207}Pb(\gamma,n)$ reaction and improved theoretical calculations for $^{206,207}Pb(\gamma,n)$.

Monoenergetic ($\Delta E \approx 20eV$) photons in the energy range 7-11.4MeV were produced by thermal neutron capture in nickel and chromium disks placed near the core of the IRR-2 reactor. The photoneutrons were detected in a high resolution ^3He detector placed on a movable arm at 20cm from the target position. Eleven angles were measured between 40-140. The good energy resolution (about 30keV at 1MeV) enabled measurement of angular distributions of neuron groups leading to ground state and various excited states in the residual nucleus.

In the figure we present the a_i/a_0 coefficients of the Legendre polynomials for the $^{207}Pb(\gamma,n)$ reaction and the previous[1]) results for $^{206}Pb(\gamma,n_{0+1})$. In both cases non-zero values of a_1/a_0 and a_3/a_0 were obtained, indicating existence of E1-E2 and maybe also E1-M1 interference effects. The solid lines were obtained from calculations based on the direct-semidirect model[2,3]). The giant E1 and isoscalar E2 resonances were taken into account, the latter one exhausting the EWSR, while the E1 strength was taken from experiment[4]). The lines marked $5/2^-$, $1/2^-$ correspond to calculations for the transitions to the ground state and first excited 2.3keV state in ^{205}Pb, which could not be resolved energetically.



The calculations presented here for $^{206}Pb(\gamma,n)$ are closer to the experimental data than the previous ones[1]. A possible reason is the introduction of complex volume form for the particle-vibration coupling[5]). The results for $^{207}Pb(\gamma,n_0)$ follow the general trend predicted by the calculations, although more experimental data is needed to get more definite conclusions.

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THE (γ,p) REACTION MECHANISM AND THE ISOSPIN SPLITTING IN THE ^{89}Y GDR

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P. Van Otten, D. Ryckbosch & P. Berkvens

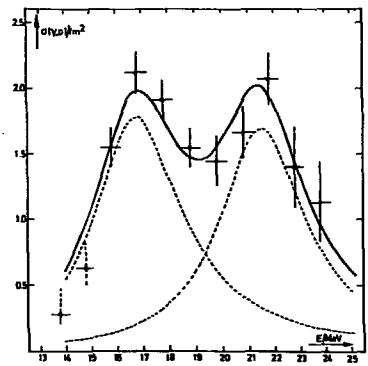
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The properties of the nucleus ^{89}Y were experimentally investigated by means of the ^{89}Y(γ,p)^{88}Sr photonuclear reaction, in the energy region of the electric giant dipole resonance.

It was possible to separate some of the reaction channels, i.e. (γ,p_0), (γ,p_1), ... by means of the construction of an artificial monoenergetic photon beam, based upon the weighted sum of three consecutive bremsstrahlung spectra. For these channels the absolute cross section and angular distributions could be determined. This detailed knowledge of the individual cross sections allowed us to draw conclusions about the reaction mechanism and about the structure properties of ^{89}Y.

A lower and an upper limit for the quadrupole contribution in the (γ,p_0) channel could be deduced as there exists a simple relationship between the angular distribution coefficients and the T-matrix elements. These limits amount to 6 % and 22 % respectively of the ($\Delta T = 0 + \Delta T = 1$) E2 energy-weighted sum rule.

Since the complexity of the low-lying excited states in the residual nucleus ^{88}Sr is known, this means that these are mainly states with a proton-hole configuration, it was possible to separate both the direct and the statistical proton decay channels of the coherent dipole state. Statistical (γ,p) decay is small below 18 MeV and goes up to about 50 % of the total (γ,p) cross section at energies higher than 22 MeV. Only 25 % of the total energy-integrated cross section up to 24 MeV is due to the statistical process.



Summing the different (γ,p) channels allows us to obtain the total (γ,p) cross section which shows a clear splitting of the dipole resonance (see fig.). This splitting can be explained by the existence of a $T_>$ collective dipole state 4 MeV above the $T_<$ giant resonance. The latter one can be observed in the (γ,n) reaction because neutron decay from the $T_>$ resonance is isospin forbidden. A Lorentz line with the parameters obtained in the (γ,n) channel is fitted to the first maximum in the (γ,p) cross section, while a Lorentz line fitting to the second maximum shows that the FWHM is about 4 MeV for the $T_>$ resonance, located at 21.5 MeV excitation energy. The ratio of the $T_>$ and $T_<$ dipole strengths, obtained from (γ,n) and (γ,p), has a value of 0.12 ± 0.02 which is in agreement with the theoretical estimation of Fallieros[1].

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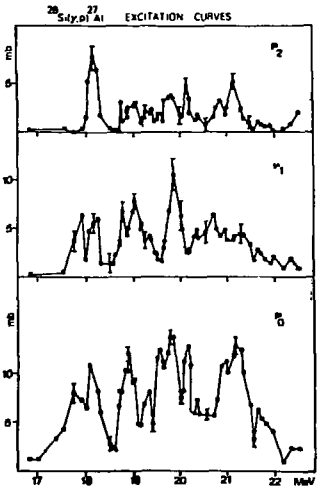
$^{28}Si(\gamma,p)^{27}Al$ AND $^{28}Si(\gamma,\alpha)^{24}Mg$ REACTIONS IN THE GIANT DIPOLE RESONANCE REGION[†]

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Using the tagged photon beam from the MUSL-II superconducting microtron, the emission of protons and alphas from the giant dipole resonance of ^{28}Si has been measured. Silicon detectors of different thickness were used as both targets and detectors. The energy range covered was 15.6-22.5 MeV and the resolution of the incident photons was 150-200 keV. Several proton decay channels up to an excitation energy of 5 MeV and α emission to the ground state and first excited state were observed.

For protons the decay to the ground state dominates but considerable strength is also observed in the p_1, p_2, p_4 and p_5 channels. As an example the partial cross sections for the first three states are shown in the figure. The α strength is an order of magnitude smaller and the two final states are almost equally populated.



The partial cross sections for the ground state channels were compared with those obtained in p and α capture[1,2]). After averaging the data to comparable energy resolution the (p,γ_0) and (γ,p_0) cross sections were in agreement, but the (α,γ_0) and (γ,α_0) cross sections were not.

Many peaks of intermediate structure (Γ 300 keV) seen in the (γ,p_0) cross section are also observed in the cross sections for the excited states.

Comparison with Hauser-Feshbach calculations indicates that proton decay is predominantly direct but the alpha decay is mainly statistical. The structual overlap between the GDR and the final states is also revealed from comparison of the integrated partial cross sections with spectroscopic factors from the (d,^{3}He) reactions[3]).

[†]This work was supported in part by the National Science Foundation grant number NSF PHY 77-27281,
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COULOMB DISSOCIATION OF ^{18}O†

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Measurements of fragmentation cross sections have been made with 1.69 and 0.85 GeV/nucleon ^{18}O projectiles incident upon targets of Be, C, Al, Ti, Cu, Sn, W, Pb, and U at the LBL Bevalac. The Coulomb dissociation cross sections for the reactions T + ^{18}O → T + ^{17}O + n, T + ^{16}O + 2n, and T + ^{17}N + p were determined and were found to agree in magnitude and Z(target) dependence with predictions based upon the known photonuclear cross sections[1] and classical relativistic virtual-photon theory.

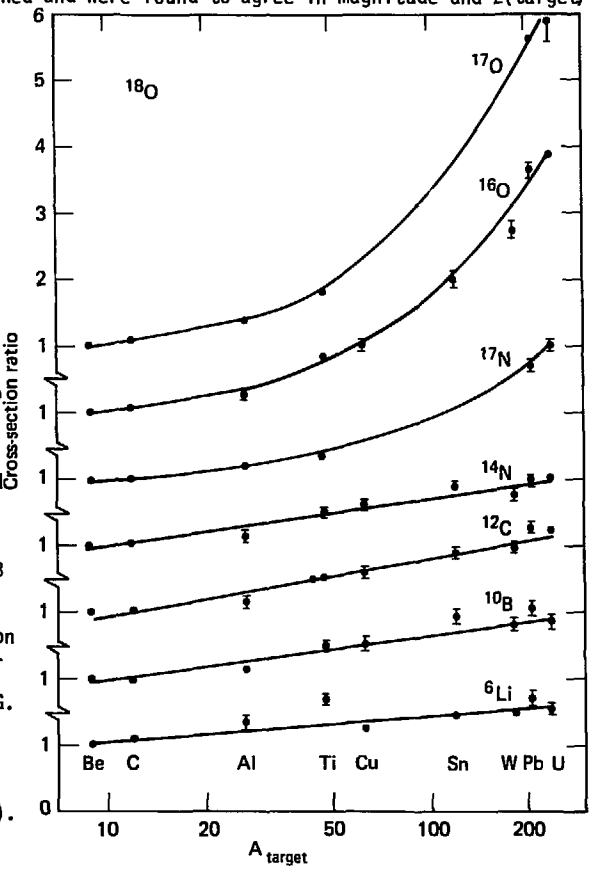


Figure Caption: Ratios of differential (in momentum) fragmentation cross sections $\sigma(T,F)/\sigma(Be,F)$ for the reaction ^{18}O + T → F + X at 1.69 GeV/nucleon with target T and fragment F. Cross sections for ^{17}O, ^{16}O, and ^{17}N fragments are enchanced by Coulomb dissociation for large-Z targets.

†This work was supported by the U.S. Dept. of Energy under contract numbers W-7405-ENG-48 (LLL) and W-7405-ENG-78 (LBL) and by the National Aeronautics and Space Administration under Grant NGR 05-003-513.

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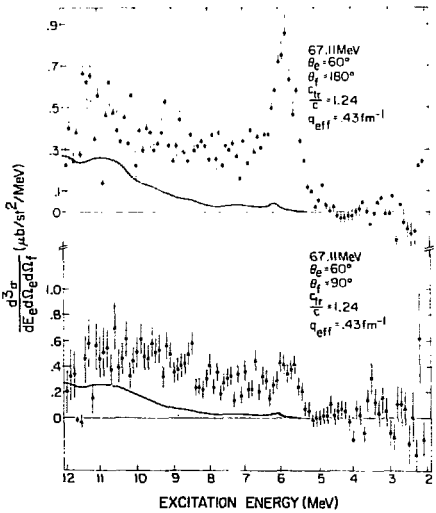
THE COINCIDENT ELECTROFISSION CROSS SECTION FOR ^{238}U NEAR THRESHOLD+

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Using the 100% duty cycle electron beam from the University of Illinois superconducting microtron we have measured the coincident electrofission cross section in the region of the fission threshold and above (2 MeV < ω < 12 MeV). Electron beam energies of 46.5 to 67.0 MeV and scattering angles of 60° and 80° were used, yielding momentum transfers q=.35-.59 fm^{-1}. Coincident fission fragments were observed at 90° and 180° relative to the q axis by two thin (~ 500 μg/cm^2), 500 msr. plastic scintillation detectors.

The cross sections measured at q=.43fm^{-1} are shown in the figure as a function of excitation energy. The larger cross section at 180° near fission threshold indicates a dominance of K=0. As expected, this anisotropy disappears at higher excitation energies due to the statistical population of the K states. The solid curve in the figure is the E1 contribution to the cross section calculated from photofission data assuming an isotropic angular distribution and the E1 transition charge density of Pitthan et al[1]. Note that electrofission is observed at energies lower than would be implied by E1 alone, as would be expected for E0 or E2 processes. The data clearly show substantial fission probability for multipoles other than E1 throughout the measured energy region. Given the limited momentum transfers involved this strength is most likely E0 and E2. The sharp decrease in the cross section above 6 MeV is due to the reduction of the fission branch by a factor of ~3 due to neutron competition. The fission branch may continue to decrease to about 20%, as has been observed for E1 fission[2], until energies sufficient for second chance fission (ω ~ 12.6 MeV). The energy dependence of the strength function for higher multipolarity is almost proportional to the cross section above the solid line except for possible bias introduced by an energy dependent fission probability. The determination of the magnitude of this strength function will be sensitive to the radial dependence of the transition charge density, and require a complete analysis of data for all measured momentum transfers.



+This work was supported in part by the National Science Foundation under grant NSF PHY 77-27281.

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$^{208}Pb(\vec{n},\gamma_0)$ IN SIMPLE DOORWAY STATE MODELS

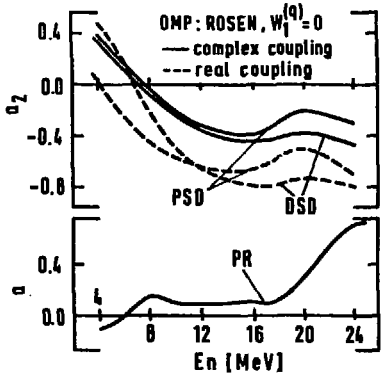
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A fully microscopic discription of the radiative nucleon capture as well as its inverse reaction in the GDR region requires a shell-model state obtained by an exact diagonalization with continuum included. To our knowledge such a calculation has not been done yet properly. All the studies of these reactions have relied to the analysis of experimental data within simple semiphenomenological doorway state models. In fact, almost exclusively the so called direct-semidirect (DSD) model has been used. Only very recently an alternative simple model appeared, the pure-resonance model (PR)[1], in a more complete form called the pure-semidirect (PSD) model[2].

There is an important difference in the physical view of the two models. While the DSD model allows partial decoupling of the incident (or outgoing) particle orbit from the GDR, the PSD (and PR) model assumes that all the dipole strength is concentrated in the GDR.

Of course a confrontation of theoretical predictions to experimental data is necessary to find out which physical view is closer to the truth. We have calculated in all three model versions the excitation functions and the angular distributions for $^{208}Pb(\vec{n},\gamma_0)$ reaction, which seems to be a most valuable case to study. Our results show, that a) the excitation function is strongly dependent on the strength of the imaginary term in the particle-vibration coupling interaction[3] in the DSD model, but only moderately in the PSD (and PR) model, b) the excitation function of the PSD model is more asymmetric than the one of the PR model, c) the angular distribution coefficient a_2 is drastically dependent on the nature of the coupling interaction in all three approaches; while similar results for a_2 emerge if strong imaginary coupling term is applied, a "shift" of few MeV toward lower energies is found for the PSD model if the coupling is real, d) good quality polarized neutron experiment is needed to get the knowledge of resonable limits for dipole matrix elements, and e) the latter is even more true for the case of quadrupole strength.



Some of the results are shown in the Fig.

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THE ANGULAR DISTRIBUTIONS OF THE $^4He(\gamma,p)^3H$ AND THE $^4He(\gamma,n)^3He$ REACTIONS BETWEEN 80 AND 150 MeV*

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In recent ten years, studing highly excited regions above GDR have been attracting both experimental and theoretical attentions because it is a source of many informations about nucleon-nucleon interactions with Δ(1236) resonance and mesonic effect in complex nuclei. Experimental data in detail are required for the quantitative analysis, and the electromagnetic interaction is one of the best probe for this purpose because it is well understood and weak.

We measured the angular dependence of the cross sections for the $^4He(\gamma,p)$ and (γ,n) reactions for $80 < E\gamma < 150$ MeV using a bremsstrahlung beam having an end point energy of 150 MeV which was produced by the Saskatchewan Lineac. A 2.5 atm ^4He gas target was used. Four telescope counters, each of which employs two transmission type silicon surface barrier detectors and a pure germanium detector, with overall energy resolution $\Delta E/E < 1\%$, were used for the experiment simultaneously. The counters also permitted the identifications of the particles, and tritons and ^3He's emitted by two-body breakup were detected at eight angles and then the data were converted into the (γ,p) and (γ,n) reactions. An NBS type P2 ionization chamber was used for monitoring the bremsstrahlung beam dose and Shiff's formula was used for the bremsstrahlung spectrum. The cross sections obtained are monotonically decreasing with incleasing energy for all angles, and no noticeable structure was found, as shown in fig. 1 for $\theta^{LAB}=105°$. Data analysis is on the way, however, preliminary results of the angular distributions are shown in fig. 2 with the best fit curve by $\Sigma_{\ell=0}^{\ell=4} P_\ell(\cos\theta)$. They show strongly forward peak and small bump at backward angles for both reactions.

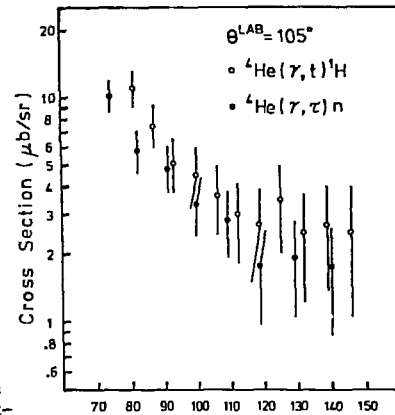


Fig.1

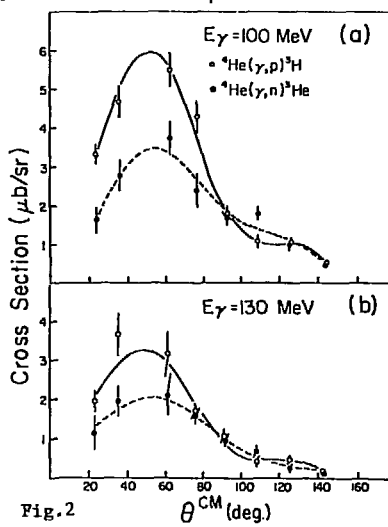


Fig.2

* This work was supported in part by the Natural Sciences and Engineering Research Council of Canada.

^{3}He capture reactions to ^{7}Be, ^{17}F, ^{18}F, ^{19}Ne, ^{23}Mg and ^{43}Ti

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Excitation functions and angular distributions for the above ^{3}He capture reactions have been studied in the range $E_{^{3}He}$ = 3 - 19 MeV, which covers the giant resonance region. A preliminary version of some of the data was presented last year [1].

Most excitation functions show a broad structure with a width of several MeV, with narrower peaks superimposed on it. Angular distributions show that the capture is mainly dipole, but with a significant opposite-parity component.

Shell-model calculations now in progress suggest that the giant dipole resonance is excited in almost all cases. However, the excitation is an order of magnitude weaker than in proton capture. The suggestion made in earlier work, that the narrower peaks can be understood on the cluster model, seem to be incorrect; in all cases the calculated ^{3}He width for cluster states is substantially larger than the widths observed here.

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SELFCONSISTENT DESCRIPTION OF PHOTOABSORPTION CROSS-SECTIONS

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We consider the integrated photoabsorption cross-sections σ_{-1} and σ_{-2}, with $\sigma_p \equiv \int \sigma(\omega)\omega^p d\omega = 4\pi^2(e^2/\hbar c)\Sigma E_n^{p+1}|\langle n|D_z|0\rangle|^2$, D_z being the dipole operator ; σ_{-1} is proportional to the ground state expectation value $\langle 0|D_z^2|0\rangle$ and gives direct information on two-body correlations [1], σ_{-2} is proportional to the static dipole polarizability. The dipole strength is computed in the HF-RPA selfconsistent scheme, using Skyrme-type interactions. The polarizability is also directly obtained by performing a constrained HF calculation.

Results are presented in the table, together with the experimental values obtained by measuring either the total photoabsorption cross-sections (^{16}O and ^{40}Ca) [2] or the photoneutron cross-sections (γ,xn) on ^{208}Pb [3]. In brackets we give the values of σ_{-1} calculated with the HF uncorrelated ground state, i.e. the Tamm-Dancoff evaluation of σ_{-1}. The last column and the bottom line are respectively the lower bounds of σ_{-2} given by sum-rule techniques, and Migdal's estimate [4] of the polarizability $\sigma_{-2}=2\pi^2(e^2/\hbar c)(R^2A/40a_\tau)$ where R is the sharp nuclear radius and a_τ is the volume symmetry energy.

The following conclusions can be drawn : 1) General agreement between theory and experiment can be achieved. This provides a very strong indication that measurements of total photoabsorption cross-sections in light nuclei and of photoneutron cross-sections in heavy nuclei are consistent. 2) Dipole long range correlations in the ground state reduce considerably (from 25 to 40%) the uncorrelated values of σ_{-1} and bring them to agreement with the data. 3) The lower bounds of σ_{-2} are 5-15% lower than the exact RPA values. 4) Migdal's estimation is very rough.

	$\sigma_{-1}A^{-4/3}$ (mb)		$\sigma_{-2}A^{-5/3}$ (μb.MeV^{-1})					
	Exp.	Present work SIII	Exp.	Present work SIII	SkM[5]	Ska[6]	SII	Ref.[7] SII
^{16}O	0.36±0.01	0.33 (0.45)	5.8±0.1	5.0	5.6	7.7	5.0	4.8
^{40}Ca	0.33±0.01		4.8±0.1	3.9	4.3	5.8	3.8	3.4
^{208}Pb	0.22	0.22 (0.33)	2.6±0.2	2.6	2.8	3.6	2.5	2.1
				1.9	1.7	1.6	1.6	Migdal

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IS THE DECAY OF THE GIANT E1 RESONANCE IN ^{90}Zr STATISTICAL?

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The study of two strong E1 $T_>$ analogue resonances (IAR) superposed on the main ($T_<$) giant E1 resonance (GDR) in ^{90}Zr, by ^{89}Y$(\vec{p},\gamma_0)^{90}$Zr, provides a means of determining the nature of the decay of the GDR. The region of interest in ^{90}Zr is E_x = 14-17 MeV which includes the peak of the GDR at 16.5 MeV as well as the E1 IAR's at E_x = 14.4 and 16.3 MeV. Complete angular distributions of yields and analyzing powers have been obtained throughout this region.

Since ^{89}Y has a ground state with $J^\pi = 1/2^-$, only two T-matrix elements, which involve $s_{1/2}$ and $d_{3/2}$ proton waves, are responsible for radiative capture through 1^- dipole states. Analysis of the angular distributions give two solutions, one predominantly s-wave, the other mainly d-wave. If the s-wave dominated solution is preferred at E_x = 14.4 MeV (since this IAR has been assigned an s-wave character from elastic scattering[1]) and if the d-wave dominated solution is preferred in the main part of the GDR, then a crossing over of the two solutions is expected in the region in between. However, the measurements are in energy steps about equal to the target thickness, but no such crossing is observed.

A resolution of this dilemma is to suppose that a direct-semidirect (DSD) mechanism dominates the capture in the main part of the GDR ($E_x \simeq 16.5$ MeV) but that a statistical mechanism dominates around $E_x \simeq 14.4$ MeV. In the former case the angular correlation coefficients are

$$A_0 = |s|^2 + |d|^2$$
$$A_0a_2 = -0.5|d|^2 + \sqrt{2}|s||d|\cos(\phi_d - \phi_s)$$
$$A_0b_2 = (1/\sqrt{2})|s||d|\sin(\phi_d - \phi_s)$$

which lead to the desired d-wave solution discussed above. In the statistical case these equations become

$$\langle A_0 \rangle \cong |s|^2 + |d|^2$$
$$\langle A_0a_2 \rangle \cong -0.5|d|^2$$
$$\langle A_0b_2 \rangle \cong 0$$

given that the amplitudes vary smoothly and the major statistical fluctuations are restricted to the phases. The last equation accounts for the result $\langle A_0b_2 \rangle \simeq 0$ observed around $E_x \simeq 14.4$ MeV. Optical-model estimates obtained from ABACUS give $|d|^2/(|s|^2 + |d|^2) \simeq 0.3$ for a statistical mechanism. This would account for the small, but non-zero, value of A_0a_2 seen in the same region.

Thus, we can explain the trends seen in the coefficients a_2 and b_2 if we assume a statistical mechanism near $E_x \simeq 14.4$ MeV that decreases to zero near $E_x \simeq 16.5$ MeV as the DSD mechanism takes over. This model supports the observation (in other mass regions) that the decay of the main part of the GDR to low-lying hole states is definitely not statistical.

We wish to thank Frank Dietrich for helpful discussion and Mimiko Sasao for aid in carrying out the calculations. This work was supported in part by the National Science Foundation.

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A SEARCH FOR *M1* EXCITATION STRENGTH IN ^{208}Pb USING 180° INELASTIC ELECTRON SCATTERING†

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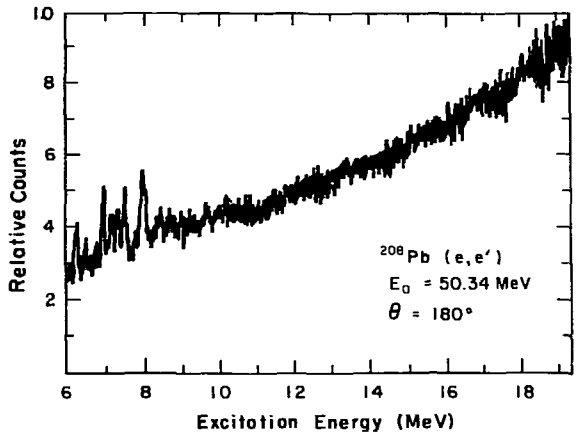
Theoretical estimates of the total *M1* strength in ^{208}Pb vary between 20 and 50 μ_o^2, considerably in excess of the presently confirmed strength of approximately 8 μ_o^2. Using an effective mass argument, Brown, Dehesa, and Speth[1]) have recently suggested that much of this missing strength may be between 10.5 and 12 MeV, an excitation region higher than previously predicted. The UMass-Bates 180° electron scattering facility has been utilized to search for *M1* strength up to excitation energies of 19 MeV.

The figure shows the scattered electron spectrum for an incident beam energy of 50.34 MeV. Of the prominent peaks observed in the 6-8 MeV excitation region, only the peak at 7.48 MeV can be associated with established 1^+ levels. This peak represents the accumulated *M1* strength[2]) of approximately 18 known 1^+ states between 7.4 and 7.7 MeV, and provides an important test for the sensitivity of our measurement.

An inspection of the 9-19 MeV excitation region in the figure reveals little evidence for narrow structure comparable in magnitude to the 7.48 MeV *M1* peak. It is concluded that any *M1* strength in this region is either very weak, or is spread broadly. Furthermore, no evidence is found for a 4.843 MeV, *M1* peak of strength 5.8 μ_o^2, as suggested by Swann[3]).

†Work supported by the U.S. Department of Energy under contract with the Union Carbide Corp., the Mass. Inst. of Technology, and the Univ. of Mass.

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EVIDENCE FOR INTERFERING GIANT RESONANCES IN ^{12}C FROM (e,e'p) COINCIDENCE MEASUREMENTS*

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Available information on giant resonances (GR) comes primarily from electron scattering, capture reactions, and photoneutron data. Singles electron scattering is inclusive; what is determined is the dependence of electromagnetic absorption on transferred momentum q and energy ω. Capture measurements provide detailed data but only for the ground state decay channel. Photoneutron measurements have either been made with monochromatic photons but with energy and angle insensitive neutron counters, or with bremsstrahlung which yields information on the ground state decay.

The (e,e'x) reaction provides all the information obtainable from capture and photoproduction and, furthermore, allows the simultaneous study of all the allowed decay channels. Moreover, the freedom of fixing ω while varying q allows the measurement of the form factors associated with discrete final states.

We have initiated studies of the $^{12}C(e,e'p)^{11}B$ reaction utilizing a 180° double focussing electron spectrometer in coincidence with a multi-counter telescope of surface barrier detectors. This system used in conjunction with the HEPL high duty factor superconducting electron accelerator permits the measurements of coincidence cross sections with a good true/accidental coincidence ratio. We have extracted yields for GR proton decay to the ground state, p_0, the first excited state, p_1, and the unresolved second and third excited states, $p_{2,3}$, of ^{11}B, at 5 proton angles for incident electrons of 86 and 126 MeV scattered at 40°.

If the GR were dominated by a single $J^\pi = 1^-$ doorway, we would expect the p_1 yield to have the same dependence on ω as that for p_0. Instead we observe that the p_1 yield peaks near ω = 24.5 MeV where the p_0 yield exhibits a minimum, suggesting an interference. This behavior persists at both E_e = 86 and 126 MeV. At the same time, the angular correlations for both p_0 and p_1 between ω = 22 and 25 MeV show very little fore-aft asymmetry along the direction of q, indicating that there is only weak interference with states of opposite parity, e.g. 0^+, 2^+ etc. This behavior of the p_1 yield relative to that for p_0 is clear evidence that more than one $J^\pi = 1^-$ doorway is important for the GR of ^{12}C. Furthermore, the change in the angular correlation pattern for p_1 relative to that for p_0 as the incident energy is raised suggests that the p_1 decay is associated with a stronger transverse form factor than is the p_0 decay (which is strongly dominated by the longitudinal form factor).

Finally, on the low ω side of the 1^- GR, a fore-aft asymmetry is observed characteristic of a large negative $P_1(\cos\theta)$ dependence while E1/E2 interference, extrapolated from the real photon point, would suggest a positive $P_1(\cos\theta)$ dependence. Such a positive dependence is observed at ω above the 1^- GR.

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NEUTRON EMISSION AFTER MUON CAPTURE BY ^{16}O

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For nuclear muon capture by light nuclei, the dominant role of isovector GDR excitations is widely accepted but incompletely verified. To examine the spins and the strengths of contributions of such states, we measured the energy spectra and n-γ angular correlations of neutrons emitted in coincidence with γ rays that identified final nuclear states. The experiment was done at S.I.N. with NaI(Tl) crystals for γ detection and with NE 213 scintillators, timed from the γ signals, for neutron time-of-flight measurements. Preliminary results for ^{16}O are discussed below.

Only two γ energies were observed, one of 5.3 MeV from the $1/2^+$ and/or $5/2^+$ state of ^{15}N, and one of 6.3 MeV from the $3/2^-$ state of ^{15}N. Figs. 1a and 1b show the coincident neutron spectra. The high energy data are in rough agreement with DWBA calculations [1] (dashed lines). The low energy parts deviate substantially from the DWBA results, and the enhancement in the 2-8 MeV region of the spectrum in coincidence with the 6.3 MeV γ's indicates a 1p-1h structure of the intermediate state. Fig. 2 shows the neutron energy dependence of the A_2 angular correlation coefficient for the 6.3 MeV γ transition. Excitation of the 1^- GDR ^{16}N state by muon capture is expected to give negative values [2] of A_2, and our data show this behavior.

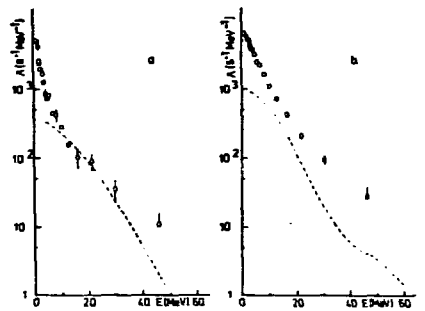


Fig. 1

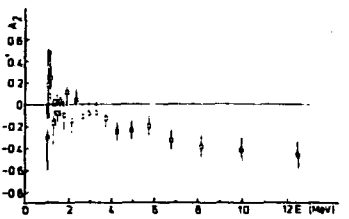


Fig. 2

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ELECTROEXCITATION OF GIANT MULTIPOLE RESONANCE IN ^{24}Mg

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and

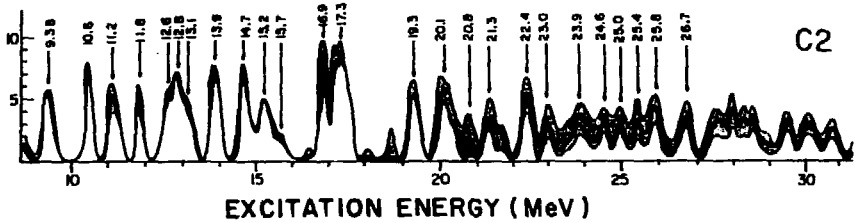
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Highly excited multipole resonances in ^{24}Mg up to 34 MeV in excitation energy have been investigated by inelastic electron scattering. The experiment was performed at Tohoku University Electron Linear Accelerator. The inelastic spectra were obtained by 100-200 MeV incident electrons and at forward scattering angles, which span a momentum transfer range from 0.37 - 1.3 fm^{-1}.

Radiatively corrected spectra have been decomposed to the dipole, quadrupole, octupole, and higher multipole transitions using the method of least square. The momentum transfer dependence of the Goldhaber-Teller and Tassie model were used in the multipole expansion. The effects of nuclear deformation on the giant resonance have been also searched by using the form factors of K=0,1 transitions for the dipole, and K=0,1, and 2 for the quadrupole resonance. These form factors were obtained by Suzuki and Rowe model.

The giant dipole strength exhausts about 85% of the Energy-Weighted Sum Rule (EWSR), with a very similar shape to the (γ,n) cross section. The prominent dipole resonances are revealed at 16.7, 17.1, 18.9 and 20.0 MeV. The quadrupole resonance is fragmented up to 34 MeV, and approximately twenty five resonances are separated in this energy region. Figure shows the quadrupole transitions resulting from the multipole expansion. The shaded area indicates the envelop of the decompositions using the combinations of the form factors for different K- numbers. The quadrupole resonance exhausts the isoscalar EWSR. The present result is in fair agreement with α-scattering experiment[1]), however the present data indicates a strong mixing of octupole states at the same energy region. The octupole strength is also fragmented, and approximately twenty octupole resonances are separated. The total octupole strength exhaust the isoscalar EWSR.



[†]Work supported by the Natural Sciences and Engineering Research Council.

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STUDY OF NUCLEAR RESPONSE TAIL BY HIGH THRESHOLD REACTIONS IN MUON CAPTURE

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In processes such as muon and radiative pion capture, weak or electromagnetic reactions are used to transfer typically a few tens of MeV of energy to the nucleus. These could be useful to study the poorly-known [1] high-energy tail of the nuclear response function.

In this contribution, we consider muon capture in complex nuclei, and show that the study of specific reaction channels, with high thresholds, can be used to discriminate various theoretical approaches to the nuclear excitation function at large energy transfer. Our chosen reactions are the muon-induced fission in nuclei around Pb, and high-multiplicity ($x \geq 6$) nucleon emission. Their observations would demonstrate a large probability for the nucleus to absorb energies above a high threshold. In our calculation, we use two typical impulse models [2] and one example [3] of the non-impulse variety. We show that these different classes of models yield significantly different yields of the high-threshold reactions discussed by us. The fission probability in the Pb region obtained in the chosen impulse models is $\sim 10^{-6}$ or lower, while the non-impulse models yield an order of magnitude higher values. The high multiplicity emission probability for multiplicity larger than 7 is zero in the impulse models, while the non-impulse response function predicts $P(8n) \approx 10^{-3}$, close to the experimental results.

1 N.C. Mukhopadhyay, Nucl. Phys. A 335, 111 (1980).

2 J. Hadermann and K. Junker, ibid. A 271, 401 (1976); M. Lifshitz and P. Singer, to be published.

3 T.E.O. Ericson et al., Phys. Lett. 69B, 161 (1977)

SINGLE PARTICLE HOLE STRUCTURE AND CORE POLARISATION IN ^{89}Y MEASURED BY ELECTRON SCATTERING

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Inelastic scattering cross sections have been measured in ^{89}Y in forward and backward direction to study the single particle hole structure around ^{90}Zr. The data have been taken over a neutron transfer range of 0.5 to 2.6 fm^{-1} at the Bates MIT Linear Accelerator.

The data in forward and backward directions allow to separate longitudinal and transverse form factors. Using simple model assumptions the transverse electric and the transverse magnetic scattering is separated, while the longitudinal form factor is analysed with the Fourier Bessel analysis to give a representation of the transition charge in coordinate space.

This transition charge density compared to the single particle prediction shows a reduction in the magnitude of the charge density in the interior of the nucleus while it shows an enhancement at the surface.

This discrepancy is not substantially changed if the non-realistic shell model wave functions of Hofstra and Allaart* are being used. It indicates a residual p-p interaction that is repulsive in the interior and attractive at the surface of the nucleus.

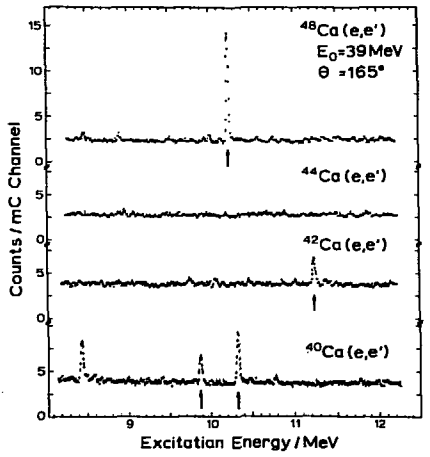
*Z. Physik A292 (1979) 159

MAGNETIC DIPOLE AND QUADRUPOLE TRANSITIONS IN NUCLEI STUDIED WITH HIGH-RESOLUTION INELASTIC ELECTRON SCATTERING*

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We have continued our search for M1 and M2 transitions in high resolution (e,e') scattering ($\Delta E \approx 30$ keV FWHM) at low momentum transfer ($q<0.7$ fm^{-1}) in order to study such topics as isospin mixing, ground state correlations and the distribution of transition strength, magnetic sum rules and the strength of the effective p-h interaction in nuclei. We report in detail about the following nuclei: ^{12}C: The Coulomb matrix element for the mixing between the J^π, $T = 1^+$; 0 state at 12.71 MeV and the 1^+; 1 state at 15.11 MeV has been determined to be $\langle H_C \rangle = 117 \pm 20$ keV. ^{16}O: M1 transitions previously seen in (e,e') and $(\vec{p},\gamma)$ reactions to states at $E_x = 16.22$, 17.14 and 18.80 MeV carry a transition strength of $\Sigma B(M1)\uparrow = 0.65 \pm 0.12 \mu_K^2$. ^{28}Si: 3 additional 1^+ states at $E_x = 14.03$, 15.15 and 15.50 MeV have been detected besides the 5 known 1^+ states at lower energy. The total strength $\Sigma B(M1)\uparrow = 6.78 \pm 0.32 \mu_K^2$ in ^{28}Si is in excellent agreement with theoretical predictions and point to sizable ground state correlations. ^{40,42,44,48}Ca: Strong ground state correlations are also responsible for the occurence of M1 transitions found in ^{40}Ca, while $f_{7/2} \rightarrow f_{5/2}$ spin flip M1 transitions are expected in the other Ca-isotopes. As the arrow in the figure indicates ^{42}Ca possesses only one weakly excited 1^+ state at $E_x = 11.24$ MeV and ^{44}Ca surprisingly none. In ^{48}Ca we discovered, however, a strong 1^+ state at $E_x = 10.23$ MeV ($B(M1)\uparrow = 4.0 \pm 0.2 \mu_K^2$) which should be ideally suited for the study of precritical phenomena in the context of pion condensation. ^{90}Zr, ^{140}Ce and ^{208}Pb: Contrary to the lighter nuclei only in ^{90}Zr could three weakly excited 1^+ states at $E_x = 8.23$, 9.00 and 9.37 MeV ($\Sigma B(M1)\uparrow = 0.8 \pm 0.1 \mu_K^2$) still be identified while there is in (e,e') no indication for M1 strength in the heavier nuclei. Especially, the search for fragmented M1 strength between $E_x = 8$-11.5 MeV in ^{208}Pb has been negative (detection limit $\lesssim 0.5 \mu_K^2$). Also, the M2 strength (which follows an $E_x \approx 44 A^{-1/3}$ MeV law) is much reduced in heavy nuclei (EWSR estimates are 14, 33 and 27% in ^{90}Zr, ^{140}Ce and ^{208}Pb, respectively) and point to a strong pionic renormalization of the g_s factor over and above normal core polarization.



* Work supported by Deutsche Forschungsgemeinschaft.
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HIGH-RESOLUTION INELASTIC ELECTRON SCATTERING ON ^{208}Pb AND DISTRIBUTION OF THE ELECTRIC DIPOLE AND QUADRUPOLE STRENGTH*

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We have extended our high-resolution ^{208}Pb(e,e') experiment[1]) performed at the DALINAC into the excitation energy range from $E_x \approx 8$-15 MeV. The four broad peaks at $E_x \approx 8.9$, 10.2, 10.6 and 11.2 MeV seen in our (e,e') experiment with medium energy resolution ($\Delta E \approx 250$ keV FWHM) and previously identified with the isoscalar E2 giant resonance[2]) are now dissolved into many fine structure peaks (c.f. upper two spectra in fig. 1). Measurements of angular distributions and excitation functions and a comparison of them with DWBA predictions employing transition densities calculated in the MSI-RPA model yields the rather detailed E1 and E2 strength distributions shown in Fig. 2.

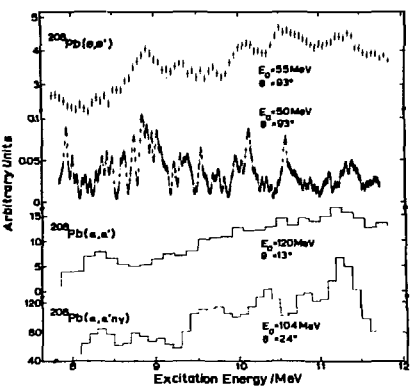


Fig. 1

The E1 strength distribution is in fair agreement with what is known from (γ,γ) and (n,γ) experiments but there is considerably less E2 strength (the EWSR for isoscalar E2 transitions is only exhausted by 20%) detected than in hadron scattering experiments, especially seen in (α,α') reactions[3,4]). Two ^{208}Pb(α,α') spectra are plotted in the lower part of fig. 1. The problem to be solved is if the same nuclear phenomena are measured in (e,e') and (α,α').

*Work supported by Deutsche Forschungsgemeinschaft.

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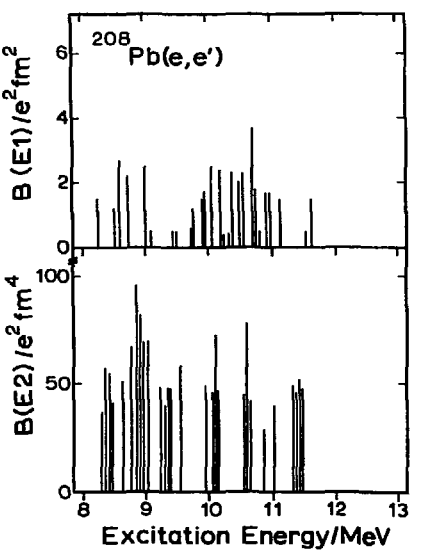


Fig. 2

A SEARCH FOR TWO-STEP RESONANT α-EXCHANGE IN THE ELASTIC SCATTERING OF $^{6}Li + ^{12}C$

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Several years ago the first polarised ^{6}Li experiments revealed an anomaly for scattering in ^{12}C at 22.8 MeV[1]. The origin was suggested to be contributions from the $^{12}C(^{6}Li,d)^{16}O(d,^{6}Li)^{12}C$ two-step α-exchange process, via a strong α cluster state in ^{16}O. This 16.2 MeV 6+ state is strongly excited in $^{12}C(^{6}Li,d)^{16}O$, and shows up as a resonance in $\alpha + ^{12}C$ scattering. At 22.8 MeV the energy of an α-cluster in ^{6}Li corresponds to the resonance energy when allowance is made for the Coulomb interaction of the accompanying deuteron.

If this interpretation is correct, we expect to see similar effects at energies corresponding to neighbouring strong α-cluster states in ^{16}O (e.g. the 5^- at 18.6 MeV and 7^- at 20.9 MeV). To look for these we have measured excitation functions at 10 angles over the energy range 20-36 MeV (ΔE = 400 keV) for the elastic and 2^+ 4.43 MeV first excited channel. While the 22.8 MeV anomaly appears as an ∿ 1 MeV wide structure at intermediate angles in the elastic channel, and back angles in the inelastic, no evidence is seen for other states.

The elastic data shows large back-angle cross sections, orders of magnitude above conventional optical model calculations. This is a feature common to many heavy ion systems and has been suggested to be evidence for either compound nucleus, elastic exchange, two-step or quasi-elastic resonance effects. It is hoped that analysis of this extensive body of data will help differentiate these processes.

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* Work supported by the National Science Foundation
1. W. Weiss et al., Phys. Letts. 61B (1976) 237.

THE $^{33}S(n,\gamma)$ REACTION WITH THERMAL NEUTRONS†

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Since ^{33}S has low natural abundance (0.75%) and small thermal neutron capture cross section (≈350 mb), the ^{33}S (thermal n,γ) reaction has not been investigated till now. We have studied this reaction utilizing a 1.1 g target enriched to 88% in ^{33}S placed in the Los Alamos Omega West Reactor thermal column at a distance of 1.7 m from the reactor core. A 26 cm^3 Ge(Li) detector with a NaI(Tℓ) annulus was located approximately 6 m from the target and was operated in either a Compton-suppressed or a pair spectrometer mode. Approximately 260 γ rays were identified in the 0.1-11.5 MeV region, several with intensities as low as 0.03 photons/100 n-captures. Over 170 γ rays have been incorporated into a ^{34}S level scheme with 50 levels (see Table). The 38 primary γ rays placed on this scheme account for ≈75% of the thermal neutron capture cross section. A surprising number of γ rays in the 1.1-3.5 MeV region (10-30% of the neutron separation energy which was determined to be 11417.23 ± 0.15 keV), with intensities as low as 0.02 and as high as 2.6 photons/100 n-captures, appear to be primary γ rays leading to 14 highly excited states in ^{34}S.

Table 1. Energy Levels in ^{34}S

E(level) (kev)	J^π[a]	E(level) (kev)	J^π[a]	E(level) (keV)	E(level) (keV)
0.0	0^+	5679.9	2^-	6954.3*	8385.4
2127.6	2^+	5755.9	1^-	7110.4	8506.8
3304.2	2^+	5847.5	0^+	7219.3	8615.7
3916.4	0^+	5998.1*	2^+	7248.1*	8727.7
4074.7	1^+	6121.8	2^+	7364.4	8805.5
4114.8*	2^+	6168.9	3^-	7556.8*	8874.1
4624.4	3^-	6250.5*	4^+	7629.9	9026.3
4689.0*	4^+	6256.1*	$(1,3)^-$	7781.1	9208.1
4876.8	3^+	6342.4	1^-	7974.6	9546.1
4889.8	2^+	6421.3*	4^-	8036.1*	9933.3
5228.2	0^+	6478.8	1^-	8138.2	10311.5
5322.5	2^-	6681.4*	$(0-3)^-$	8175.3	
5381.0	1^+	6862.7*	5^-	8185.4	

*Not fed by primary γ rays in thermal neutron capture.
[a]P.M. Endt and C. van der Leun, Nucl. Phys. A310 (1978) 378.

†Research sponsored by the U.S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation (ORNL) and under contract W-7405-eng-36 with the University of California (LASL).

ON TWO VERSIONS OF THE DIRECT-SEMIDIRECT MODEL

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Original direct-semidirect (DSD) model[1]) is an intuitive approach to describe the radiative fast nucleon capture. Its direct part corresponds to the radiating of the incident particle from it initial optical model state, and the semi-direct part to the radiating of the target nucleus from its "GDR state". There are several ways to derive the model from general reaction theories. We discuss two of this forms which may be obtained starting from Feshbach's unified reaction theory.

The transition amplitude of the first form has been written[2]) before the approximations as:

$$T_I = \langle \Psi_f | \mathcal{H}_\gamma | \Psi^{(+)}_{GOPT} \rangle + \langle \Psi_f | \mathcal{H}_\gamma \frac{1}{E - \mathcal{H}_{dd}} \mathcal{H}_{dP} | \Psi^{(+)}_{GOPT} \rangle$$

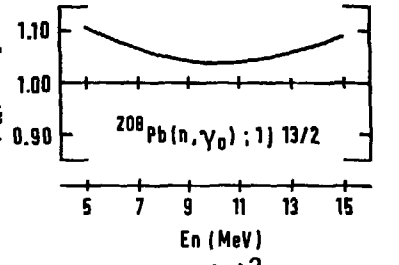
and the second one[2]):

$$T_{II} = \langle \Psi_f | \mathcal{H}_\gamma | \chi_{GOPT} \rangle + \langle \Psi_f | \mathcal{H}_\gamma | [1 + (E^+ - \mathcal{H}_{PP})^{-1} \mathcal{H}_{Pd}] \cdot \frac{1}{E - \mathcal{H}_{dd} + \mathcal{H}_{dP} G^{(+)}_P \mathcal{H}_{Pd}} \mathcal{H}_{dP} | \chi^{(+)}_{GOPT} \rangle$$

Here, P is the projector to elastic scattering channel (including the GDR part), d is the projector to the doorway state (GDR state with no elastic channel part), $\mathcal{H} = H + H(E - H_{qq} + iI)^{-1} H$, where q = 1-P-d. Further, $G_P = (E^+ - \mathcal{H}_{PP})^{-1}$.

The two transition amplitudes are of course identical. However, for the practical calculations several approximations are applied and various phenomenological ingradients used. The question arises whether the two forms for T lead to the identical final results.

To study the problem, we have examined the case of $1j_{13/2}$ amplitude of $^{209}Pb(n,\gamma_1)$ reaction. The results partially based on estimates rather than exact calculations are shown as $|T_{II}|^2/|T_I|^2$ in the Fig. In calculations we have used well known approximations[1]) to get the working formula for T_I, and similar approximations[2]) in the case of T_{II}. For example, the generalized optical model potential wave function $|\Psi^{(+)}_{GOPT}\rangle$ was replaced by the phenomenological OMP wave function which describes the elastic scattering, and $|\chi^{(+)}_{GOPT}\rangle$ by the wave function of the same phenomenological OMP but with excluded doorway state effects. We see that the differences in the two $|T|^2$ are small, i.e. that the two results are very close. This may not always be the case. For example the use of a pathological OMP may be reflected in large discrepancies between the two calculated reaction amplitudes.



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2. M.Potokar, Phys. Lett. B in press.

A PUZZLE IN A FAST PROTON CAPTURE REACTION?

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It is well known that electromagnetic probe is an ideal tool to study rather directly the nuclear wave functions involved. In the case of radiative fast nucleon capture and its inverse photo-reaction (decay of GR-s) the real photons are involved. Consequently, the dipole transitions are strongly dominant, so that the total cross section ($4\pi A_0$) and the expansion coefficients a_2 and b_2 in the angular distribution of the cross section and the analyzing power, respectively, are mainly determined in terms of dipole matrix elements. Assuming the reaction is of direct type, in special cases the knowledge of A_0, a_2 and b_2 allows us to specify completely the dipole matrix elements. In general, however, this is not possible, and we only can get certain restriction on their absolute values and relative phases. In any case, due to the quadratic nature of the equations relating the matrix elements to the coefficients, a theory has to be employed to select the physical solution. In turn, of course, we learn on of the nuclear wave function.

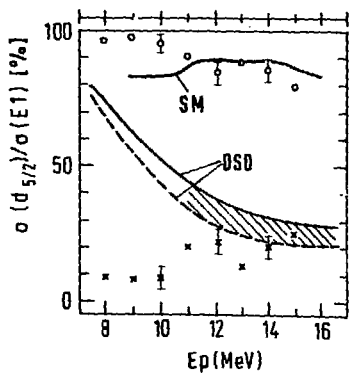
Here we report on analysis of $^{54}Fe(\vec{p},\gamma_0)$ reaction. In this case A_0, a_2 and b_2 are related to dipole transition amplitudes $d_{5/2}$, $g_{7/2}$ and $g_{9/2}$ by

$$A_0 = 3|d_{5/2}|^2 + 4|g_{7/2}|^2 + 5|g_{9/2}|^2$$

$$a_2A_0 = -0.43|d_{5/2}|^2 + 0.86|d_{5/2}||g_{7/2}|\cos(5,7) + 5.67|d_{5/2}||g_{9/2}|\cos(5,9) + 1.91|g_{7/2}|^2 - 1.26|g_{7/2}||g_{9/2}|\cos(7,9) - 1.66|g_{9/2}|^2$$

$$b_2A_0 = -1.00|d_{5/2}||g_{7/2}|\sin(5,7) + 1.89|d_{5/2}||g_{9/2}|\sin(5,9) - 1.89|g_{7/2}||g_{9/2}|\sin(7,9)$$

On theoretical grounds it can be shown that $g_{7/2}$ amplitude is small. When ignoring it in the analysis of experimental data[1]) two solutions, shown in the Fig. by crosses and cirles, are obtained for the portion of the $d_{5/2}$ - cross section in the total dipole cross section. Recent calculation[2]) in the shell model (SM) formalism has given nuclear wave functions which reproduce the solution with $d_{5/2}$ contributions dominanting. On the other hand, the alternative solution, i.e. the solution which is predominantly $g_{9/2}$, is obtained by direct-semi-direct (DSD) capture theory. The question arises: is there a model which is failing?



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THE ROLE PLAYED BY THE GIANT RESONANCES IN THE INELASTIC NEUTRON-NUCLEUS SCATTERING

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For target nuclei with a hole in a neutron close-shell such as 87Sr49, the centribution from the giant resonances is important even when the incident neutron energy is about 3 Mev.

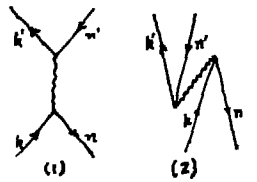
For the reaction 87Sr(n,n) 87mSr, when the incident neutron energy is between 2.20 and 3.48 Mev, the contribution to the inelastic scattering cross section from the compound nucleus reaction as calculated by the usual Hauser-Feshbach theory or Weidenmüller's theory is only about 20-50 mb, much smaller than the experimental value of 250-340 mb.

We have estimated the contribution from the G.R.'s for the above mentioned reaction and found that the most important contributions come from the following two diagrams.

The corresponding T-matrix elements are

$$T^{(1)}=\sum_{\lambda\lambda'\tau}(\alpha_0)^2_{\lambda\tau}\langle\vec{k}'^{(-)}|U^c_{\lambda'\tau}|\vec{n}'\rangle\frac{1}{\varepsilon_n+\varepsilon_{n'}-\hbar\omega_{\lambda\tau}-i\frac{\Gamma_{\lambda\tau}}{2}}\langle\vec{n}|U^c_{\lambda\tau}|\vec{k}^{(+)}\rangle$$

$$T^{(2)}=\sum_{\lambda\lambda'\tau}(\alpha_0)^2_{\lambda\tau}\langle\vec{n}|U^c_{\lambda'\tau}|\vec{k}^{(+)}\rangle\frac{1}{\varepsilon_n+\varepsilon_{n'}+\hbar\omega_{\lambda\tau}+i\frac{\Gamma_{\lambda\tau}}{2}}\langle\vec{k}'^{(-)}|U^c_{\lambda\tau}|\vec{n}\rangle$$



Among the different modes of G.R.'s, that with $\lambda=2$, $\tau=0$ contributes most significantly. The contributions from the other modes $\lambda=1$, $\tau=1$, and $\lambda=3$, $\tau=0$ are also considered.

The coupling between the particle and the vibration is taken to be of the form

$$U^c_{\lambda\mu\tau}=f_{\lambda\tau}(r)\left[i^\lambda Y_{\lambda\mu}(\Omega)\right]^*(\delta_{0\tau}+\tau_0\delta_{1\tau})$$

$$f_{\lambda\tau}(r)=-R_0\frac{d}{dr}U(r-R_0)\ ,$$

Where $U(r-R_0)$ is the Woods-Saxon potential. The scattering wave function are calculated from optical model potential, while oscillator wave functions are used for the hole states. For the value of the zero point amplitudes $(\alpha_0)^2_{\lambda\tau}=\hbar\omega_{\lambda\tau}/2C_{\lambda\tau}$ or restoring force parameters $C_{\lambda\tau}$, they are taken to be

C_{11}=1578 C_{20}=105 C_{30}=134

which are not too far from those of A. Bohr and B. Mottleson(2) and of H. V. Geramb.(1)

The results we obtained are as follows:

E_n(Mev)	$\sigma_{c.N.}$(mb)	$\sigma_{G.R.}$ (mb)	σ_{tot} (mb)	σ_{exp} (mb)
2.20	50.5	113.3	167.8	288 34
2.71	37.7	192.7	230.4	345 42
3.48	18.3	320.0	338.3	232 27

The experimental data are taken from NSE 32, 195(1968).

The essential reason that the contribution of the G.R.'s is important even for E_n=3 Mev is that the neutron separation energy in neutron close shell nuclei is usually much higher than that in neutron close shell plus one nuclei.

We believe such anomany may also present in similar reactions such as ^{131}Ba(n n') ^{131m}Ba, ^{139}Ce(n n') ^{139m}Ce, etc..

(1) H. V. Geramb, Nucl. Phys. A199 (93) 545
(2) A. Bohr and B. Mottleson, Nuclear Structure, Vol. 2.

MECHANISMS LEADING TO AND DECAY MODES OF NUCLEAR CONTINUUM EXCITED IN PROTON-NUCLEUS INTERACTION†

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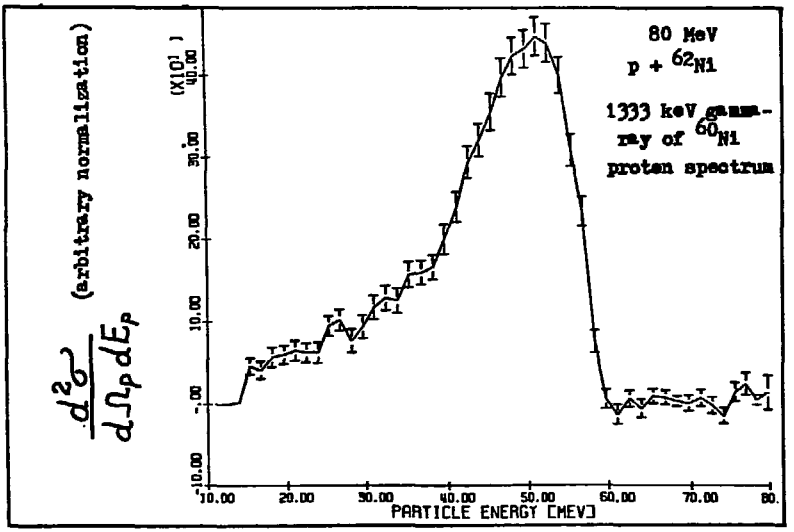
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In plane particle-gamma ray coincidences have been measured following 80 MeV proton bombardment of ^{62}Ni using the cyclotron facilities of the two institutions. Particles were detected and identified using a two element telescope placed at 25.5°, 35.0°, and 45.5° and three gamma-ray, Ge(Li), detectors were located at 135°, -75°, and -138° with respect to the beam. As demonstrated in the figure, a preliminary analysis shows that discrete gamma rays corresponding to transitions among the low-lying levels of various nickel isotopes are in coincidence with a proton spectrum consisting of a peak, FWHM ≈ 10 MeV, centered at about 10 MeV above the threshold for each



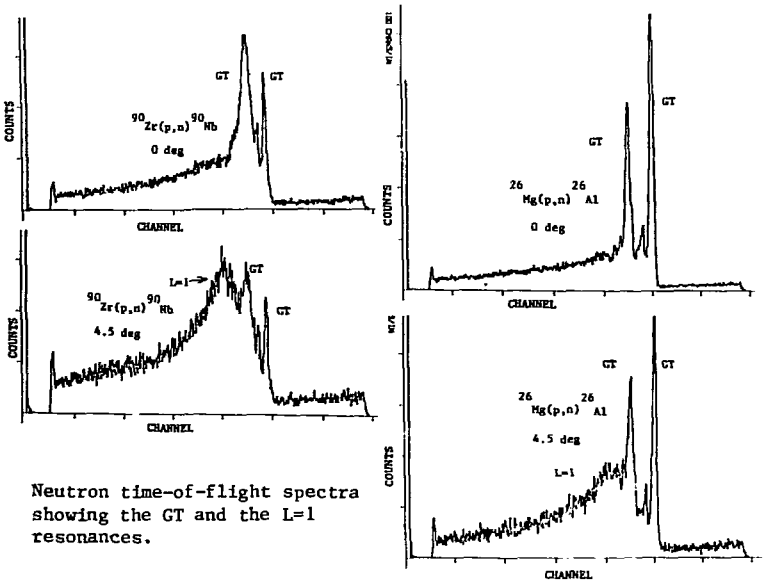
case, and a tail towards lower energies. The peaks in these spectra can be understood to arise from mechanisms such as ^{62}Ni(p,p')^{62}Ni* → (xn) + $^{62-x}$Ni where x denotes the number of evaporation neutrons. The tails reflect the role of processes such as ^{62}Ni(p,xn)$^{62-x}$Ni. The results of analysis and comparison with cascade and evaporation models will be presented.

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LOW q GIANT RESONANCES IN MEDIUM ENERGY (p,n) REACTIONS

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We have surveyed energy spectra for (p,n) reactions on targets from lithium to lead at E_p=200 MeV and observed strength concentrations that bear the characteristics of giant resonances. Of these, at 0 degrees, the most prominent is the Gamow-Teller(GT) resonance which, although fragmented in detail, contains two principal peaks in light elements with the lower excitation component becoming weaker in medium weight elements and all but disappearing in heavy elements, leaving most of the strength in one moderately broad giant peak. Excitation of the GT resonance can be understood as a manifestation of a $\sigma\cdot\sigma\ \tau\cdot\tau$ force, which is the central component of OPEP, although OPEP alone does not explain the whole observed (p,n) cross section. At about 5 deg. another broader resonance appears at a higher excitation energy. This is plausibly the manifestation of an L=1 spin-isospin interaction term. We know from the weak excitation of the IAS that the spin independent isospin term is weak at 200 MeV. From a structure point of view the GT resonance represents p-h states within the same L shell, largely spin-orbit pairs. The L=1 resonance plausibly represents p-h states in adjacent L shells.



Neutron time-of-flight spectra showing the GT and the L=1 resonances.

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INVESTIGATION OF EXCITED STATES IN ^{208}Pb BY INELASTIC SCATTERING OF 100 MeV POLARIZED PROTONS†

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Differential cross sections and analyzing powers have been measured for the excitation of states in ^{208}Pb using a 100 MeV polarized proton beam from the Indiana University Cyclotron Facility and a QDDM magnetic spectrometer. The observed spectra, with an overall resolution of about 40 keV, span the excitation energy range 0-8 MeV and the angular range 7.5°-75°. Angular distributions have been extracted for the following states in ^{208}Pb: 3^-(2.62), 5^-(3.20), 4^-(3.48), 5^-(3.71), 2^+(4.10), 4^+(4.32), 6^+(4.42), 8^+(4.61), 10^+(4.89), 10^+(5.07), 12^+(6.08), 12^-(6.42), 14^-(6.74), 12^-(7.04).

The inelastic excitation of these states by 135 MeV (unpolarized) protons has been measured, and a microscopic description[1] using the DWIA and the t-matrix interaction of Love, derived from free nucleon-nucleon scattering, resulted in good agreement[2] with the data. Encouraged by this understanding of the reaction mechanism for strong inelastic excitations, we are using this reaction to investigate the structure of particle-hole states of special character in ^{208}Pb.

Among the states under study are the two 12^- levels at 6.42 and 7.06 MeV. Studies[3] using inelastic electron scattering indicate that each of these states has a rather pure configuration, namely $\nu(i_{15/2}i_{13/2}^{-1})_{12^-}$ and $\pi(i_{13/2}h_{11/2}^{-1})_{12^-}$ for the 6.42 and 7.06 MeV states, respectively. On the other hand, analyses of our (p,p') data at 135 MeV suggest appreciable mixing between the two configurations. A resolution of this anomaly may result from polarized proton studies since the DWIA calculations of the analyzing powers for excitation of the 12^- states indicate a significant sensitivity to the degree of configuration mixing. Preliminary analyses of the data at 100 MeV show rather different analyzing powers for the two states, and these appear to be consistent with a configuration-mixing hypothesis.

The general success in understanding the mechanism for strong inelastic excitations may not apply for weak excitations, for which other, more complicated mechanisms, such as two-step processes, may be significant. The 4^-, 3.48 MeV state in ^{208}Pb, which is weakly excited in all inelastic scattering reactions, should be a good case in which to study such contributions. In addition, recent discussions of nuclear critical opalescence[4] have led to predictions that the cross section for this state should be enhanced at large momentum transfer. Preliminary analyses of the data for the 4^- transition at both 100 and 135 MeV show no evidence for such an enhancement. The importance of two-step processes is presently being assessed.

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RADIATIVE CAPTURE OF 14.2 MeV NEUTRON BY ^{56}Fe and ^{238}U

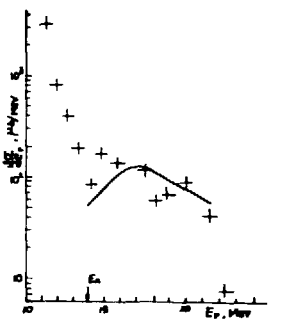
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The capture γ-ray spectra of 14.2 MeV neutron by ^{56}Fe and ^{238}U have been studied.

The γ-ray detector consists of a Φ200x100 NaI (Tl) and a 58AVP photomultiplier enclosed in a heavy shilding and the γ-ray emitted in the 90° direction is detected. The γ-ray detector is time gated by the associated α particles produced in $T(\alpha,n)$ reaction to reduce background. The time signal of α-particles is picked up by a silicon surface barrier detector and the time resolution of whole system is typically 3ns. The linearity and γ-ray response function of the detector were calibrated by some discrete lines produced in nuclear reaction. Unfolding of γ-ray spectra were carried out by iterative weighting square fitting method and thus the gross structure of capture γ-ray spectra were obtained. The unfolded spectrum of $^{56}Fe(n,\gamma)$ is shown in the figure and by integrating the spectrum from 14 MeV the cross section is obtained. The cross sections of $^{56}Fe(n,\gamma)$ and ^{238}U (n,γ) reaction are 790±130 μb and 1070±180 μb respectively.

There are some problems to describe the total γ-ray sprectrum by DSD theory, especially for the deformed nuclei. We try to fit our result by means of a pre-equilibrium exciton-phonon coupling model [1] and the agreement between theoretical and experimental results seems to be satisfactory. In the figure also is shown the calculated γ-ray spectrum of $^{56}Fe(n,\gamma)$ reaction. The calculated cross sections of those two reactions are 724 μb and 872 μb respectively.



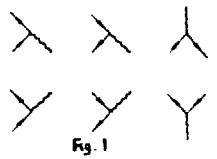
1. Ma Z. Y. et al., contribution paper submitted to this conference.

PRE-EQUILIBRIUM EXCITON-PHONON COUPLING MODEL FOR (n,γ) REACTION

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Neutron radiative capture of tens of MeV are usually analysed on the basis of DSD model. But the physical picture of the imaginary part of the complex coupling interaction is not quite clear and the calculations based on DSD model for deformed nuclei are rather uncertain. Recently pre-equilibrium exciton model has been extended to the reaction process including γ emission by E. Betak et al. 1), but the calculated γ-ray spectra were lower than the experimental results. In this work pre-equilibrium exciton-phonon coupling model is suggested as a new approach to treat energetic neutron radiative capture reaction by introducing a phonon to take account of the collective effect of the giant dipole resonance for target nuclei. There are six patterns of the coupling between the excitons and the phonon to be considered. (Fig.1) The transition matrix elements for the six patterns are assumed to be identical and parameterized as $|M_c|^2=K_cA^{-3}$, where K_c is the only free parameter in this model and in our case K_c is chosen as 8.6×10^2 MeV^2 to fit all data. The master equations of the coupling system by including the particle and γ emissions have been derived. Based on this model the cross sections and γ ray spectra of (n,γ) reactions for ^{238}U and ^{56}Fe have been obtained. (Fig.2) To compare with the experimental excitation curve, the cross sections of (n,γ) reaction for ^{208}Pb have also been calculated. (Fig.3) The agreement between the theoretical and experimental values seems to be satisfactory.


Fig. 1

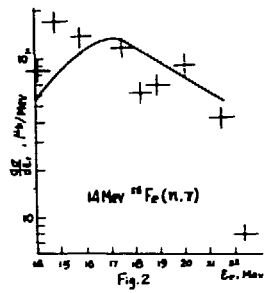


Fig.2

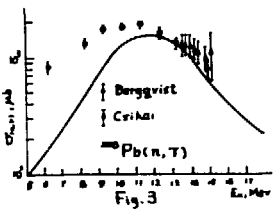


Fig.3

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INTERMEDIATE GIANT RESONANCE EXCITATION EFFECTS IN DIRECT REACTION (p,2p) CORRELATIONS

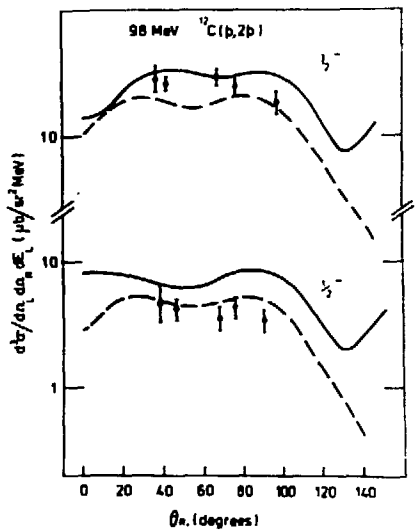
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The analysis of (p,2p) transitions requires an understanding of competing reaction mechanisms. In this work we consider one such aspect, namely the study of indirect scattering to the continuum by virtual excitation of giant resonance states in the target. Such a process has been found important both in the analysis of symmetric geometry (p,2p) experiments[1]) and in the analysis of inelastic proton scattering to select low-lying states[2]).

Attention here has been concentrated on the asymmetric energy-sharing (p,2p) geometry experiment[3]). This experimental arrangement has some distinct advantages: the incident and high energy exit protons are well approximated by attenuated plane waves, the effects of antisymmetrization between the two exit nucleons will be small, and the two-nucleon t-matrix elements involved are closer to being on-shell than those involved in energy symmetric mode analysis.

Within the above framework analyses have been made of the $^{12}C(p,2p)$ reaction to the low-lying $\frac{3}{2}^-$ and $\frac{1}{2}^-$ states of ^{11}B. Comparison with the recent 98 MeV data[3]) has shown that when semi-phenomenological effective interactions of the type in current use in (p,p[1]) analyses are used, the extracted spectroscopic information is in good agreement with 0p shell-model predictions (broken curve in figure). The inclusion of intermediate resonance amplitudes, using coupling strengths deemed appropriate from $^{12}C(p,p^1)$ analyses[2]), indicate that while the 98 MeV predictions would be only slightly modified by including intermediate octupole strength (solid line), that under the most favourable kinematic conditions correlation data should sensitively reflect the energy variation of the giant resonances in the target nucleus.



The extension of the calculation techniques to the 400 MeV incident proton regime[4]) is currently under investigation.

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GIANT RESONANCE EFFECTS ON 14-40 MEV PROTON SPIN-FLIP PROBABILITY

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The spin-flip probability (SFP) in proton scattering to the first 2^+ levels of ^{24}Mg and ^{32}S has been investigated in the energy range 14-40 MeV to evidence in the reaction mechanism the contributions from the doorway excitation of giant resonances (GR). Similar SFP data for ^{12}C and ^{28}Si are available from the literature[1]). A particular feature of all these data is the deviation of experimental SFP, averaged around the backward maximum in the interval 115°÷165°, from the predictions of coupled channel calculations (CCC) obtained with energy averaged optical model parameters (OMP) (dashed lines in figure).

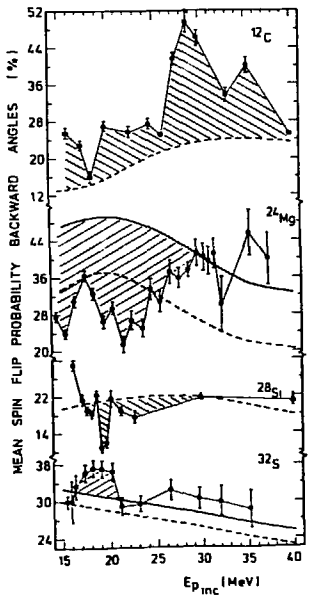
In ^{12}C and ^{28}Si the deviations resemble very closely the strength distribution of the more excited GR in proton scattering, i.e. the quadrupole one (GQR). This approach seems less valid for ^{24}Mg and ^{32}S (see figure) for which back angle averaged SFP and CCC predictions do not match well at high energies where the contributions from GR excitation are expected to vanish.

Analyses are in progress to ascertain the source of such disagreement.

Notwithstanding it, if the CCC curves are arbitrarily renormalized to account for higher energy experimental points (solid lines), the resulting deviations of data grossly reproduce the GQR strength distribution also for ^{24}Mg and ^{32}S(dashed areas).

It is interesting to notice that peculiar features of the GQR, such as the broadening of its distribution for low mass nuclei, are reproduced by the deviations so obtained. In particular in ^{32}S the deviation clusters in a single bump centered at the energy where GQR has been detected[2]).

The investigation of other medium mass nuclei could ascertain if the deviations follow the $A^{-1/3}$ law that could represent the definitive proof for their hypothesized provenance.



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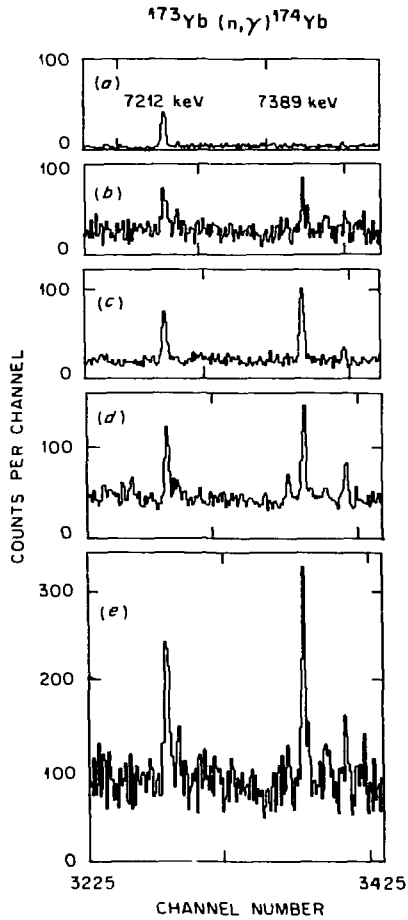
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DISCRETE APPROACH TO RESONANCE-AVERAGED (n,γ) SPECTROSCOPY[†]

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In recent years, the limitations imposed by Porter-Thomas fluctuations in the study of primary γ rays following neutron capature have been partly overcome by "resonance-averaging" techniques. The incident neutron beam is chosen with an energy distribution sufficiently broad that many compound-nucleus resonances contribute to the capture process. The two techniques most commonly employed in averaged-resonance-capture measurements involve the use of "reactor-neutrons" and "filtered-beams".

A third method of obtaining individual γ-ray spectra from a large number of resonances and summing them has not been attempted till now because of experimental difficulties. At ORELA, we have obtained ninety-five 4096-channel spectra (69 on-resonance and 26 off-resonance) from the ^{173}Yb(n,γ) reaction. By considering two pairs of suitable low-energy γ rays and forming intensity ratios, we were able to separate the 48 resonances below 520 eV into two distinct groups of twenty J = 2 and twenty-eight J = 3 resonances. The figure shows the results of summing the γ ray spectra from many resonances after compatibilization for neutron flux, neutron width and total width. We focus attention on the 7389 and 7212 keV γ rays leading respectively to the 76 keV, 2^+ state and the 253 keV, 4^+ state. With proper averaging, the 7389 keV γ ray should be approximately 1.6 times as intense as the 7212 keV γ ray. When all 48 resonances are included, the observed intensity ratio is 1.43 ± 0.08. When the summing is restricted to the 32 resonances below 310 eV, this ratio becomes 1.56 ± 0.15.



γ-ray spectra from (a) the 197 eV resonance. The sum of (b) 16 resonances between 520 and 310 eV, (c) 16 resonances between 310 and 140 eV, (d) the 16 resonances below 140 eV, (e) all 48 resonances below 520 eV.

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GIANT RESONANCES EXCITED BY SCATTERING OF 800-MeV PROTONS

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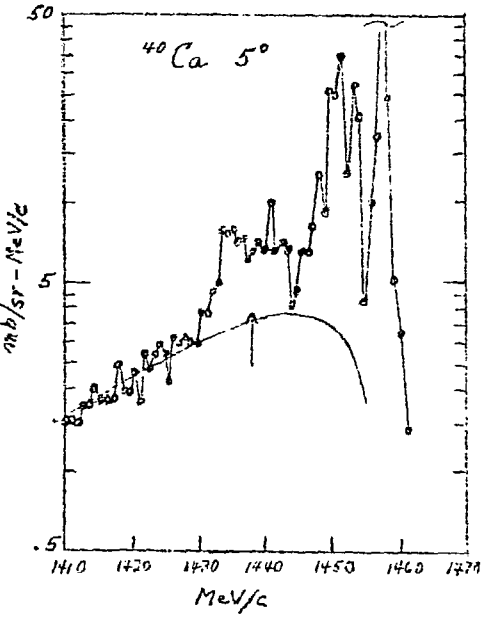
The excitation of giant resonances through inelastic scattering of 800 MeV protons has been studied as part of a broad survey[1] of proton scattering undertaken at the High Resolution Proton Spectrometer at the LAMPF. For targets of ^{12}C, ^{27}Al, ^{40}Ca, ^{51}V, ^{90}Zr, and ^{208}Pb, we observe considerable intermediate structure in the cross section, with the position and width expected for the giant isoscalar quadrupole resonance. The data have been studied for laboratory angles ranging from 4 to 16°. An example of the structure is shown in the figure, which displays the outgoing proton momentum spectrum for ^{40}Ca for 5°, with a momentum resolution of 0.53 MeV/c. The arrow indicates the position of the giant isoscalar quadrupole resonance.

The size of the resonance over background appears considerably larger at 800 MeV than observed for lower energy protons.[3] For the background underlying the structure, we have used a calculation from a DWIA analysis due to Kroll and Wall.[2] This seems to fit the data trends reasonably well, as shown on the figure. The background subtraction is of especial importance where the structure is small.

The structure appears systematically for most of the targets, with the possible exception of ^{12}C and ^{27}Al. The peak has an angular distribution characteristic of L=2 transfer.

The cross section for exciting this giant quadrupole resonance, and its angular distribution, have been studied by applying DWBA analysis. The comparison of the measured and calculated cross sections yields the fraction of the energy-weighted sum rule (EWSR) exhausted by the resonance. For the case of ^{40}Ca we find that β is $\tilde{\sim}$ 0.1 and that about 33% of the EWSR is exhausted.

Detailed analysis for the targets is underway and will be presented.



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* Research supported by the U.S. DOE under Contract DE-AC02-76CH00016.

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OBSERVATION OF THE ANALOGUE-DIPOLE STATE IN THE $^{90}Zr(n,p)^{90}Y$ REACTION

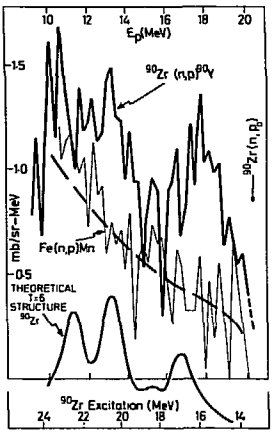
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In earlier work[1]) we studied the $^{28}Si(n,p)^{28}Al$ reaction where the giant dipole resonance (GDR) of the target nucleus (with N=Z) is entirely $T_>$ in character. The results were essentially in agreement with predictions of the theory developed by Clement and Perez[2]) for the direct excitation of the GDR-analogue in (n,p) reactions. In ^{90}Zr the GDR is split into T=5 and T=6 components which are not readily identified experimentally[3]) except by comparison with the theoretical predictions for T=6 dipole states in ^{90}Zr. The $^{90}Zr(n,p)^{90}Y$ reaction offers a more direct identification of T=6 components in ^{90}Zr via the excitation of their analogues in ^{90}Y.

The $^{90}Zr(n,p)^{90}Y$ reaction was studied at E_n = 22 MeV using a detection system developed for this purpose. The ^{90}Zr in the form of a metal foil was sandwiched together with three flat multiwire proportional counters which establish particle identification and coincidence criteria together with a curved plastic scintillator 30 cm long. Light attenuation in the scintillator provides position sensitivity and gives an effective angle resolution of <3° FWHM. The energy resolution for 20 MeV protons is <1 MeV FWHM. It is thus possible to observe the angle dependence of the proton energy spectrum over a 70° range of reaction angles in a single measurement.

The figure shows the observed $^{90}Zr(n,p)^{90}Y$ proton spectrum averaged over the angular range 0-45° for an incident neutron energy of 22 MeV. From energy balance and Coulomb shift, the proton energies correspond to the excitation energies in ^{90}Zr given in the figure. This makes it possible to compare the observed structure in the proton spectrum with the T=6 structure in ^{90}Zr as calculated by Hughes and Fallieros[4]).



The observed $^{56}Fe(n,p)$ proton spectrum is also shown in the figure. Any GDR analogue structure in this reaction should be restricted to proton energies below 12 MeV. We find that for higher energies the Fe(n,p) proton spectrum is featureless and nearly isotropic.

Taking the dashed line in the figure as an estimate of the "non-direct" background for the $^{90}Zr(n,p)$ spectrum we obtain a cross section for the "resonant" part of that spectrum in rough agreement with the theory of Clement and Perez[2]) and with a forward peaked angular distribution as predicted by them.

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EXCITATION OF A CORE POLARISED STATE IN ^{59}Cu THROUGH (p,γ) RESONANCE†

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A $g_{9/2}$ isobaric analogue resonance (IAR) was reported[1] in ^{59}Cu following the ^{58}Ni(p,γ) reaction at E_p=2839 keV. The bombarding energy for the well established $g_{9/2}$ IAR is 711 keV higher. This claim not only represents a much larger energy spread for the fragments, as usual, but it also points to an obvious explanation for the missing $g_{9/2}$ analogue-antianalogue strength in this mass region, namely to the experimental difficulty to pick up fragments spread over such an energy range. If substantiated, this claim would call for an interaction mechanism capable to produce the spread.

We carefully reinvestigated the 2.8 ≤ E_p (MeV) ≤ 3.6 energy region in the (p,γ) and (p,p'γ) channels (Table 1). Although we found the (p,p'γ) strength very small at the E_p=2839 keV resonance, as compared to the $g_{9/2}$ IAR at E_p=3550 keV, we too observed the reported transitions, mainly a strong $9/2^+ \rightarrow 9/2^+ \rightarrow 7/2^-$ cascade. This is consistant with pure M1 followed by E1 transitions, similar to the IAR case.

Table 1. $J^\pi = 9/2^+$ resonance widths in the ^{59}Cu isotope

E_p (keV)	E_γ(R→3042) (keV)	Γ_γ (meV)	$\Gamma_\gamma/\Gamma_{u.W.}$	$\Gamma_{p,\ell}(2^+)$(eV) (^{3}He,dp)	present
3550	3861	410[a]	0.34	9.3[b]	6.8
3488	3800	94	0.08	2.0[b]	2.8
2839	3158	63	0.10		<0.1

a) measured by (^{3}He,d) reaction with ℓ=4 momentum transfer (ref.2). We used this gamma width to normalize our results.
b) ref.3.

The resonance at E_p=2839 keV populates the level at E_x=6.2 MeV energy in ^{59}Cu, which can be a $g_{9/2}$ analogue, antianalogue or core polarised (CP) state. The present 50 keV spreading width would be 7 times the largest already reported, which considerably weakens the analogue state interpretation. The analogue-antianalogue energy separation $E_{T>} - E_{T<} = (T_0 + 1/2)V_1/A$ would lead to a symetry potential V_1<70 MeV, much less than the accepted 125±25 MeV value. This eliminates the antianalogue interpretation. Using a CP model[4], the calculated energy is E_{CP}=6.3 MeV, close to the experimental value. We thus propose the 6.2 MeV level in ^{59}Cu as the first $g_{9/2}$ CP state experimentally observed.

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EVIDENCE OF LINEAR CHAIN STATE IN ^{8}BE

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The evidence of d-α-d linear chain molecule-like state in ^{8}Be predicted by Han et al.[1] has been obtained in ^{6}Li(d,dd)α reaction.

Fig.1 shows d-d coincidence spectrum projected on the kinematical locus at E_0 =9 MeV. In the region of $E_{\alpha} \leq 20$ keV, where E_{α} is the kinetic energy of α particle in the centre of mass system, i.e., under the collinear condition, the experimental differential cross sections are much greater than the contributions of the known effects: FSI and QFS. Moreover, this cross section enhancement is a function of incident energy as shown in Fig.2. There is a possible resonance at E_0 =9 MeV, which is corresponding to the 29 MeV excited state of ^{8}Be in consistent with the theoretical prediction.

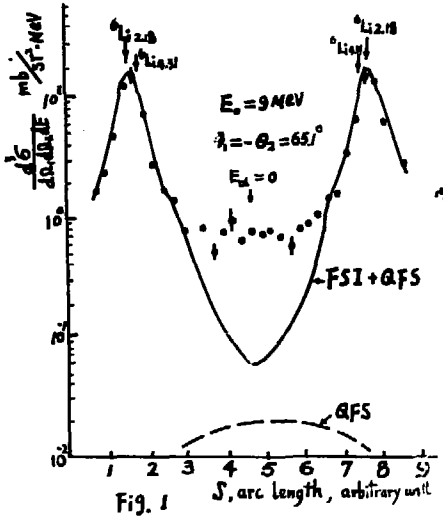


Fig. 1

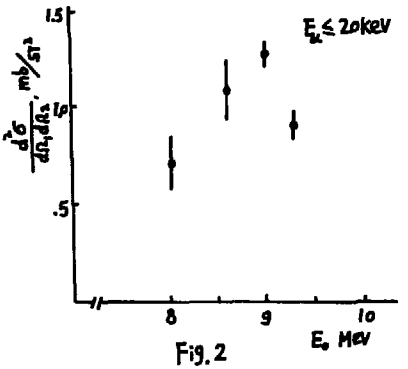


Fig.2

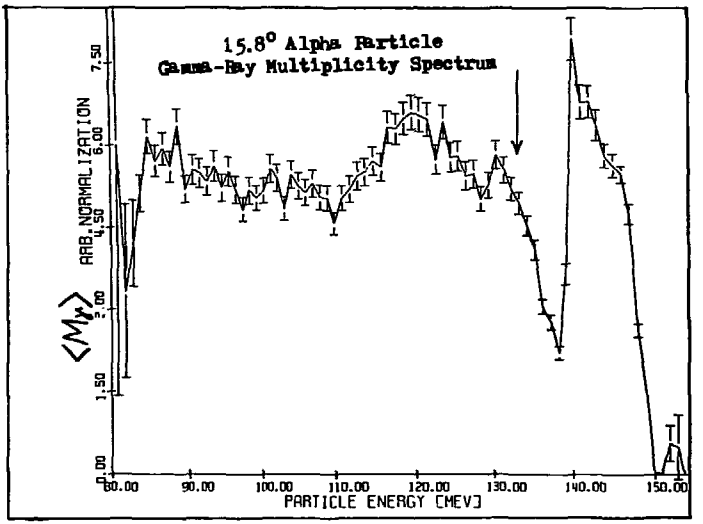
1) Han et al., Physica Energiae forts et Physica Nuclearis. 4(1980) 121.

DECAY MODES OF ISOSCALAR GIANT RESONANCES THROUGH $(\alpha,\alpha'\gamma)$ COINCIDENCES†

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Using 150 MeV alpha particle beam from IUCF the particle decay channels of isoscalar giant resonance in ^{62}Ni have been investigated by observing the discrete gamma-transitions of residual nuclei in coincidence with the scattered alpha particles. Particles were identified and detected at 15.8° and the gamma rays were detected using three Ge(Li) detectors located at 40°, 94°, and 150° with respect to the beam. Isoscalar giant resonance-like structure at 64 $A^{-1/3}$ MeV is observed in α'-γ coincidence spectra and decays predominantly by emitting a neutron. A preliminary analysis of the decay pattern of low-lying transitions is consistent with the resonance decaying in a manner similar to the continuum upon which it rides.



The ratios of true coincidences with any gamma-ray to the accidental coincidences should yield a spectrum of the gamma-ray multiplicity as a function of the alpha particle energy. The smooth multiplicity behavior in the resonance region indicated by an arrow in the figure is also consistent with statistical-type decay of the giant resonance. Final analysis and comparison with results of 80 MeV proton bombardment and investigation of a strong resonance-like structure at 64 $A^{-1/3}$ MeV excitation in ^{62}Ni$(\alpha,^{3}\text{He}\gamma)^{63}$Ni* reaction will be presented.

†This work supported by the National Science Foundation.
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*Partly supported by a NATO grant.

OBSERVATION OF A BROAD STRUCTURE IN t-SPECTRA FROM (τ,t) REACTION AT E_{inc} = 130 MeV

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Triton spectra from (τ,t) reactions induced by 130 MeV helions on ^{27}Al, ^{59}Co, ^{93}Nb and ^{197}Au targets have been measured at angles between 7.5°-24°(lab) in 1.5° steps. The targets were self-supporting foils, 5-8 mg/cm^2 thick. The charged reaction products were detected by two ΔE-E telescopes.

Sample spectra shown in fig. 1 exhibit the existence of a broad structure ("bump") with a centroid energy $E \approx 2/3\ E_{inc}$ and a FWHM $\Gamma \approx 1/3\ E_{inc}$. Similar observations were made in the previous measurements at $E_{inc} \approx 68$ and 90 MeV[1]. The bump cross section shows a forward peaking (fig. 1a) and, at a fixed angle, increases with the target mass (fig. 1b). At present no conclusive explanation can be offered for the mechanism responsible for the broad bump. However, among three possible processes, namely, i) breakup-pickup (τ,d)(d,t), ii) formation and decay of an α* (τ,α*)(α*,t) and iii) quasi-free charge-exchange reaction, the first of these appears to be the most probable.

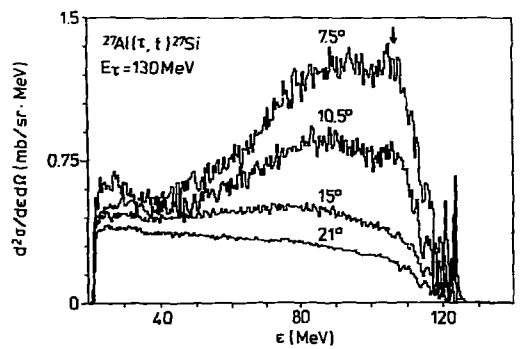


Fig.1a

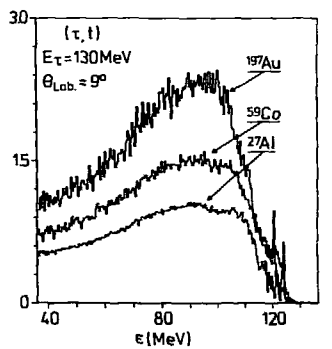


Fig.1b

It is worth noting that for ^{27}Al (see arrow in fig. 1a) the t-spectra exhibit in addition a smaller bump centered at $E_x \approx 15$ MeV in the ^{27}Si residual nucleus. This bump might be due to the giant Gamow-Teller resonance or to the isovector L=3 resonances. Large isoscalar L=3 strength was deduced earlier in the $^{27}Al(\alpha,\alpha')$ reaction[2] for a group of levels in the excitation energy range $6 \leq E_x \leq 14$ MeV.

1. O. Bousshid et al., Annual Report 1979, KFA-IKP Jülich, W. Germany (in press)

2. C. Mayer-Böricke et al., Nucl. Phys. A293 (1977) 189

INVESTIGATION OF AN 8p-4h STATE IN ^{20}Ne AT 12.44 MeV

E.F. Garman, L.K. Fifield, W.N. Catford and K.W. Allen

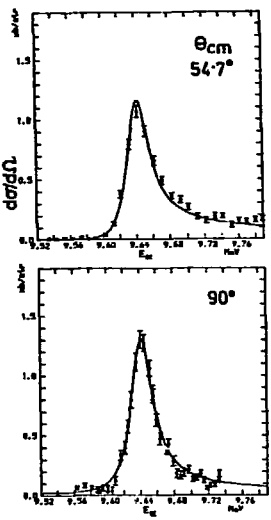
Nuclear Physics Laboratory, Oxford, England

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In an earlier publication[1], we reported the existence of a probable 0^+ state in an excitation energy of 12.44 MeV in ^{20}Ne, which had a large overlap with $^{16}O^*$(6.05 MeV)+ α. This observation was interpreted by suggesting that the 12.44 MeV level has an 8p-4h configuration with respect to the ^{16}O core.

Subsequently, we have carried out, in Oxford, an extensive study of this state using the $^{16}O(\alpha,\alpha')^{16}O^*(0^+$, 6.05 MeV) reaction. The α_1 and α_2 groups, populating the 6.05 and 6.13 MeV states in ^{16}O respectively, were separated by a magnetic spectrometer. Similar measurements were performed at the University of Pennsylvania, but with the α-particles detected in solid state counters. The α_1 group was selected by requiring a coincidence between an α-particle and an energetic electron or positron from the pair decay of the 6.05 MeV state in ^{16}O detected in a thin plastic scintillator. It was found that the α_1 angular distributions were markedly anisotropic at each of a number of energies across the resonance. Further, the differential cross-sections as a function of energy departed significantly from a Breit-Wigner shape at each of the angles at which measurements were performed.



These observations are in apparent conflict with the isotropic angular distributions and B-W resonance shapes expected for a 0^+ resonance. However, it was found that the data were well reproduced by including an energy independent coherent background in addition to a 0^+ resonance. Contributions to this background from partial waves up to L=3 were required. Representative data and fits are shown in the figure. The background may arise from a small direct component in the reaction mechanism.

For the 0^+ resonant component, the fits to the data require that $\Gamma_{\alpha_0}\Gamma_{\alpha_1}/\Gamma_{tot}$ = 3.53±0.38 keV and Γ_{tot} = 30.2±0.6 keV where all widths refer to the laboratory frame. Using the earlier result[1] that $\Gamma_{\alpha_1}/\Gamma_{tot} > 22\%$, we are forced to conclude that $\Gamma_{\alpha_1} > \Gamma_{\alpha_0}$, contrary to the assumption made in ref.[1]. It follows that Γ_{α_1} = 26.0±2.8 keV, which corresponds to a spectroscopic factor of 2.5 if we follow the prescription outlined in ref.[1] for calculating single particle α-widths.

Such a large spectroscopic factor may indicate that the wavefunction of the 12.44 MeV 0^+ level in ^{20}Ne is dominated by 8p-4h configurations in which some of the particles are outside the sd shell.

1) D.P. Balamuth et al.,Proc.Int.Conf. on Nuclear Structure, Tokyo, 1977, J.Phys.Soc.Japan 44(1978) Suppl.244.

NEW GIANT RESONANCES IN 172 MeV α SCATTERING FROM ^{208}Pb

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We have investigated 172 MeV α scattering from ^{208}Pb using the Jülich isochronous cyclotron JULIC. Our spectra indicate in addition to strong excitation of the giant monopole and quadrupole resonance new structure at higher excitation energy which is broad and extends up to about 28 MeV. This structure exhibits a different shape at different scattering angles indicating the existence of two resonances of different multipolarity. The data are well fitted assuming two resonances at E_x=17.5±0.8 MeV and 21.3±0.8 MeV with corresponding widths (FWHM) of 4.8±0.8 and 5.9±0.8 MeV. The energies of giant quadrupole and monopole resonances are 10.9±0.3 and 13.7±0.3 MeV with a width of 2.6±0.3 MeV. In an ^{16}O scattering experiment[1] also a peak around 20 MeV excitation energy was observed which was interpreted as being due to 3^- and 5^- giant resonances. However, the shape of this peak is different from that in our spectra, especially at the low excitation energy side and tends to be more narrow.

Angular distributions for the new resonances show pronounced structure; that for the 17.5 MeV resonance is well described assuming octupole excitation. By comparing our differential cross sections to microscopic DWBA calculations an octupole strength is estimated which corresponds to 60 % of the isoscalar energy weighted sum rule. This is consistent with the evidence for E3 excitation from electron scattering[2]. Together with the excitation of the 3^- state at 2.61 MeV (23.5 % EWSR) and higher lying L=3 excitations[3] we can account for the total octupole sum rule strength. The data for the high lying resonance at 21.3 MeV can be well understood in terms of a isoscalar giant dipole resonance.

1. P. Doll, et al., Phys. Rev. Lett. 42 (1979) 366
2. M. Nagao and Y. Torizuka, Phys. Rev. Lett. 30 (1973) 1068,
   M. Sasao and Y. Torizuka, Phys. Rev. C15 (1977) 217
3. W.T. Wagner, G.M. Crawley, G.R. Hammerstein and H. McManus, Phys. Rev C12 (1975) 757,
   H.P. Morsch, P. Decowski and W. Benenson, Nucl. Phys. A297 (1978) 317

E1 AND M1 STRENGTH IN THE $^{40}Ca(^{3}He,t)$ REACTION*

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and

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Charge exchange reactions at intermediate energy provide a means of investigating nuclear structure which is somewhat complementary to inelastic scattering. This is particularly true for the (^{3}He,t) reaction on T=0 targets, which is inherently isovector. We have studied the ^{40}Ca (^{3}He,t) reaction using ^{3}He beams of 130 and 170 MeV from the University of Maryland cyclotron. Tritons were detected using counter telescopes with intrinsic Ge detectors supplied by R. H. Pehl and collaborators at Lawrence Berkeley Laboratory.

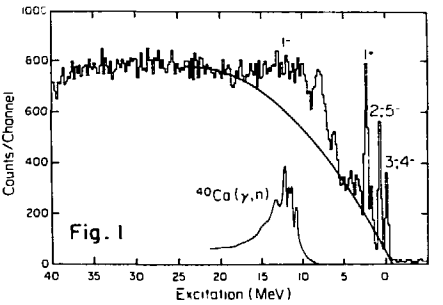


Fig. 1

The $^{40}Ca(^{3}He,t)^{40}Sc$ spectrum at 15° and 170 MeV is shown in Fig. 1. The peak labeled 1^{+} at an excitation energy of 2.37 MeV in ^{40}Sc appears to be the analog of a 1^{+} state at 10.319 MeV in ^{40}Ca, which is excited by a strong M1 transition in inelastic electron scattering. The broad structure labeled 1^{-} occurs at the same excitation energy as the giant dipole resonance (GDR) in ^{40}Ca, shifted by the Coulomb energy difference. This is shown by the inset.

Angular distributions for these 2 states at 130 MeV are shown in Fig. 2 with lines drawn to guide the eye. Microscopic DWBA calculations are in progress using a folded nucleon-nucleon interaction.

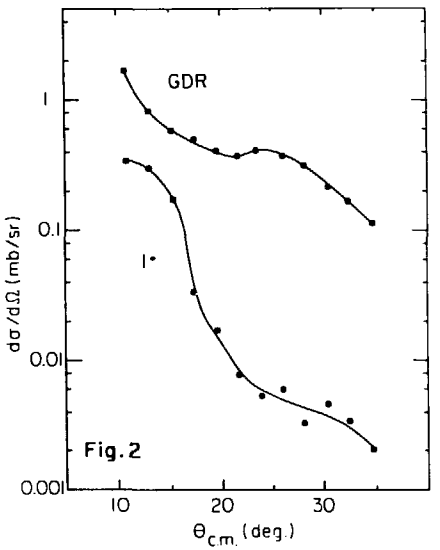


Fig. 2

*Supported in part by the National Science Foundation.

INVESTIGATION OF HIGHLY EXCITED LIGHT NUCLEI THROUGH KINEMATICALLY COMPLETE THREE-BODY BREAK-UP EXPERIMENTS[§]

W. von Witsch, B. Gómez[+], K. Kochskämper[‡] and W. Rosenstock[‡]

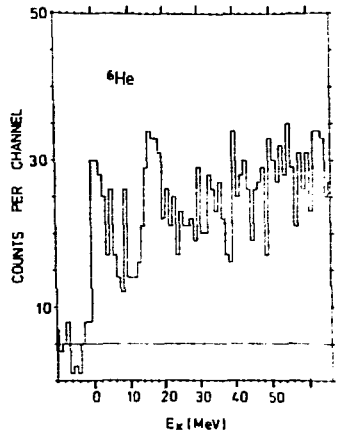
Institut für Strahlen- und Kernphysik der Universität Bonn, D-5300 Bonn, Germany

and

H. Machner

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Various three-body break-up channels have been measured in a kinematically complete experiment on the 7Li+3He reaction with the aim of investigating the A=4 system and other light nuclei at high excitation energies. A beam of 120 MeV from the Jülich isochron cyclotron was used and reaction products were identified in two solid-state detector telescopes. One of the main objectives of the experiment was the search for and possible identification of excited states with T=2 in 4He which would be possible in principle through a comparison of the reactions $^{7}Li(^{3}He;t,^{3}He)^{4}He^{*}$ and $^{7}Li(^{3}He;d,\alpha)^{4}He^{*}$ since the excitation of T=2 in the residual 4He is isospin-forbidden in the latter reaction. An appreciable yield with some apparent structure has been observed in both reactions at excitation energies up to 60 MeV but no new excited states could yet be identified due to insufficient statistics.



In the $^{7}Li(^{3}He;^{3}He,^{3}He)^{4}H$ reaction the ground state of 4H is clearly visible about 3.5 MeV above the mass of 3H+n, with indication of at least two additional states at 5 MeV and 7.5 MeV, respectively, and possibly more at higher energies. The missing-mass spectrum of the $^{7}Li(^{3}He;p,^{3}He)^{6}He$ reaction exhibits a prominent peak at about 17 MeV excitation energy above the ground state of 6He, with a width of less than 5 MeV (see figure); similar peaks have been observed in the analog (p,2p) and (e,e'p) reactions and in the (γ,p) reaction.

In addition, missing-mass spectra of several other light nuclei with masses between A=3 and A=6 have been investigated in the same experiment for excitation energies up to 60 MeV.

[§]This work was supported in part by the Bundesministerium für Forschung und Technologie of the Federal Republic of Germany.

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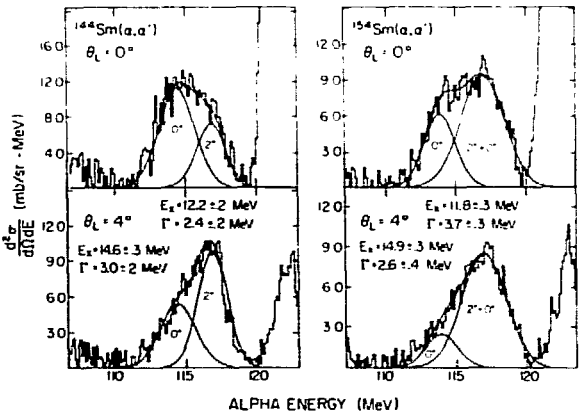
[‡]Now at the INT, Fraunhofergesellschaft, Euskirchen, Germany.

SPLITTING OF THE GIANT MONOPOLE RESONANCE IN DEFORMED NUCLEI*

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The effects of ground state deformation on the parameters of the giant monopole resonance (GMR) have been studied by comparing the giant resonances in ^{144}Sm and ^{154}Sm. Inelastically scattered 129 MeV alpha particles were detected over the angular range 0°-8° in the focal plane of an Enge split-pole spectrograph. After a smooth continuum background was subtracted, the GR regions in all the spectra obtained for a given target were fit simultaneously with a least squares multi-peak fitting routine. The observed group in the GR region was assumed to consist of two components of a Gaussian shape. Spectra after subtraction of the continuum, along with two-peak fits to the data, are shown in the figure. The higher excitation component in each nucleus was identified as the GMR from the angular distribution. In ^{154}Sm, the observed GMR cross section was about 50% of that in ^{144}Sm; this decrease in the GMR cross section corresponded almost exactly to the observed increase in the cross section of the lower excitation peak. This implies that the GMR has split into two components in ^{154}Sm and that one of these components coincides in excitation energy with the giant quadrupole resonance (GQR). This splitting is further corroborated by the increase in the difference between the excitation energies of the two peaks in ^{154}Sm relative to ^{144}Sm.



This behavior of the GMR is in qualitative agreement with the RPA calculation of Zawischa et al.[1], which for the deformed nucleus ^{170}Yb showed two concentrations of 0^+ strength in the GR region. The experimental data can be qualitatively understood with an extension of the model applied to the splitting of the GQR.[2] In a deformed nucleus the GMR and GQR oscillation mix and there are two K = 0 states: one somewhat below the GQR centroid which is predominantly $J^\pi = 2^+$ but contains some $J^\pi = 0^+$ strength and one near the GMR centroid which is predominantly $J^\pi = 0^+$. Such a schematic model is qualitatively in agreement with experiment for the positions of the components, but predicts a three to one division of $J^\pi = 0^+$ strength between the upper and lower K = 0 states, whereas the experiment suggests a more equally shared strength.

*Supported in part by the National Science Foundation and the Robert A. Welch Foundation.

1. D. Zawischa et al., Nucl. Phys. A311 (1978) 445.
2. T. Kishimoto et al., Phys. Rev. Lett. 35 (1975) 552; T. Kishimoto, private communication.

DISTRIBUTION OF SINGLE-PARTICLE STATES IN ^{16}O

M.Yasue, T.Tanabe, A.Goto and H.Kamitsubo

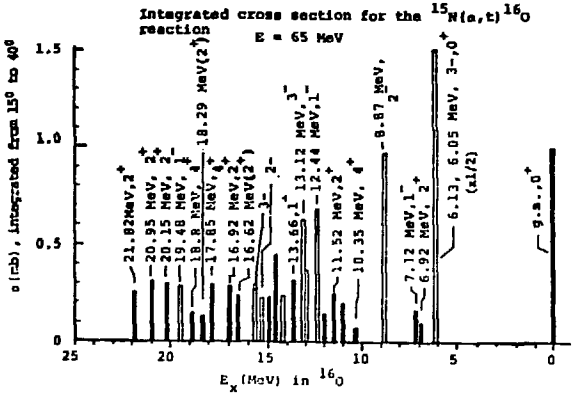
Institute for Nuclear Study, University of Tokyo, Tokyo, Japan

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Department of Nuclear Engineering, Kyoto University, Kyoto, Japan

In the highly excited energy region, where giant resonances are observed, there is a problem how single-particle states are distributed in the energy region. To investigate the distribution of single-particle components in ^{16}O nucleus, experimantal study on the $^{15}N(\alpha,t)^{16}O$ reaction was performed at E_{lab} = 65 MeV by using an α-beam from INS-SF cyclotron in conjunction with the QDD spectrograph. A gas target with $^{15}N_2$ gas isotopically enriched to 99 % was used. Fig. 1 shows cross sections for the $^{15}N(\alpha,t)^{16}O$ reaction integrated over the range of angles from 15^0 to 40^0. No remarkable peaks in the energy spectra were observed beyond the excitation energy of 22 MeV.

In the excitation energy region from 16 MeV to 22 MeV, several 2^+ states were observed in the present work. In this energy region, the existence of the isoscalar E2 resonance is reported by Knöpfle et al.[1] These 2^+ states are correlated to the fine structures in the inelastic scattering of alpha particles[1]. It is interesting to compare our data with the inelastic scattering data.



1) K.T.Knöpfle,G.J.Wagner, P.Paul, H.Breuer et al., Phys. Lett. ('78) 191.

HIGH SPIN STATES IN 2s-1d SHELL NUCLEI VIA (α,d) REACTION

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*Institute for Nuclear Study, University of Tokyo, Tokyo, Japan
**Institute of Physics and Tandem Accelerator Center,
University of Tsukuba, Ibaraki, Japan

We measured angular distributions of the states strongly populated by the (α,d) reaction on $^{16,18}O$, $^{20,22}Ne$, ^{24}Mg and ^{28}Si using alpha beam of 64.3 MeV from INS-SF cyclotron. Emitted deuterons were analyzed with a magnetic spectrograph.

A typical momentum spectrum of deuterons from $^{22}Ne(\alpha,d)$ reaction is shown in fig. 1. A zero range DWBA analysis was performed with the code DWUCK IV. Taking into account of the characteristics and systematics of the (α,d) reactions[1,2], high spin states with the configuration $(j^2)J_{max}$ were identified fairly well. The $(f7/2^2)7^+$ states in ^{20}F(10.51MeV), ^{22}Na(10.99MeV) and ^{24}Na(10.79MeV) and the $(f7/2d5/2)6^-$ states in ^{20}F(7.29MeV) and ^{24}Na(5.93MeV) are newly proposed. The 10.54 MeV state in ^{18}F can be a candidate for the 7^+ state from the systematics mentioned later.

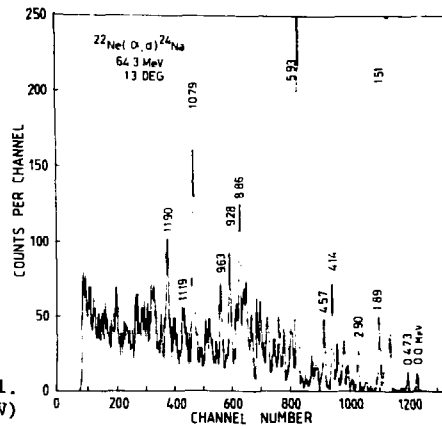


Fig. 1.

A nearly linear dependence of the (α,d) Q-values to the 7^+ states versus atomic mass holds the 2s-1d shell nuclei with mass number greater than A=26[2]. The (α,d) Q-values of the proposed $(d5/2^2)5^+$, $(f7/2d5/2)6^-$ and $(f7/2^2)7^+$ states versus the mass number of the residual nucleus are plotted in fig. 2 together with previous data[1,2], where asterisks show newly proposed states. For the 7^+ states, new data points deviate from the linear curve interpreted within the framework of the Bansal-French-Zamick weak coupling model. These new data hold the crudest shell model picture[3]: The Energy of such a two-nucleon state is equal to the sum of the two individual single-particle energies.

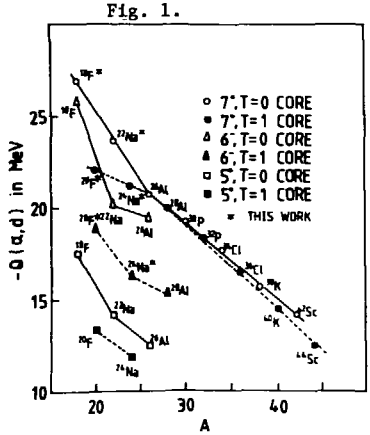


Fig. 2.

1. C. C. Lu, M. S. Ziman and B. G. Harvey, Phys. Rev. 166 (1969) 1086
2. R. M. Del Vecchio, R. T. Kouzes and R. Sherr, Nucl. Phys. A265 (1976) 220
3. Tsan Ung Chan, M. Agard, J. F. Bruandet and C. Morand, Phys. Rev. C19 (1979) 244

EXCITATION OF GIANT MONOPOLE RESONANCE IN ^{144}Sm AND ^{208}Pb

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We studied excitations of the giant monopole resonance in ^{144}Sm and ^{208}Pb nuclei by (α,α') reactions. The purpose of the present study is to deduce the resonance parameters from the experiments at various incident energies.

Experiments were performed with α-beams from the AVF cyclotron of RCNP at incident energies of 84, 99 and 109 MeV for ^{144}Sm target and 84 and 119 MeV for ^{208}Pb target. Spectra of scattered α-particles were measured using a quadrupole magnetic system. Detection angle was varied from θ_L=1.6 to 7.5° with a small dipole magnet mounted in the scattering chamber.

Fig.1 shows spectra of α-particles scattered by ^{144}Sm to 2 and 4° at 99 MeV. At the excitation energy of Ex=12.5 MeV the giant quadrupole resonance is clearly observed. In addition, another resonance is observed at Ex=15.1 MeV in the forward angle spectrum. This result gives a strong evidence for the excitation of the monopole resonance. Parameters of both resonances were deduced from fitting of the resonance shape with two gaussians on a linear underlying continuum, as shown in Fig.1. The values of excitation energies and widths were consistent for all the incident energies and were Ex=12.5 and Γ=2.5 MeV for lower resonance and 15.1 and 2.5 MeV for higher resonance. The angular distributions for the 12.5 MeV resonance were well reproduced by L=2 DWBA calculations. However, those for the 15.1 MeV resonance were reproduced by a mixture of L=0 and L=2 components. Therefore the giant monopole resonance locates at Ex=15.1 MeV on the tail of the giant quadrupole resonance. The fractions of energy-weighted sum-rule (EWSR) of both resonances were deduced from comparison of the experimental cross section with that of the DWBA calculations. As shown in Fig.2, the EWSR fractions of the quadrupole components at Ex=12.5 and 15,1 MeV have nearly constant values of 50 and 15%, respectively. On the other hand, the monopole fraction of EWSR at Ex=15.1 MeV decreases drastically from 55% at 109 MeV to 24% at 84 MeV. Similar result has been obtained for ^{208}Pb. It is interesting that the velocity of 84 MeV α-particles at the nuclear surface of the target is close to the nuclear sound velocity.[1])

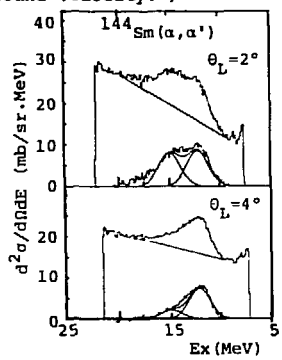


Fig.1

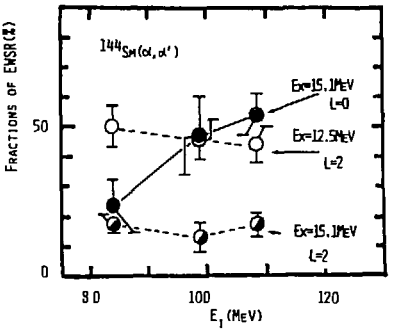


Fig.2

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K-SPLITTING OF ISOSCALAR GIANT QUADRUPOLE RESONANCES IN Ca-ISOTOPES

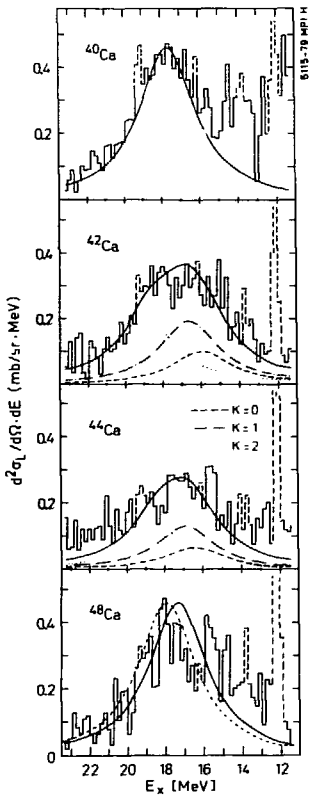
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The study[1]) of isoscalar giant resonances by inelastic ^{6}Li scattering at 153 MeV has been extended to ^{40,42,44,48}Ca and its potentiality as a spectroscopic tool has been explored by extracting isoscalar transition rates for lowlying states. The data taken at the LBL 88" cyclotron with semiconductor telescopes cover 3 diffraction maxima of the strongly structured angular distributions. DWBA calculations with real collective form factors yield good fits to 2^+,3^- and 5^- states and isoscalar transition rates G_0 in fair agreement (see table for examples) with those from α-scattering. Together with electromagnetic rates G_p we derive a ratio of neutron to proton transition matrix elements[2]) M_n/M_p=N/Z for 3^- states and M_n/M_p>N/Z for 2^+ states.



	E_x (MeV)	J^π	G(W.U.) ^{6}Li'	G(W.U.) α'	G(W.U.) e.m.	M_n/M_p
^{40}Ca	3.74	3^-	24.5	25.7	26	0.94
	5.63	2^+	0.36	0.27	0.19	
	6.29	3^-	4.3	4.1	4.6	0.93
^{42}Ca	1.52	2^+	18.4	12.1	9.5	~1.5
	3.44	3^-	16.5	13.3		
^{44}Ca	1.16	2^+	15.8	13.3	9.8	1.4
	3.31	3^-	7.3	9.7		
^{48}Ca	3.83	2^+	8.3	7.8	1.7	3.4
	4.51	3^-	9.7	11.5	6.8	1.4

After a careful and consistent subtraction of an asymmetric bell shaped background[1]) we obtain isoscalar giant resonances (Fig; dashed parts are from ^{16}O contaminant) with L=2 angular distributions exhausting 60-80% of the energy weighted sum rule. The E2 strength distributions of ^{40}Ca and less so for ^{48}Ca show a low energy component at about 15 MeV and the GQR proper. We fitted the shape of the GQR in ^{40}Ca by a Lorentzian and without additional free parameters reproduced (see fig.) the K-splitting in the deformed ^{42,44}Ca nuclei in the vibrating potential model[3]). The GQR in ^{48}Ca has the same width and energy as that in ^{40}Ca (dashed curve) and not as if scaled by $A^{-1/3}$ (full line). This implies equal mass radii for the high frequency modes in ^{40}Ca and ^{48}Ca.

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EXCITATION OF GIANT RESONANCES IN ^{208}Pb USING INELASTIC ^{14}N SCATTERING*

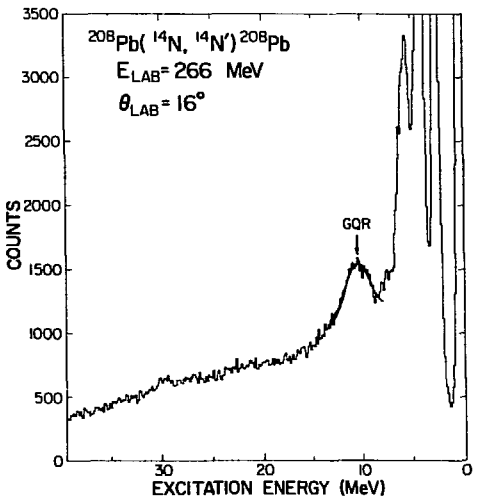
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The excitation of collective modes in nuclei using heavy-ion inelastic scattering is of considerable interest because the angular-momentum matching conditions, favoring large L-transfer, can be utilized to probe new collective modes. Recently, Doll et al.[1], in a study of inelastic scattering of 20 MeV/amu ^{16}O from ^{208}Pb, reported structures at high excitation ($E_x \sim$ 20 MeV) which they attributed to 3^- and 5^- giant resonances. These ^{16}O results have been cited by Broglia et al.[2] as a crucial test of their coherent state model of heavy-ion reactions. We have measured the inelastic scattering of ^{14}N from ^{208}Pb at 19 MeV/amu. In our experiment, the giant quadrupole resonance (GQR) is excited quite strongly, but the spectra at higher excitation are quite smooth; there are no discernible peaks which could be associated with the reported 3^- and 5^- strength.

The inelastic spectrum of 266 MeV ^{14}N from ^{208}Pb at θ(lab) = 16° is shown in the figure. Only one giant resonance peak, located at $E_x \sim 11$ MeV, is apparent in addition to the low-lying states. Both the energy and the width of this peak are consistent with its identification as the well-known GQR; a Gaussian with parameters from α-scattering results is shown superimposed on the data in the figure. There is no evidence of any significant giant resonance strength around $E_x \sim 20$ MeV or at any excitation energy above the GQR.

Straightforward DWBA calculations suggest that with 20 MeV/amu ^{14}N and ^{16}O the excitation of giant resonances should be comparable; indeed, our GQR cross-section is similar to that obtained in the ^{16}O results. It seems unlikely that there is anything unique about ^{16}O as a projectile which would highlight the collective states at $E_x \sim 20$ MeV. The present results strongly indicate that the broad hump at $E_x \sim 20$ MeV, observed in the ^{16}O measurements, does not represent a collective state in ^{208}Pb but rather arises from other effects.



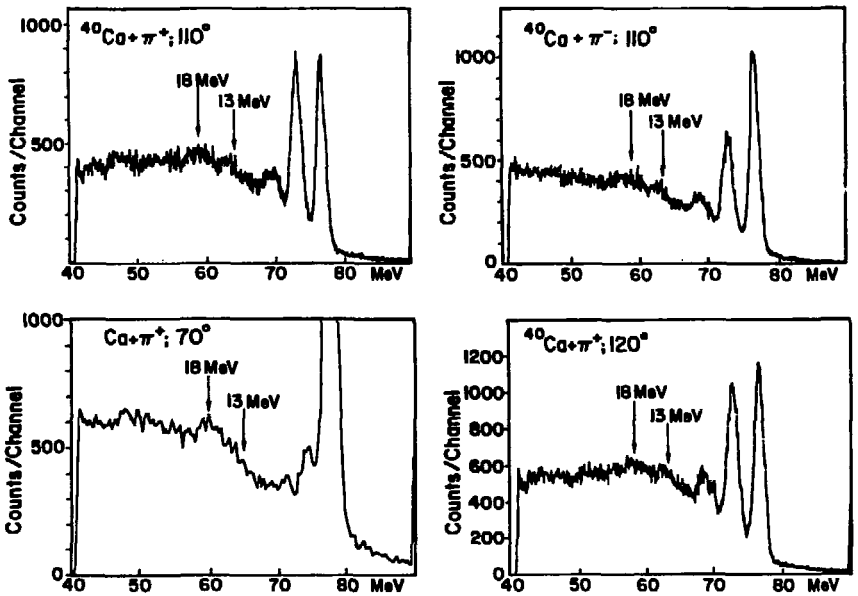
*Supported in part by the National Science Foundation and the Robert A. Welch Foundation.

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GIANT RESONANCE EXCITATION OF ^{40}Ca WITH π^+ AND π^- AT 80 MEV @

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M. A. Kovash,‡ M. J. Leitch,†† F. E. Obenshain,*" B. M. Preedom,**
R. P. Redwine,‡ B. Ritchie,* V. D. Sandberg,†† and J. Wu*

We report observations of giant resonance excitation with π^+ and π^- on ^{40}Ca at 80 MeV. The data were obtained at the Low Energy Pion Channel of LAMPF. Scattered pions were analyzed with the Bicentennial Spectrometer and a 1.5-m long vertical drift chamber[1]) located near the focal plane. The spectrometer produced energy spectra covering energies from the elastic peak to an excitation of 40 MeV at one magnetic field setting. Some of the on-line spectra are shown below. The enhancements at the expected GQR and GDR energies and the cluster at 13 MeV are similar to those observed at pion (3,3) resonance energies,[2]) but the strength of excitation is much weaker, consistent with less absorption and weaker interaction of pions at 80 MeV. Results will be presented on analyses of the π^+ angular distribution and comparisons of π^+ and π^- excitation of the resonance.

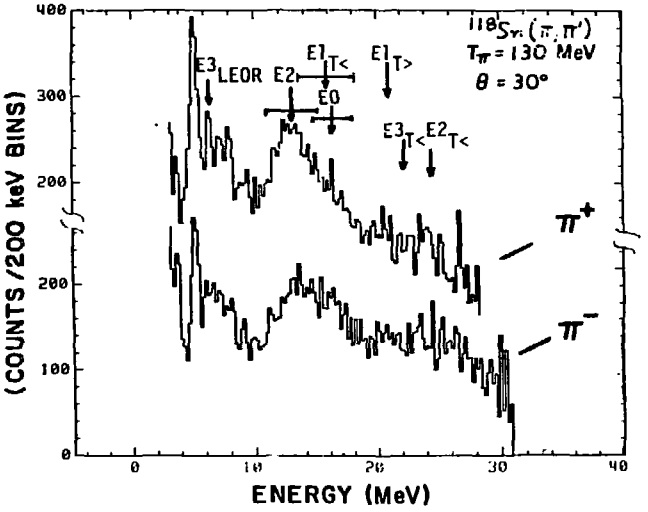


@This work is supported by U.S. D.O.E. and N.S.F.
†Virginia Polytechnic Institute and State University
*Oak Ridge National Laboratory
††Los Alamos Scientific Laboratory
**University of South Carolina
"University of Tennessee
‡Massachusetts Institute of Technology
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EXCITATION OF GIANT RESONANCES IN ^{118}Sn VIA 130 MeV PION SCATTERING*

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N. S. P. King,† T. G. Masterson,** C. L. Morris,†
R. J. Peterson,** and R. A. Ristinen**

The inelastic scattering of 130 MeV positive and negative pi mesons to high-lying states of ^{118}Sn has been studied with the EPICS system at the Clinton P. Anderson Meson Physics Facility. The figure shows spectra at 30° corrected for the focal plane acceptance of the spectrometer. An arbitrary normalization exists between the two data sets. The vertical lines are located at excitation energies predicted from systematics for giant resonances and labeled with their respective multipolarities. Horizontal bars correspond to anticipated widths. Background due to muon contamination has been removed by time-of-flight techniques.



Prominent peaks are seen at energies consistent with the low energy octuple resonance for both π^+ and π^- probes. A clear difference in the π^+ and π^- spectra can be seen near 16 MeV. This region of excitation is where contributions from E0 and E1 resonances are anticipated. Since one expects little difference in the population of the isoscaler E0 for π^+ and π^-, explanations may arise from the E1 resonance properties.

Different strengths for isovector resonance populations in π^+ vs π^- scattering or isospin mixing of the overlapping $T_<$ = 9 and $T_>$ = 10 GDR components are two possible explanations.

*Supported in part by the USDOE
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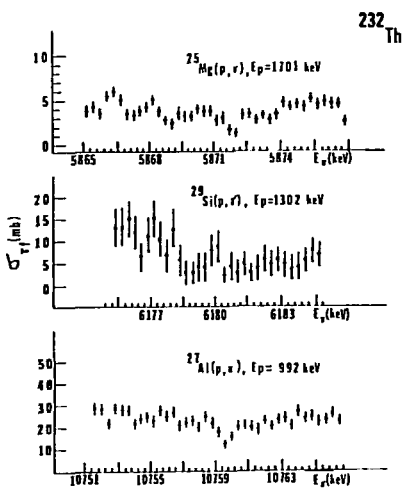
HIGH RESOLUTION PHOTOFISSION MEASUREMENTS IN ^{238}U AND ^{232}TH+

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Previous photofission measurements[1]) have been carried out with a gamma ray energy resolution of $\sim$100 keV, mainly using bremsstrahlung. This resolution makes it impossible to study details of structure in the energy dependence of photofission cross sections near threshold. We have done measurements of photofission cross sections of ^{238}U and ^{232}Th using photons from known (p, γ) resonances in a number of nuclei. This technique takes advantage of the Doppler shift of the energy of the photon emitted by the recoiling nucleus at a given proton resonance. Typical energy spreads of 5-13 MeV photons vary between 20 and 40 keV and an energy resolution of 200 eV is easily attainable. The yield is typically 10^3 photons per μA of proton beam on target, which makes it necessary to use high beam currents. Our measurements are being carried out on the Brooklyn College 3.75 MeV Dynamitron which has a maximum proton beam current of 2 mA.

The number of known (p, γ) resonances suitable for these measurements is adequate for covering the 5-13 MeV range of excitation with an average step of 100 keV. Regions of particular interest, especially the region near threshold can be covered almost continuously.



Typical spectra of photofission fragments of ^{232}Th are plotted in the figure. Polycarbonate films were used as fission track detectors. At high energies the spectra show no structure. The dip in the middle of each spectrum is due to gamma ray attenuation in the target backing. Structure is observed at energies close to the fission threshold, e.g. the peaks at 5866, 5868 and 6177 keV are likely to correspond to class II states in the second well of the fission barrier. The spectra of ^{238}U fragments exhibit a similar behaviour.

The photofission cross sections averaged over each spectrum have been compared with the statistical model of Back and Britt[2]) in order to extract barrier parameter of the two nuclei.

+This work was supported by the Nuclear Science Division of the U. S. Department of Energy.

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$^{28}Si(e,e') \longrightarrow {}^{12}C^{*}+{}^{16}O$: THE STRUCTURE OF THE DECAYING STATE†

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In the recently observed electrofission of ^{28}Si the decay proceeds mainly via the channel $^{12}C(2^{+})+{}^{16}O(0^{+})$. The measured fission yield has a peak centered at 28.3 MeV excitation energy. From the angular distribution of the ^{12}C fragments an assignment of $J^{\pi}=2^{+}$ and K=2 has been made for the fissioning state.

We have studied the fissioning state in $^{28}Si(e,e')f$ in a variational alpha-cluster-model calculation with a standard finite-range Hamiltonian including the Coulomb interaction and the full center-of-mass term. The variation has been performed after projection onto the experimental spin, parity and K values, and under certain symmetry constraints that the fissioning state must fulfill in order to match the existing experimental information, viz. the state should have $^{12}C+{}^{16}O$ structure such that the overlaps with the final fragments are large. The possible relative orientations of these substructures are highly restricted by the experimental K=2 assignment: A state with K=2 must have an axis of two-fold symmetry (if any), and there are only four possibilities to arrange the ^{12}C and ^{16}O substuctures along such a common axis. A variational search for a best candidate has been performed under these symmetry constraints. The calculated excitation of the resulting state is larger than observed but can easily be adjusted by an increase of only 6 % in the Majorana exchange parameter of the standard nucleon-nucleon interaction. The other properties of the calculated state match the data in any respect. The state has, by construction, the observed spin, parity and K-value. The single-particle overlaps between the nascent fragments are small thus indicating sizable clustering and high fissility. The clustering corresponds to the observed fragmentation as the large values of the calculated overlaps between nascent and final fragments show. In particular the overlap of the ^{12}C substructure in the intermediate state with the 2^{+} state in ^{12}C is larger than with the ^{12}C ground state. This is in perfect agreement with the experimental finding that the ^{12}C fragment is predominantly emitted in the excited 2^{+} state rather than the ground state.

†supported by the BMFT and the DFG.

A TEST OF E2 VIRTUAL-PHOTON SPECTRA*

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Calculations of virtual-photon spectra have been performed in DWBA by Onley and collaborators.[1] The reliability of these calculations, particularly for E1 and E2, plays a critical role in the determination of the fission-decay channel of the isoscalar GQR for $^{236,238}U$ by the São Paulo group.[2] The accuracy of the E1 spectra have been verified by the comparison of positron- and electron-induced nuclear reactions.[3]

In order to test the reliability of the E2 spectra, we have analyzed the electrofission-fragment angular distributions for $^{236,238}U$ using the expressions[4]

$$\frac{d\sigma_e}{d\Omega} = A + B \sin^2\theta + C \sin^2 2\theta \qquad (1)$$

and

$$C(E_0) = \frac{15}{32\pi} \int_0^{E_0} \sigma_\gamma(E) \{N_1(E,E_0) - \frac{3}{2} N_0(E,E_0) - \frac{1}{4} N_2(E,E_0)\} E^{-1} dE \qquad (2)$$

where C is a purely E2 term involving the E2 virtual-photon spectra N_i (i is the magnetic substate) and σ_γ is the E2 photofission cross section for $J^\pi = 2^+$, K = 0 measured recently.[5]

We have determined the ratio C(DWBA)/C(Exp) for $5 \leq E_0 \leq 7$ MeV {where eqn. (2) holds[4]}; the values for C(DWBA) were obtained from numerical integration of eqn. (2) and those for C(Exp) from the electrofission data. The mean values and their dispersions for ^{236}U and ^{238}U so obtained are $0.94 \pm .14$ and 1.07 ± 0.04, respectively.

We conclude that the E2 virtual-photon spectra of Ref. 1 are accurate to better than ± 20%.

*Supported in part by the Fundação de Amparo a Pesquisa do Estado de São Paulo
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THE FISSION OF ^{238}U INDUCED BY INELASTIC SCATTERING OF 120 MeV ALPHA-PARTICLES

J. van der Plicht, M.N. Harakeh and A. van der Woude

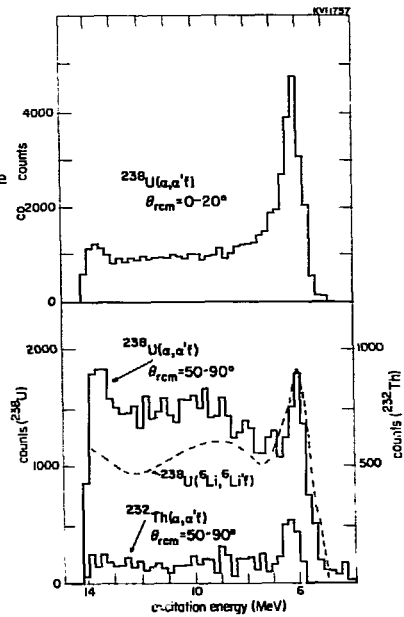
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We have measured the probability for fission of ^{232}Th and ^{238}U induced by inelastic scattering of 120 MeV α-particles (see also ref. 1). This was done by detecting in coincidence the α-particles scattered inelastically through an angle of $(18\pm3)^{o}$ with an energy resolution of 75 keV and the in-plane fission fragments. We assume that the measured anisotropy pattern of the fission fragments is rotationally symmetric around the recoil axis as the in-plane data and PWBA calculations suggest. The fission-coincident α-spectrum with the fragments detected close to the recoil axis, is flat and featureless for $8 \lesssim E_x \lesssim 13$ MeV (see figure). Notably is the absence of a bump corresponding to the one observed in the singles (α,α') spectrum at $E_x \sim 11$ MeV and which is due to the excitation of giant resonances[2]. The spectrum corresponding to the detection of fragments at large angles with respect to the recoil axis shows a bump centered at $E_x \sim 9$ MeV similar to, but not as pronounced as what has been observed previously in the $(^{6}Li,^{6}Li'\ f)$-spectrum[5]. The origin of this bump is not yet clear.

For ^{238}U subbarrier resonances were found at $E_x \sim 5.3$ and 5.8 MeV. The absolute fission probability at the barrier is in good agreement with the previous (γ,f)[3] and $(t,p\ f)$[4] measurement. The angular distribution of the fission fragments at $E_x \sim 5.6$ MeV indicate predominantly negative parity, in agreement with (γ,f) measurements.



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NEUTRON DECAYS FROM HIGHLY EXCITED CONTINUUM REGION COVERING THE GIANT QUADRUPOLE RESONANCE VIA INELASTIC ALPHA SCATTERING ON ^{119}Sn

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Highly excited (10~40 MeV) continuum regions excited by inelastic alpha scattering on medium heavy nuclei consist of giant multipole (GQR etc.) resonances and the continuum region underneath. They decay mostly by neutron emission because Coulomb barrier suppress the charged particle emission. Study of neutron decay is crucial to clarify the dynamic properties of these highly excited regions. We report a first quantitative measurement of the decaying neutron in coincidence with the inelastically scattered α.

Neutrons following the ^{119}Sn(α,α'n) reaction at E_α= 109 MeV were measured by a TOF method in θ_n=-150°~ +150° to the beam in coincidence with the α' at θ_α=19.5°. Thus the recoil nuclei from the (α,α') move toward θ_R=-70°. The neutron energy spectra (Fig.1) gated by inelastic α energy bins covering the GQR show that the forward neutrons have the fast (5~10 MeV) component as well as evaporating slow neutrons, while the backward neutrons have only the evaporating neutrons. The fast forward neutrons, arising certainly from the pre-equilibrium stage, leave the ^{118}Sn at 4~10 MeV excitation region with large spectroscopic density of the single-hole components. The alpha engry spectra plotted against the excitation energy of the residual nuclei (Fig.2) gated by slow, intermediate and fast neutrons at angles θ_n=-150°~ +150° indicate the followings; (i) The slow neutrons are almost isotropic (ii) intermediate (~5 MeV) neutrons are enhanced at the GQR region at the recoil angle (θ_R=-70°) suggesting constructive interplay of the GQR neutrons and the underneath continuum PEQ ones (iii) fast neutrons (~10 MeV) from the continuum PEQ region are enhanced at the forward angles to the beam.

Fig.1

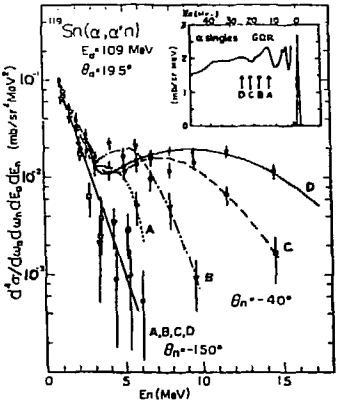
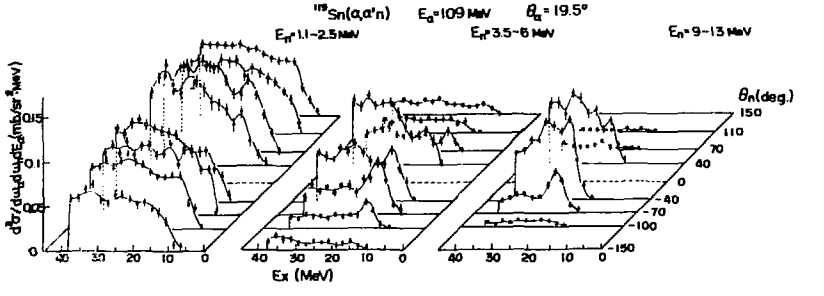


Fig.2

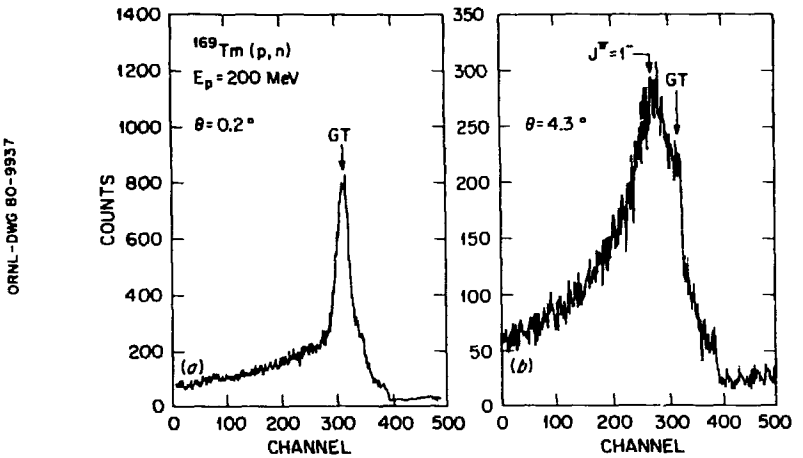


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SPINFLIP RESONANCES OBSERVED IN THE ^{169}Tm(p,n) REACTION AT 200 MeV*

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The ^{169}Tm(p,n) reaction has been studied at the IUCF beam swinger facility[1]) using protons with an incident energy of 200 MeV and a 70-m neutron flight path. This investigation was initiated with the objectives of exploring the effects of nuclear deformation on the GT and recently reported[2,3]) Δt = 1, spinflip giant resonances. Spectra obtained at 0° and 4.3° are shown in the accompanying figure. The arrows indicate the positions of the GT and 1$^-$ resonances. The ground state isobaric analogue resonance is



masked by the GT resonance which has a much greater cross section at E_p = 200 MeV. Comparison of the location of the 1$^-$ resonance in these time of flight spectra with the analogous resonance observed in the ^{208}Pb(p,n) reaction agrees with an approximate calculation using the relation $Q(J^\pi = 1^-) = E_C + E_{GDR} - E_{\Delta T}$, where E_C is the Coulomb displacement energy, E_{GDR} is the energy of the giant dipole resonance in the target, and $E_{\Delta T}$ is the isospin splitting. A comparison of the resonance widths for ^{169}Tm with those found for closed shell nuclei will be presented.

*Research sponsored by Div. of Nuclear Sciences, U.S. DOE, under contract No. W-7405-eng-26 with Union Carbide Corp., the National Science Foundation and the Danish National Science Research Council.

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SEARCH FOR ISOBARIC ANALOGUES OF M1 STATES AND SPINFLIP RESONANCES IN ^{206,208}Pb(p,n) REACTIONS*

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We have studied the ^{206,208}Pb(p,n) reactions utilizing the beam swinger facility[1]) at IUCF with a 70-m neutron flight path. Part of the reason for initiating this experiment was to test the feasibility of locating M1 strength in medium to heavy mass nuclei. A recent survey[2]) of magnetic dipole strength has shown the data to be almost negligible for A $\gtrsim$60. For the ^{208}Pb target, measurements have been made using incident proton energies of 120, 160 and 200 MeV. Fairly complete angular distributions have been obtained for ^{208}Pb at 120 and 200 MeV. Measurements for ^{206}Pb were made at 0° and 4.5° with 120-MeV protons. Spectra for the two targets are quite similar at 0° and 4.5°. Resonances observed with ^{208}Pb are given in the accompanying table. The energy and strength of the collective GT resonance is in reasonable agreement with the predictions[3]) of Ikeda, although the latter placed its excitation slightly below the g.s. IAS. The observed concentration of GT strength is in disagreement with a recent theoretical suggestion[4]) that the GT strength is highly fragmented in heavy nuclei. The resonance in ^{208}Bi at an excitation of 22.9 MeV is suggested to correspond to the analogue of M1 strength reported[5,6]) in ^{208}Pb. The resonance at 21.5 MeV is excited by a $\Delta\ell$=1, spinflip transition and has $J^\pi = (1)^-$. It is suggested to be the T = 21 component of a 1^- "supermultiplet" in ^{208}Bi. A detailed comparison between the ^{206}Pb and ^{208}Pb data will be presented.

$E_x(^{208}Bi)$ (MeV)	$d\sigma/d\Omega$ (0°)[a] (mb/sr)	(FWHM) (MeV)	J^π
2.8	0.86 ± 0.1[b]		2^-
15.2	9.0 ± 1.5		0^+ (IAS)
15.6	41 ± 12	4.1	1^+ (GT)
21.5 ± 1.0	b	10 ± 3	$(1)^-$
22.9	0.9 ± 0.4		1^+
24.6	1.0 ± 0.5	1.2	1^+

[a]At E_p = 120 MeV.
[b]Cross section only determined at ~5°.

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ENERGY SYSTEMATICS OF A $\Delta\ell$ = 1, SPINFLIP RESONANCE OBSERVED IN THE (p,n) REACTION*

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Recently, a $\Delta\ell$ = 1 resonance has been reported in studies of the (p,n) reaction on ^{90}Zr[1] and ^{208}Pb.[2] This resonance has been suggested[1,2] as being the T = T_3 member of a 1^- "supermultiplet". Its peak cross section was shown to be comparable to and to track with that of the giant GT resonance as a function of incident proton energy, hence, it was argued[2] that it is most likely excited by the spin-isospin part of the effective nucleon-nucleon interaction.

We have utilized the beam-swinger facility[3] at IUCF with protons having an incident energy of 200 MeV to study this resonance for a series of targets[4] ranging from lithium to lead. Angular distributions were measured at ≈2.5° intervals out to 15° (10° for some targets). A striking feature of the time-of-flight spectra is that the $\Delta\ell$ = 1 peak occurs at nearly the same channel for most targets. This implies that the resonance has nearly the same Q-value for most targets. This can be explained by a simple energetic argument as follows: If the suggested interpretation of this resonance is correct, then its Q-value should be given approximately by $Q = E_C + E_{GDR} - E_{\Delta T}$, where E_C is the Coulomb displacement energy, E_{GDR} is the energy of the giant dipole state in the target, and $E_{\Delta T}$ is the energy of the isospin splitting in the final nucleus. For most of the cases studied, the increase in E_C with mass is almost balanced by a corresponding decrease in E_{GDR} and an increase in $E_{\Delta T}$. An interesting comparison is ^{112}Sn versus ^{124}Sn where because of the larger $E_{\Delta T}$ the Q-value for the latter is calculated to be smaller than that for ^{112}Sn. This is born out by the data. For targets with T = 0 such as ^{12}C and ^{40}Ca, one expects to populate the analogue of the GDR, and hence expects the corresponding Q-values to be larger than those leading to the $T_<$, 1^- resonance. This is also born out by the data.

Measured and estimated energies of the observed $\Delta\ell$ = 1, spinflip resonances will be presented.

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4. See other contributions to this conference

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LARGE BOUND E1-STRENGTH IN T=1 sd-SHELL NUCLEI[+]

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The low energy tail of the giant electric dipole resonance of T≠0 nuclei can overlap the region where strong M1 states are expected. It is, therefore, necessary to distinguish carefully between different parities of dipole transitions excited in nuclear resonance fluorescence (NRF) experiments. A model independent parity assignment of the transitions observed can be done using linearly polarized bremsstrahlung.

We have studied T=0 and T=1 sd-shell nuclei in NRF experiments with linearly polarized bremsstrahlung at the University of Giessen 65 MeV electron linac. Resonance fluorescence lines were detected with the help of two large volume Ge(Li)-detectors at 90° with respect to the bremsstrahlung beam, where the analyzing power of the reaction equals one. The polarization of the incoming photons was monitored by the $^2H(\vec{\gamma},p)$ reaction. The figure shows all dipole states and parity assignments obtained from NRF-scattering, so far. Empty bars are indicating M1 and hatched bars E1 transitions. For the T=0 nuclei it is known from inelastic electron scattering[1]) that all transitions are M1, while nuclei with neutron excess exhibit large bound E1 strength. Furthermore, we observe a splitting of dipole strength due to the additional degrees of freedom for T≠0 nuclei.

These NRF investigations are presently being continued and extended to heavier nuclei.

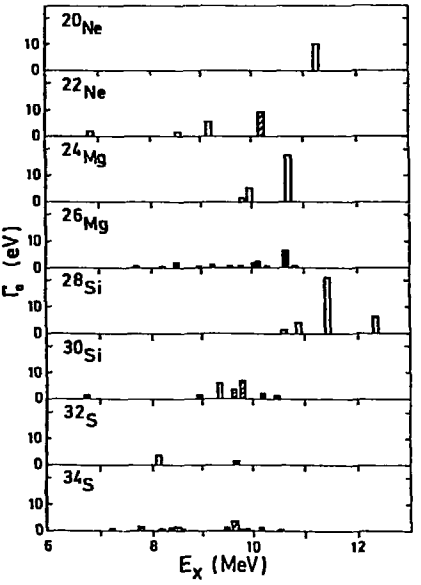


Fig.

Ground state radiative widths and parity assignments for dipole states observed in NRF-scattering. Empty bars are indicating M1 and hatched bars E1-transitions.

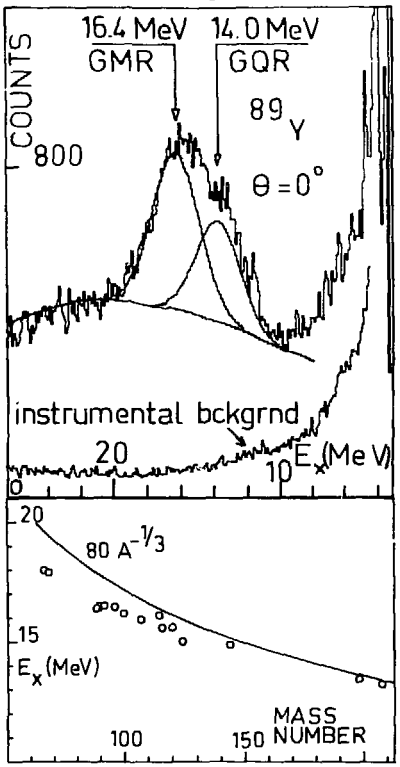
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SYSTEMATIC STUDY OF THE GIANT MONOPOLE RESONANCE THROUGH THE MASS TABLE

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The experimental study of the giant monopole resonance (GMR) with strongly absorbed projectiles like d, ^{3}He, ^{4}He can be performed in best conditions in the region of very small momentum transfer where the cross-section for GMR excitation is maximum (L = 0 transfer) and sometimes larger than that of the nearby Giant Quadrupole resonance (GQR)[1]. The work reported here was undertaken at Grenoble ISN using the 110 MeV ^{3}He beam to bombard a wide set of targets. The detection used technics of magnetic spectrometry. Its original aspect lies in the use of an active collimator system defining the solid angle of the spectrometer, to eliminate slit scattering and to allow data taking down the zero degree scattering angle. The first results were reported in ref. 1 and a more detailed account of this study will be reported in a forthcoming paper.



For each target, the angular distribution was measured between 0° and 8° or beyond. The smallest angle attainable above zero degree was 1.5°. In between the direct beam was hitting one edge of the active collimator, making its use impossible. The spectrum of the figure illustrates the quality of the data and shows the unfolding of GMR and GQR peaks.

The multipole assignment of the GMR and the corresponding strength were obtained from the angular distribution compared to DWBA calculations. The lower part of the figure shows the excitation energy of the GMR for the set of nuclei studied so far, as a function of the nuclear mass. In the light mass region, clear evidence for a GMR could not be obtained from the data for nuclei lighter than ^{66}Zn, although the data indicate that GMR and GQR might lie at the same excitation energy in the ^{40}Ca nucleus. The systematic behaviour of the monopole frequency clearly discards from the $80A^{-1/3}$ behaviour (solid line) in this region of mass. This is likely due to the surface energy contribution to the compression modulus K of the nucleus [2].

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COLLECTIVE ASPECTS OF THE SHELL MODEL[†]

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We conjecture collective vibrational motion of a deformed nucleus which appear naturally within the framework of a deformed oscillator shell model. The first "The Giant Angle Dipole" represents an angular analogue of the giant dipole mode and is pictorially described as excitations in which the proton and neutron densities vibrate against one another in angular fashion about an axis perpendicular to the symmetry axis of the system. For $N \neq Z$ nuclei these states comprise a low and high energy mode which are in general an isospin mixture of $T=0,1$ with $L=2$, $M=\pm 1$ components.

The second a "Stretching Mode" represents high energy vibration in which the nucleus elongates and contracts along the symmetry axis (Z), the other nuclear dimensions remaining fixed. Such a state would be a $T=0$, in phase linear combination of monopole and quadrupole modes.

Finally a "Fattening Mode" is describable in which the radius in the x,y plane vibrates about its equilibrium value, the nuclear length remaining constant. Such a high energy mode represents a $T=0$, out of phase linear combination of monopole and quadrupole modes.

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STABILITY OF NEUTRON-RICH HEAVY ELEMENTS AND THE AGE OF THE GALAXY*

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We study the production rates of the actinide elements in the astrophysical r-process. These production rates, together with the determination of the natural abundances of ^{232}Th, ^{235}U and ^{238}U help determine the age of our Galaxy. In particular we study the decay from r-process path to the actinide region. We use the macroscopic-microscopic method, with the modified-harmonic oscillator single-particle potential and the droplet model to calculate the nuclear potential energy surfaces for heavy neutron-rich nuclei in the region $82 \leq Z \leq 110$ and $120 \leq N \leq 184$. In addition to symmetric elongation and necking coordinates we also study the effect of mass-asymmetric and tri-axial shape coordinates. Odd-particle, odd, as well as even nuclei are included in the calculation by assuming that the odd-particle stays in the lowest possible single-particle orbital during fission. The fission thresholds, the ground state masses and the corresponding particle separation energies and beta decay energies are used as input into a calculation of multi-chance particle emission and beta-induced fission. Effects of spontaneous fission during the decay back to the line of β-stability are also included. A calculation of the decay from the r-process path to the actinide region indicates that the production of ^{232}Th, ^{235}U, ^{238}U and ^{244}Pu will be significantly effected by beta-induced neutron emission and beta-induced fission. The structure of the beta strength function for these heavy neutron-rich nuclei is found to be of prime importance.

We discuss the significance of our results in light of the recent measurements of the Hubble constant. Some areas for further study are pointed out.

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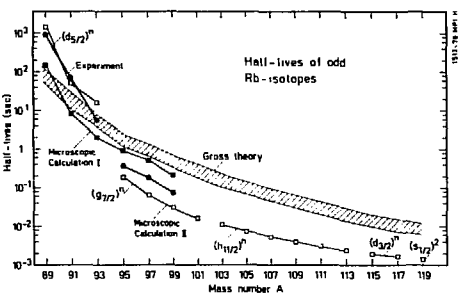
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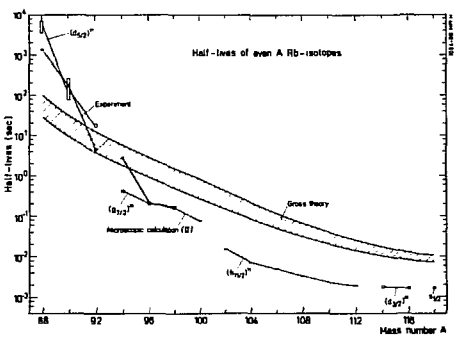
HALF-LIVES OF Rb ISOTOPES UP TO THE r-PROCESS PATH

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The shape of the beta strength function S_{β^-} and β-decay half-lives have been calculated in a schematical Brown-Bolsterli model for the Gamow-Teller β^- decay of $^{88-119}$Rb, i.e. up to nuclei lying in the r-process path (Figure). A Gamow-Teller residual interaction and a Lane potential $G_0 = 62.5$ MeV/A, $G_1 = 2/3\ G_0$ are used (calculation I (from Ref. [1])) differs by using $G_0 = 50$ MeV/A and by the occupancies of the neutron orbits). The calculated transition probability into the GT giant resonance corresponds to log ft ≈2, in excellent agreement with recent experimental results[2]) from (p,n) reactions. The β-decay half-life is determined by the position and strength of back spin flip states (see also [3])). The calculations reproduce the experimental half-lives and also the shell effect in τ due to the beginning of the filling of the $g_{7/2}$ neutron shell. The gross theory of β decay[4]) obviously overestimates the half-lives for the r-process path nuclei. The calculated structure in S_β which affects not only the half-lives but also the rates of β-delayed particle emission and β-delayed fission[3]) is ignored in any of the presently existing calculations for the synthesis of heavy elements by astrophysical processes. The implications, also for emergency cooling systems of reactors, will be discussed.





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STATE DENSITY AND ASTROPHYSICAL NUCLEAR PARTITION FUNCTION*

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State densities are used in a variety of nuclear reaction calculations. The commonly used Fermi-gas model form $\omega(E) \sim \exp[2(aE)^{\frac{1}{2}}]/(a^{1/4}E^{5/4})$ is derived from an equidistant single particle Hamiltonian using the saddle point integeration method. Comparing with experimental data, it fails to fit both the low and high energy values with a single set of parameters. The nuclear partition function, Z(T), Laplace transform of the state density, is useful in astrophysics, e.g., in determining the relative abundance of elements and in the equation of state of nuclear matter for a collapsing star. The Fermi-gas model gives $Z(T) \sim \exp(aT)/aT$ which diverges as $T \to \infty$, a result of the infinite spectroscopic space implied in the model.

One possible way to resolve most of these difficulties is to use the statistical spectroscopy approach[1]. The space is defined by a (finite) set of single particle orbits and the total m-particle strength is subdivided into many configurations, each defined by a set of occupation numbers $\{m_i\}$ in all the orbits. Because of the central limit theorem, the configuration strength distributions are expected to be very close to Gaussian and hence can be expressed in terms of a Gram-Charlier series. Since the series is a fast convergent one, a knowledge of the lowest few moements is sufficient to fix the distribution. Application of the method to state density and partition function for one-body Hamiltonian using realistic sinle particle energies have already been reported[2].

The dominant effect of two-body residual interaction is to lower the ground state energy. This in principle will decrease the state density at a given excitation energy. On the other hand, the strength distribution of each configuration is also broadened. At high excitation energies, where many configurations contribute, this will produce a shift of the relative importance of different configurations at a given energy without greatly affecting the state density, the sum of the strengths. Near the ground state, where there are more strength above then below, an increase of the state density is expected, conpensating for the lose of state density from depressing the ground state energy. The net effect of the two-body interaction is therefore expected to be rather small, affecting mostly the low-energy state density and, hence, the low-temperature nuclear partition function. Numerical results with realistic Hamiltonian will be presented.

State densities and partition functions are, by their nature, average quantities; the statistical spectroscopy method is therefore ideally suited to study them. Contact with realistic nuclear Hamiltonian are made through the moments of the configuration distributions. The numerical calculations involved are well within the present day technicall capability. In addition, possiblity to derive an new form of the state density will be discussed.

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AN EXACTLY SOLVABLE MODEL FOR THE REDUCED ALPHA-AMPLITUDE

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Alpha-decay, α-transfer and similar reactions are usually described in a single particle picture for the α-particle. The many-body wave functions of the nuclei involved have to be reduced to the amplitude for this α-particle. The norm of the resulting reduced amplitude is the spectroscopic factor.

Several years ago it has been proposed[1] to use for α-decay a different amplitude,

$$G_{new} = (1-\hat{K})^{-1/2}\, G_{conv},$$

instead of the one conventionally used, G_{conv}. Here $1-\hat{K}$ is the norm kernel of the α-particle - daughter nucleus system. There has been considerable controversy[2] about this proposal. Thus it seems to be worthwile to present a simple model in which the reduction from the original many-body matrix element to a single particle matrix element can be performed exactly.

The model considers the matrix element of the quadrupole operator Q between the initial ^{20}Ne ground state and an α-^{16}O final state. For the oscillator shell model this matrix element is reduced to a single particle matrix element of the quadrupole operator Q_{rel} for the relative coordinate of the α-^{16}O system. The appropriate reduced amplitude can then be read off from the final expression.

As a special case of the model we may take the 0^+ and 2^+ states of the SU3-ground state band. The many-body matrix element corresponds here to a γ-excitation of a bound α-cluster state. The exact reduction of this matrix element yields

$$T_{if} = \langle {}^{20}\mathrm{Ne},\ 0^+ | Q | {}^{20}\mathrm{Ne},\ 2^+ \rangle = \int d^3R\ G^{0+}_{new}\ Q_{rel}\ G^{2+}_{new}$$

In this case the appropriate reduced amplitude is unambiguously G_{new}. If the final 2^+ state is α-unstable we have a (γ,α) reaction. The wave function of relative motion in the final channel is then proportional to $G_{new}(2^+)$ in the interior, leading again to $G_{new}(0^+)$ as the correct reduced amplitude. For increasing energy in the final state we get a transition from G_{new} to G_{conv}. The corresponding model for a (γ,p) reaction leads always to G_{conv} for the reduced nucleon amplitude.

The model can be extended to more general interactions[3].

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SELF-CONSISTENT DESCRIPTION OF NUCLEAR LEVEL DENSITIES

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We present a self-consistent calculation of the nuclear level density based on a generalization to finite temperature of the modified Thomas-Fermi approximation[1]. A simple analytical formula is derived for the so-called level density parameter a entering the expression of the density of states $\rho(E) \sim E^{-5/4} e^{2\sqrt{aE}}$ and relating the excitation energy to the temperature $E = aT^2$, in terms of equilibrium densities at $T = 0$ only :

$$a = \frac{\pi^2}{4} \sum_q \frac{\alpha(A_q)}{\alpha(\infty)} \int \rho_q(r) \frac{2m_q^*(r)}{\hbar^2 k_{F_q}^2(r)} d\vec{r} \qquad q = n,p \qquad (1)$$

where $k_{F_q}(r) = [3\pi^2 \rho_q(r)]^{1/3}$ and $\alpha(A_q)/\alpha(\infty)$ is a universal function depending on the number A_q of nucleons of type q only and which tends to 1 as A_q increases (see ref.[1] for details). We want to stress here the following points: 1) a appears as the mean value of the local inverse effective Fermi kinetic energy over the nucleus. As already noted qualitatively [2] it is very sensitive to the shape of the surface, where the local k_F is of course much lower than in the interior of the nucleus. For instance, the most external nucleon contributes to as much as 20 % to the value of a in ^{208}Pb and 50 % in ^{40}Ca. 2) The limit of eq.(1) in an infinitely large system gives the correct value of the level density parameter in Landau's theory of Fermi liquids: $a/A = (\pi^2/4)(2m^*/\hbar^2 k_F^2)$. We notice the remarkably simple result that in a finite nucleus, the T.F. level density parameter does not depend explicitly on the effective interaction but through the effective mass m^*, such as is the case when dealing with an infinite system. 3) The conclusion of the two last remarks can be stated as follows : the value of a obtained using effective interactions giving similar mean square radii and surface thicknesses of nuclei differ only by the value of their effective mass. Comparison with experimental data (neglecting shell effects) then favors a value of $m^*/m \gtrsim 1$ near the local Fermi level. This value confirms the conclusions drawn from microscopic analysis[3], which show that the coupling of individual Hartree-Fock states to collective vibrations leads to an energy dependence of m^*, raising its value from ~ 0.8 for the deepest states to $\gtrsim 1.1$ near the Fermi level. This conclusion can be stated as a prescription for thermal Thomas-Fermi calculations (for instance in astrophysical applications) : one should take the usual effective mass in the expression of the free energy of the system and the bare mass in the construction of the functional relation between τ and ρ at $T \neq 0$, which corresponds to setting $m^* = 1$ in eq.(1).

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EQUATION OF STATE FOR HOT DENSE MATTER AT SUBNUCLEAR DENSITIES

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The equation of state for hot dense matter occuring in stellar collapse has been calculated using the Hartree-Fock approximation at finite temperature. We have used the interaction of Ravenhall et al [1] (RBP), as well as the interaction SKM of ref.[2]. The interaction SKM has a better compression modulus and better surface properties than the interaction RBP. We have investigated the density domain between 0.02 and 0.15 baryons/cm^3 at temperatures below 4 MeV, and considered matter with a proton fraction Z/A=Ye=0.25 which is typical for stellar collapse. For fixed values of the baryon density ρ and temperature T, the free energy per baryon F/A of a Wigner-Seitz sphere $r \leqslant R = (3A/4\pi\rho)^{\frac{1}{3}}$ has been minimized with respect to the single nucleon wave functions and nucleon number A. We have calculated the Coulomb energy in the Wigner-Seitz approximation. This is legitimate[3] because the parameter $\gamma = Z^2e^2/RkT$ is always larger than 200 in our density and temperature range. We have not included the effect of alpha particles. Results for the free-energy F/A and entropy S/A are given in the table below for some values of ρ, T and A and interaction SKM. The values of A at the minimum are in qualitative agreement with the Thomas-Fermi calculations of refs.[4-5]). When the density increases, we have found, in agreement with ref.[4]), that nuclei become bubbles. The transition occurs roughly when the surface of the bubble configuration becomes equal to the surface of the nucleus. The equation of state for interaction RBP is somewhat stiffer than for interaction SKM. As an example the adiabatic index $\Gamma = (\partial \text{Log } P/\partial \text{Log } \rho)_S$ calculated for $\rho = 0.04$ fm^{-3} and T=4 MeV is $\Gamma = 1.15$ for SKM while the value obtained with RBP by Lamb et al [4]) is around 1.3.

ρ(fm^{-3})	T(MeV)	A	F/A(MeV)	S/A
0.02	1	200	12.532	.277
		300	12.481	.278
		400	12.492	.296
0.04	4	400	15.668	.852
		500	15.655	.845
		600	15.657	.843

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A MEASUREMENT OF THE LOCAL DENSITY OF ^{3}He IMPLANTED METAL FOILS BY THE DOPPLER SHIFT ATTENUATION METHOD

T.K. Alexander, G.C. Ball, W.G. Davies and I.V. Mitchell

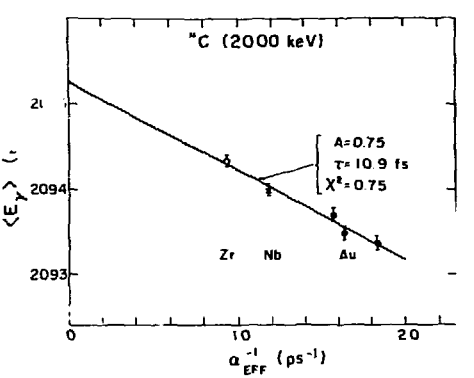
Atomic Energy of Canada Limited
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The phenomenon of material swelling caused by the bombardment of metals with energetic helium ions is well known and is of particular interest in fusion reactor technology. Previous techniques for determining the swelling of helium implanted foils include electron microscopy[1] and optical interferometry[2]. In this paper we describe a new experimental method that provides quantitative information on changes in the density of the layer where the helium resides in the metal. The technique involves the measurement of short nuclear lifetimes ($1 < \tau < 20$ fs) with the Doppler shift attenuation method for nuclei produced in a reaction between the implanted helium target atoms and a beam of high velocity heavy ions. The method is sensitive to changes in the density of the implanted layer if a significant number of ions decay while traversing this region.

A 39 MeV $^{12}C^{4+}$ beam was used to bombard ^{3}He targets implanted at 35 keV in thin (~25 μm) Au, Zr(625 μg/cm^2 on Au) and Nb foils with fluences ranging from 2 to 7 x 10^{17} ^{3}He/cm^2. Alpha particles from the ^{3}He(^{12}C,α)^{11}C reaction were detected in a ΔE-E counter telescope at 0°. Coincident Doppler shifted γ rays from the 2.000 MeV level in ^{11}C were detected in a Ge(Li) detector also positioned at 0°.

The data were analyzed assuming that the fluence of ^{3}He swells all materials according to $\Delta V/V = Ac$, where c is the local atomic concentration and A is a proportionality constant. Further, the target was approximated by a two layer medium in which the Gaussian implant profile was assumed to be rectangular. The γ-ray centroids, $\langle E_\gamma \rangle$, were fitted with an equation of the form[3]:

$\langle E_\gamma \rangle = E_\gamma(t=0) - \Delta E_\gamma \alpha_{eff}^{-1} \tau$, where $E_\gamma(t=0)$ is the fully shifted γ-ray energy, ΔE_γ is the full Doppler shift and α_{eff}^{-1} is the effective slowing down time of the material. The best fit to the data shown in the figure was obtained with A = 0.75 ± 0.25 and τ = 10.9 ± 1.5 fs. This lifetime is in good agreement with the value, 9.2 ± 0.8 fs, found from an analysis of the Doppler broadened lineshapes which are less sensitive to swelling. In addition the value obtained for A is in reasonable agreement with that found by other methods[1,2].



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A RADIOACTIVITY HANDBOOK FOR APPLIED USERS*

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A handbook for applied users of nuclear data is one of the planned publications of the U.S. Nuclear Data Network (NDN). On behalf of the NDN, the Isotopes Project at LBL will produce the Radioactivity Handbook, with specifications agreeable to members of the international network of nuclear structure and decay data centers.

The purpose of the Handbook is to provide a compilation of recommended decay data that is detailed enough for use in sophisticated applications, but that is organized clearly for straightforward use in routine applications. It is not intended as a nuclear structure reference, but should be useful to someone studying decay schemes.

Planning for the Handbook is well underway. The contents and format have been defined, and programming efforts begun. Samples illustrating the proposed contents and format have been distributed (along with a two-page questionnaire requesting specific feedback) to the other (international) data centers and to members of several professional societies.

The Handbook, as currently defined, will be produced at four-year intervals beginning in 1982. Data will be taken primarily from the international Evaluated Nuclear Structure Data File (ENSDF), with no further updating. Additional calculations and evaluation will be done to provide recommended data on atomic radiations and conversion electrons, and to provide 'best' values for γ-ray properties, independent of the decay parent. Each mass chain will be referenced to the most recent evaluation in Nuclear Data Sheets, providing a source for further details and references to the original papers.

The Handbook will be ordered by mass number (A) and subordered by atomic number (Z). Each mass chain will consist of: 1) a 'skeleton' mass-chain diagram showing the ground states and long-lived isomers, along with their properties and the decay relationships between them, 2) tabulated data for each isotope, and 3) a decay scheme for each parent isotope. The tabulated data for each isotope will include: half-life, natural isotopic abundance, mass excess, neutron cross sections, decay mode(s) and genetic relationships, means of production, energies and intensities of all radiations (α particles, β^- and β^+ particles, γ rays, conversion electrons, x-rays, Auger electrons, annihilation radiation, protons, and 'delayed' particles), and average e^+, e^-, and photon (γ + x-ray) energies. The main table will be supplemented by appendices containing physical constants, spectroscopy standards, atomic binding energies, K x-ray energies and relative intensities, and radiation absorption curves. The size of the Radioactivity Handbook, as defined here, will be about 1400 pages.

*Research sponsored by the Office of Basic Energy Sciences, U. S. Department of Energy, under contract W-7405-eng-48.

THE STABILITY OF NUCLEI IN A NON-CLOSED UNIVERSE

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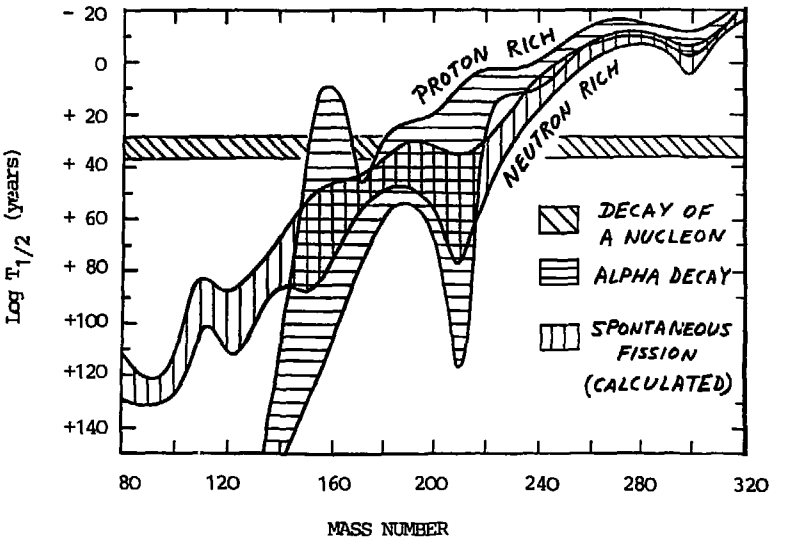
On the time scale of an open universe, i.e. $T=\infty$, most ß-stable nuclei are unstable with respect to some exothermic transmutation. In particular, many nuclei $A \gtrsim 130$ (i.e. $N > 82$) can α-decay ($Q_\alpha > 0$) while nuclei $A > 56$ are unstable relative to spontaneous fission ($Q_{SF} > 0$). We have used recent (d,^{6}Li) data[1]) together with extrapolations based on semi-empirical formulae for $T^\alpha(Z,A,Q_\alpha)$ to estimate α-decay half-lives for ß-stable nuclei. The results are displayed in the figure and compared with the predicted lifetime of a nucleon[2]). Spontaneous binary fission half-lives have been estimated by fitting a semi-empirical equation, including a shell correction[3]), to the available T^{SF} values and extrapolating for ß-stable nuclei $A < 210$ and $A > 260$.

The calculations (figure) indicate that a large fraction of the proton- and neutron-rich ß-stable nuclei $A \sim 150$ will have lifetimes, determined by T^α and T^{SF}, respectively, which are comparable or less than the predicted nucleon half-life. Although the expected T^α and T^{SF} are large relative to the present age of the universe (10^{10} years) they are still finite and comparable to many of the astronomical- and atomic-decay time scales which have been considered[4]) in discussing an open universe.

[+]On leave from the Department of Physics, University of Michigan.

Supported in part by NSF (PHY78-07754) and the GFR Science Foundation.

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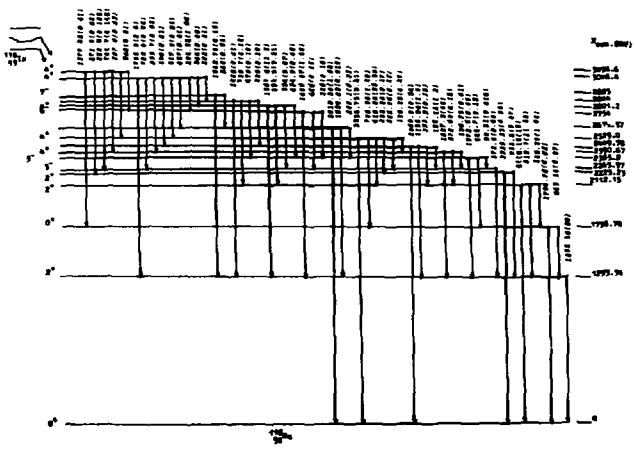


DECAY SCHEME OF ^{116}Sn FED FROM ^{116}IN

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Saudi Arabia

^{116}In was produced by activating samples of ^{115}In by thermal neutrons.The activation and the counting time were carefully chosen so as to reduce contamination with ^{117}Sn.Measurement started five minutes after irradiation was terminated and for two hours for each source.Measurement encompassed single gamma spectra measured with a Ge(Li) detector with a resolution better than 1.9 KeV for the 1332 KeV of ^{60}Co and a coincidence gamma-gamma spectra using fast coincidence technique.The decay scheme shown in figure was constructed basing on sums and differences of the gamma-ray energies and the coincidence data.



Five excited states were proposed more than the available data [1] at excitation energies 2448.78,2619.37,2754,2844 and 2885 KeV.The states 2885,2844 and 2754 KeV are given [2] at excitation energies 2890 (7-),2850 and 2760 (6-) KeV.The decay time of the states 1756.78 and 2448.78 KeV were measured.The mean life time for these states were found to be 6.42 and 7.49 n.sec.The proposed decay scheme has been compared with different models,putting in consideration that ^{116}Sn is an even-even nucleus with a closed sub-shell.The calculated values reproduce fairly well the experimental data.

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AGE DETERMINATION OF PEKING MAN (BEIJING MAN) BY FISSION TRACK DATING

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Age determination of Peking Man at Choukoutien (Zhoukoudian) has been made by fission track dating. Ancient ashes left behind by Peking Man after using fires were used. Sphenes (grain size: 0.05-0.3mm) were separated and selected from ashes. The age was derived from the number of tracks of ^{238}U spontaneous fission in sphenes. The polished surfaces of sphenes covered with muscovite micas were put into nuclear reactor core and irradiated with thermal neutrons. Induced fission tracks of ^{235}U in sphenes were counted with polished surfaces of sphenes (self-detector) or muscovite micas (extra-detector). Rigorous examination was done for the degrees of track annealing in sphenes. Only sphene grains which were completely annealed while Peking Man were firing were used for dating. Three sets of measurement have been done by self-detector and extra-detector methods independently. The ratio of detection efficiencies of sphenes to muscovite micas for fission fragments has been calibrated and corrected in extra-detector method. The results of two methods were found in good agreement. The age of $(0.462\pm0.045)\times10^{6}$y. (layer 10 at Peking Man Site) has been obtained by using the ^{238}U spontaneous fission decay constant of $6.9\times10^{-17}y^{-1}$.

BROMINE-77: A PROMISING NEW PROBE FOR BIOMOLECULAR RESEARCH THROUGH PAC

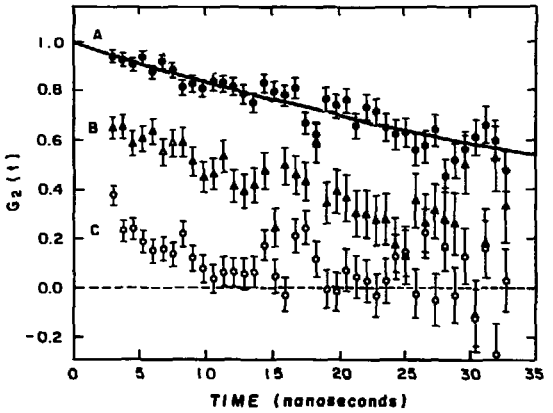
C. Haydock and K.S.R. Sastry
University of Massachusetts, Amherst, MA 01003

and

H.A. O'Brien, P. Grant, J.W. Barnes, and G.E. Bentley
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Application of perturbed gamma-ray angular correlation (PAC) to biomolecular research has been quite recent. The successes achieved so far using ^{111}In and ^{111m}Cd as radioactive rotational tracers have prompted us to explore the utility of other nuclei for similar applications. We present here the first PAC results on the 56-hr ^{77}Br. Of interest to us is the 755 keV-250 keV γ-γ cascade in ^{77}Br decay, involving the long-lived (mean life τ = 13.5 nsec) 5/2$^-$ level in ^{77}Se as the intermediate state. We used an automated 2-detector time-differential PAC spectrometer coupled to a PDP 11/35 computer. The perturbation factor $G_2(t)$ in the directional correlation function $W(\theta,t) = (\text{constant})e^{-t/\tau}\,[1 + G_2(t)A_2P_2(\theta) + G_4(t)A_4P_4(\theta)]$ for this cascade, with A_2 = -0.50, and negligible $P_4(\theta)$ term, is shown in the figure for three cases. (A) For $^{77}Br^-$ in 0.05MNaOH solution, we observe a definite time dependent relaxation effect. (B) In the presence of 46% sucrose, with a viscosity 6 times that of water, the probe tumbles with a longer rotational correlation time. The relaxation constant is correspondingly longer. (C) Finally when $^{77}Br^-$ is bound to the anion exchange resin (AG 1-X10), a highly cross-linked styrene divinylbenzene copolymer lattice with quaternary ammonium exchange groups, the probe is immobilized with a drastic reduction of angular correlation as evidenced by the low $G_2(t)$ values.

These results auger well for ^{77}Br as a PAC probe in molecular and materials research. Since a variety of currently utilized ^{125}I-labeled biological molecules can be brominated, we suggest that use of ^{77}Br would combine the sensitivity of radioactive tracers with molecular information obtainable through rotational tracers.



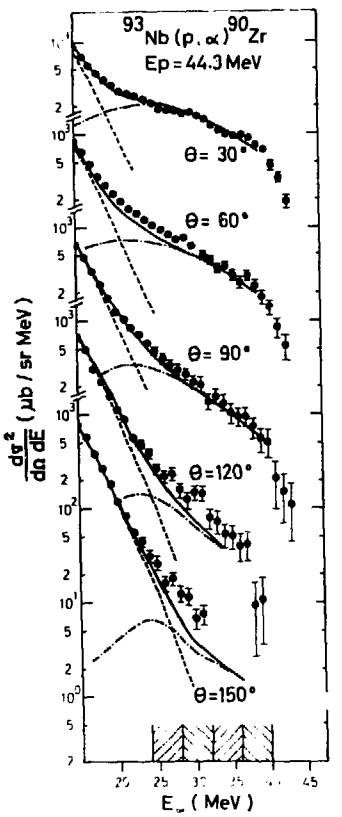
PICK-UP MECHANISM IN (p,α) PRE-EQUILIBRIUM REACTIONS APPLICATION TO ^{93}Nb AND ^{118}Sn, Ep=44.3 AND 34.6 MeV

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The contributions of the one-step triton pick-up to the continuous spectra of (p,α) reactions is analized in terms of the DWBA theory. The basic assumptions made by Tamura et al.[1] are adopted and extended to study aspects related to mass and incident energy dependence.

The use of the single particle harmonic oscillator model to describe residual states together with the assumption of an averaged spectroscopic density (which has an A-mass number dependence) lead to a multi-state averaged cross section factorized into "structure" and "dynamical" parts. In this framework, the absolute value of the theoretical cross section is not well known but the value of the overall normalization is independent of target-mass and ingoing (out going) projectile energy. As a consequence, the validity of the model and pick-up mechanism assumed is checked by fitting relative strenghts of angular distributions for different targets. The interplay between "structure" and "dynamical" factors which vary in a large extent from Nb to Sn targets is essential to obtain the excellent agreement with experimental data[2]. In the figure, point dashed (dashed) curves correspond to the one-step (compound) contributions and full-line to the total sum. Very similar fits to those shown in the figure are obtained for Nb, Ep=34.6 MeV and Sn, Ep=44.3 MeV using essentially the same overall normalization.



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CALCULATION OF NEUTRON SPECTRA AND AVERAGE NEUTRON MULTIPLICITIES FROM FISSION*

David G. Madland and J. Rayford Nix

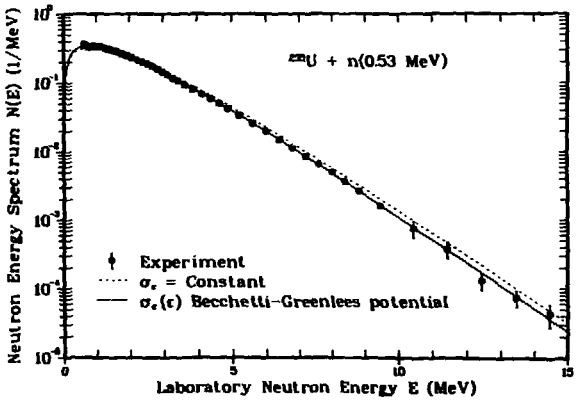
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We present a new calculation of the prompt fisson neutron spectrum and the average prompt fission neutron multiplicity as a function of both the fissioning nucleus and its excitation energy.

Our calculation of the prompt fission neutron spectrum is based upon standard nuclear-evaporation theory and accounts for the physical effects of (1) the motion of the fission fragments, (2) the distribution of fission-fragment residual nuclear temperature, (3) the energy dependence of the cross section for the inverse process of compound-nucleus formation, and (4) the occurrence of multiple-chance fission processes at high excitation energy. Using a residual nuclear temperature distribution based upon the Fermi-gas model, we have performed calculations for two different assumptions concerning the cross section for compound-nucleus formation. Use of a constant formation cross section yields a closed expression for the spectrum involving the exponential integral and incomplete gamma function. Use of an energy-dependent formation cross section, calculated with the optical model, yields a numerical double-integral expression. Results obtained for the two assumptions agree well with experimental data, although there is a clear preference for the calculation with the energy-dependent cross section. A comparison to the experimental data of Johansson and Holmqvist[1] is shown for the fission of ^{235}U induced by 0.53-MeV neutrons.

At high excitation energy of the fissioning nucleus, we include contributions from second-chance (n,nf) fission and third-chance (n,2nf) fission by calculating both the energy spectrum of the neutrons evaporated prior to multiple chance fission and, if the residual nucleus fissions, the neutron energy spectrum from that fission.

Our formalism for the prompt fission neutron spectrum has also been applied to the calculation of the average prompt fission neutron multiplicity as a function of the fissioning nucleus and its excitation energy. The calculated average number of prompt neutrons per fission as a function of the energy of the neutron inducing fission is in good agreement with experimental data for several actinide nuclei. Equally good agreement has been obtained in the case of spontaneous fission.



*This work was suported by the U.S. Department of Energy.

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INTERACTION OF 14 MeV NEUTRONS WITH BODY ELEMENTS AND THEIR DOSE EVALUATIONS

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Using compound nucleus model theory, an attempt has been made to analyse nuclear reactions like (n,n), (n,2n), (n,np), (n,nα), (n,p), (n,pn), (n,pp), (n,pα), (n,α), (n,αn), (n,αp), (n,α(α)) induced by neutrons around 14 MeV with body elements like ^{56}Fe, ^{40}Ca, ^{39}K, ^{35}Cl, ^{32}S and ^{31}P. Gilbert[1,2] level density equation of Newton has been used to evaluate the spectra of the emitted particles. The computed spectra of the emitted particles have been used[3-6] to evaluate first collision doses to the body and bone via above various nuclear reactions. The total first collision neutron doses (around 14 MeV) per unit neutron flux to a standard man via the above various elements are about

Calcium - 1.86×10^{-11} rad; Phosphorus - 1.30×10^{-11} rad.
Potassium - 2.85×10^{-12} rad; Sulphur - 2.78×10^{-12} rad.
Chlorine - 2.01×10^{-12} rad; Iron - 1.65×10^{-11} rad.

Compound nucleus theory being inadequate to predict the cross-sections of light nuclei-H, C, N, O; the best available experimental cross sections have been used, for estimating[7] 14 MeV neutron dose to the body and various tissues via these light nuclei. From the dose contributions of the individual[7] elements H, C, N, O of the tissues, a suitable interpretation of D.E.R. is found.

To have an idea of radiation hazards and side effects in neutron therapy, the alpha, beta and gamma dose rates due to the induced activity of residual nuclei in the various nuclear reactions have also been computed[3-7] using the methods described[8,9] earlier.

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INVESTIGATIONS CONCERNING THE MYSTERY OF GRAVITATION

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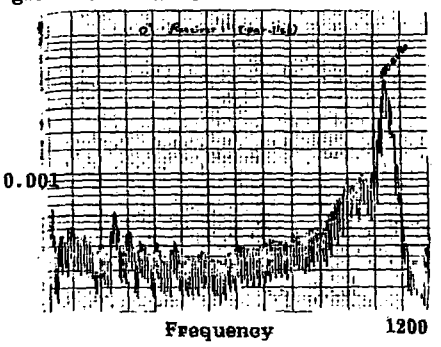
Several experiments have been conducted the past few years which have added to giving mankind a better understanding of gravity. This author, while employed for Martin Company in 1966-67, set up an experiment[†] based upon the Einstein/Weber model, wherein two cylinders having resonance coupling to each other, were acoustically and electromagnetically isolated from one another. The first cylinder was driven piezoelectrically independent of the second. Laser interferometer and piezoelectric monitors coupled to maser amplifiers were cross-correlated and an output at 1200 Hz was noted at the receiver. This near-field communications experiment was conducted with the receiver being 2m away from the sender.

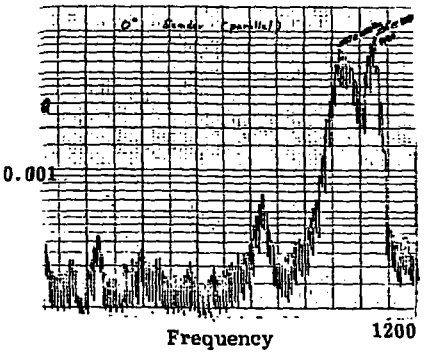
This author proposed the idea of gravitons transmuting into other elementary particles (or pair producing), further supporting Dr. J. Weber's findings concerning the existence of gravitational radiation. From an excited nuclear approach, the production of gamma ray gravitons and photons is possible.

Soviet experimental and theoretical investigation supports the concept that nuclear oscillations and resonance is the major contributor to generating gravitons of optical frequency. From the relativistic quantum mechanical equations (Jordan, Feynman, Heisenberg), one arrives at the expression for the Jordan energy transformation equation used by V. B. Broginskii.

Experimental success of the Los Alamos Godivs reactor proves the feasibility for producing laser light directly from nuclear energy. Likewise, since laser systems can generate gravitons of gamma optical frequency, nuclear energy can be indirectly converted into gravitational energy.

This author is in the process of measuring the change in decay rate from radioactive materials by a high-speed-rotor, in order to verify the Stanyukovich Model which predicts that an oscillating or rotating mass should give rise to gravitational waves.





† This work was conducted at Martin Marietta Corp. and supported by the Department of the Air Force.

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14-50 MeV NUCLEON INDUCED REACTION CROSS SECTIONS— PRE-EQUILIBRIUM AND EQUILIBRIUM MECHANISMS

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Nucleon induced reaction cross sections and the energy spectra of emitted particles are calculated in the 14-50 MeV range. Master equation approach of the exciton model[1] is employed in describing the equilibration process of the compound nucleus. Both pre-equilibrium and equilibrium compnents of reaction cross sections are calculated by solving the master equations exactly up to t=∞. Reaction cross sections and energy spectra for the (N,xy) reactions (x or y = n,p,d,t,h, or α) are calculated.

In addition to the energy spectra of the outgoing particles, the knowledge of their angular distribution is desirable. Some success has been achieved[2,3] in predicting the double differential cross sections $d^2\sigma/d\Omega d\varepsilon$ within the framework of generalized master equation exciton model.[2] At high energies (≥30 MeV) the model predictions are in good agreement with experiment. However, at lower energies (∿14 MeV) lack of good agreement is reported at backward angles for some of the target nuclei studied. It is possible that the equilibrium part (symmetric about 90°) of the angular distribution is not properly accounted for. This and the other parametric aspects of the model is under study.

Calculated energy spectra and double differential cross sections will be compared to experiment for nucleon induced reactions for Ni and for a few other nuclei.

[†]This work is supported by the U.S. Department of Energy

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14-50 MeV NUCLEON INDUCED REACTION CROSS SECTIONS— PRE-EQUILIBRIUM AND EQUILIBRIUM MECHANISMS

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DEUTERON STRIPPING REACTIONS AS A THREE-BODY PROBLEM

Ahmed Osman *

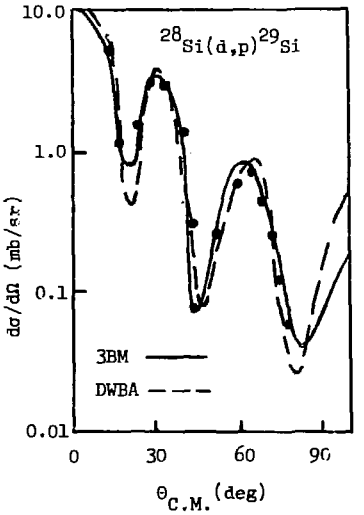
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Deuteron stripping reactions are very useful in studying the nuclear static properties of nuclei. These reactions are interesting since they describe the interaction of an incident loosely bound deuteron with a heavy mass target in the entrance channel. The process of these reactions have been widely studied with the help of the DWBA approximation using the perturbation approach, but to understand the reaction mechanism, the three-body aspects [1] must be taken into account.

In the present work, a three-body model is used in studying the deuteron stripping reactions. Introducing a decompcsition into the angular momentum states in the Lippmann-Schwinger equation and using the partial-wave amplitudes [2], the wave functions of the three-body system are given by a set of three integral equations. Numerical calculations of the differential cross-sections of the $^{28}Si(d,p)^{29}Si$ at deuteron incident energy of 18.0 MeV are carried out using simple two-body interactions with separable potentials [3], which reduce the three-body problem to one-dimensional Fredholm integral equations. The calculated angular distributions are compared with the experimental data, see the figure, giving extracted spectroscopic values of 0.9841 by using the DWBA calculations, and 0.9989 by using the present three-body model calculations.



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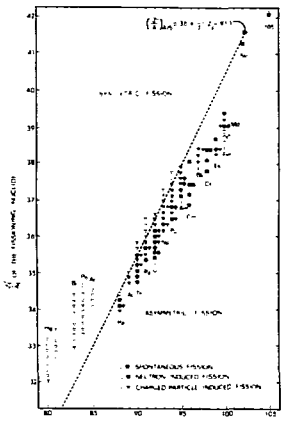
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AN INTERPRETATION OF SYMMETRIC vs. ASYMMETRIC FISSION†

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In recent years, it has been commonly assumed that low excitation energy fission may be correlated with asymmetric mass distributions and equal charge displacement while fission from a highly excited nucleus leads to symmetric fission and unchanged charge distribution. However, in the course of extending our study of the fissionability of thorium[1]) to include ab initio calculations of charge dispersion[2]) we have found that symmetric/asymmetric mass distributions correlate to the identity of the fissioning nuclide, rather than its excitation energy. A recent report[3]) also suggested that the onset of the symmetric fission peak in Th(p,f) is attributable to the opening of a new channel in multi-chance fission.



This work reports the results of applying this interpretation to experimental mass yield curves ranging from spontaneous to 60 MeV particle-induced fission for nuclides from Z = 80 to 105. Multi-chance fission mass yield curves were decomposed into symmetric and asymmetric parts. The excitation energy at which the symmetric peak becomes noticeable is used to define the fissioning nucleus which has just become available in the evaporation chain. More than 100 nuclides for which data is available were tested and the Z^2/A for symmetric/asymmetric noted (see figure). It has been found that all nuclides with Z^2/A less than a critical value given by $36 + 0.5\,(Z-91)$ fission asymmetrically while those with higher Z^2/A fission symmetrically. All nuclides in the Th-Pu region are correctly predicted.

Utilizing the Exciton Model with fission option[1]), we have evaluated the distribution of fissioning nuclei in Th fission to 85 MeV. Dividing these according to their values of Z^2/A, we find the relative symmetric and asymmetric fission yields may be correctly predicted at all energies. Those fissioning nuclides having Z^2/A less than, or more than, the critical value were then assumed to divide in accord with the equal charge displacement or unchanged charge distribution theories, respectively. With this assumption, the experimental charge dispersion curves may be successfully calculated as a function of both mass and excitation energy.

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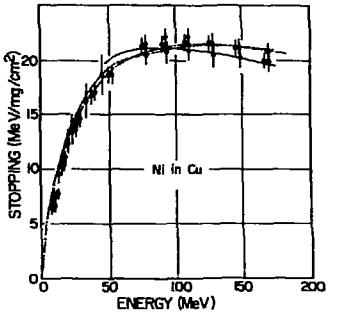
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EVIDENCE FOR HIGHER ORDER Z_1 EFFECTS IN HEAVY ION STOPPING POWERS*

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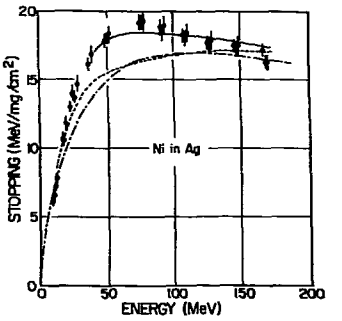
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We have made a study of the ranges of energetic heavy ions (Z_1 = 14, 28, 79 and $E_1 \leq 3$ MeV/amu) in thick targets (Z_2 = 29, 47, 82 and $t \leq 10$ mg/cm^2). The results suggest modifications of current stopping power compilations.[1,2] Two effects are seen, including 1) non-linearity of Stopping Power vs. Velocity curves at low energies, and 2) for some Z_1, Z_2 combinations the stopping power peak occurs at substantially lower energies than the current tables[1,2] predict. Direct dE/dx measurements made in two of these cases (Ni in Cu, Ag) confirm these features.



The non-linearity of dE/dx at low velocities has been seen by other workers. Nesbet and Ziegler[3] suggested a method for fitting these data which gives good agreement with our measurements (Ni in Cu, Ag) up to $V \cong 4\,V_0$ ($V_0 = e^2/\hbar$).

An expression for the ion effective charge was necessary in order to study the effects of Z_1^3 and Z_1^4 corrections to our dE/dx measurements. Following Porter,[4] we chose $Z_{1\,eff}/Z_1 = 1 - \exp(-\lambda V_r)$ where $V_r = V/V_0 Z_1^{2/3}$ and λ is a search parameter. Higher order corrections were essentially those of Lindhard,[5] while values of the Bethe stopping number L_0 were taken from Andersen,[6] et al.



The results (solid curve) are shown along with the calculations of Ziegler[2] (dashed curve) and Northcliffe and Schilling[1] (dot-dash). Although the Cu and Ag data appear quite different with respect to the standard curves, use of the Z_1^3 and Z_1^4 corrections allows satisfactory fits in both cases. Values of the parameter λ were found to be 0.821 for Ni in Cu and 0.824 for Ni in Ag, which is consistent with the assumption that the ion effective charge is relatively independent of the target material.

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TEKTITE WEATHERING*

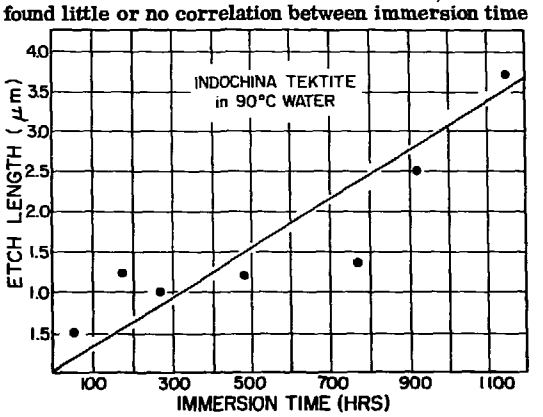
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Tektites are natural glassy objects found distributed over large but localized regions of the earth's surface. Tektites found within one of these localized fields are homogeneous in composition and are the same age as radiometrically determined. Because many tektites are found that are quite old ($\sim 10^6$ years) and yet retain intricate aerodynamic shapes showing no obvious signs of weathering, we have been investigating the weathering of tektites. Two suggestions of the origin of the tektites are (1) that they are formed during violent collisions of meteors with the earth's surface and (2) that they result from volcanic eruptions on the moon with material escaping the moon's gravitational field being captured by the earth. [1]

A single large Indochinite was fractured and the pieces were placed in 90°C water for various times. We subsequently measured the hydrogen depth profiles for these pieces using a nuclear reaction technique based on the $^{15}N(^1H, \alpha\gamma)^{12}C$ resonant reaction. [2] Unlike other silicate glasses we have studied (natural obsidians [3]) and man-made glasses [4,5]) we have found little or no correlation between immersion time and surface hydrogen.

Upon examination of the various pieces under a scanning electron microscope we found etch pits in the surface along cracks and other imperfections. The width of the etch pits from several areas were measured on each piece and there was little variation.



Plotted in the accompanying figure is the radius of the etch pits versus immersion time. The line indicates that the tektite is dissolving in the 90 °C water at a rate of $\sim 9 \times 10^{-11}$ cm/sec. This etch rate is similar to that found for commerical soda lime glass [4] (2×10^{-11} cm/sec) and reactor waste glasses [5] ($\sim 10 \times 10^{-11}$ cm/sec).

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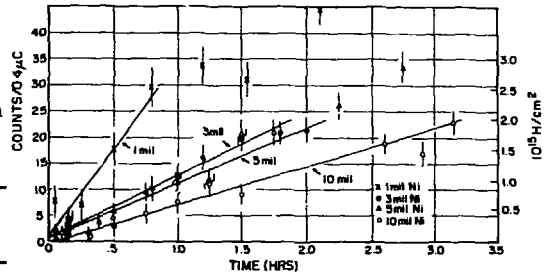
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HYDROGEN ADSORPTION ON THE SURFACE OF NICKEL FOILS*

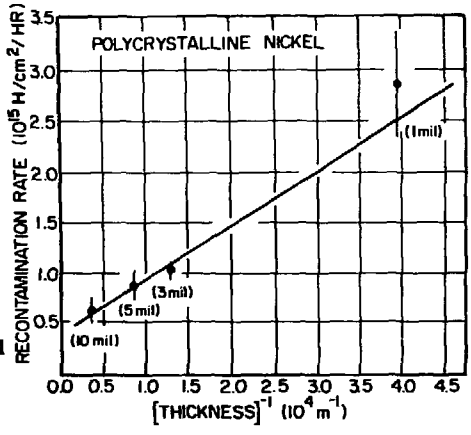
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In an attempt to make large hydrogen free surfaces suitable for ultracold neutron bottles, we have been studying the hydrogen surface contamination on various materials (SiO_2, Ni, W, Ti, 304 Stainless Steel, Ta, Zr, Fe) in a vacuum of 10^{-6} torr. We measure the concentration versus depth using the ^{15}N profiling technique.[1] All of these materials can be cleaned by heating to $\sim 10^3$ °C but they immediately begin to become recontaminated as soon as they cool back to room temperature. For metals, rather surprisingly, the hydrogen recontamination rate (see fig. 1) is very sensitive to the thickness of the metal foil even though the vacuum conditions are the same for all foils. Shown in the figure is the concentration of surface hydrogen versus time after the heating was stopped for nickel foils of various thicknesses. We plot (in fig. 2) the initial slope of these curves versus inverse thickness, the result of which is consistent with a straight line. We conclude from this study that hydrogen absorbed on the cleaned metal surface can either remain on the surface or diffuse into the bulk of the metal, probably retained on the internal grain boundary surfaces. This pattern of hydrogen transport may be general and of importance to such varied fields as the containment of ultracold neutrons in bottles, hydrogen metallurgy and catalysis, and construction of ultrahigh vacuum chambers.



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FAST HEAVY ION INDUCED DESORPTION OF MOLECULES[+]

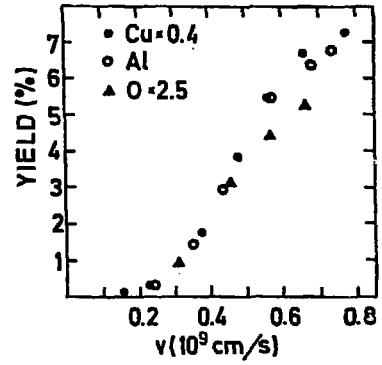
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Fast heavy ions such as fission fragments from a Cf-source were found to cause desorption of large thermally labile bio-molecules by Macfarlane and coworkers[1]. This effect has been exploited in mass spectroscopy on numerous organic compounds[2].

We have studied the mechanism for this process by measuring yields of molecular ions from samples of CsI, $C_4H_8O_3N_2$ (glycylglycine) and $C_{28}H_{44}O$ (ergosterol) as a function of velocity and angle of incidence for different fast heavy ions from the Uppsala EN-tandem accelerator. The experimental set up consists of a time-of-flight mass spectrometer. The striking experimental finding is that there is a threshold velocity above which the yields increase dramatically. The threshold velocity is found to be independent of the angle of incidence and heavy ion used within the experimental uncertainties. However, different sample molecules give different threshold velocities. In the figure the yields of Cs^+-ions for different fast heavy ions are shown. A possible explanation for the effect may be that swift heavy ions induce shock-wave electron-density fluctuations in the sample which cause the desorption. Such density fluctuations would appear in the velocity region found here. Also the recently proposed[3] core-hole Auger-decay model for electron-stimulated desorption would give a similar threshold effect due to the velocity dependence of the cross section for core-vacancy production by fast heavy ions. However, this explanation seems less likely as no O^+-ions are found in spectra from maximum valence oxides as TiO_2.



Using a Cf-source we have also studied mass spectra of aminoacids, peptides and vitamine-D compounds to clearify the field of applications of this process. Characteristic features of spectra of positive and negative ions will be illustrated as well as the possibility to perform quantitative analyses with this technique.

[+]This work was supported by the Swedish National Science Research Council.

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APPLICATION OF COMPTON SCATTERING AS A NONDESTRUCTIVE, NONRADIOGRAPHIC INSPECTION TECHNIQUE*

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A nondestructive inspection method employing the detection of Compton scattered gamma rays to measure density variations within materials has been developed to detect cracks and cavities in the high explosive filler of steel cased artillery projectiles. The filmless inspection system is referred to as an Automatic Inspection Device for Explosive Charge in Shells (project acronym AIDECS). AIDECS will provide 100 percent inspection with fast throughput (~1 projectile/min) and will be totally computer controlled.

Basically, scintillation detectors are collimated such that they detect Compton scattered gamma rays from a specific portion of a collimated ^{60}Co gamma-ray beam. The projectile is moved through this inspection volume and current from the anodes of the detectors' photomultiplier tubes is digitized for specific volumes within the projectile. The digitized current is directly related to the density within the given volume element. A decrease in current corresponds to a void; an increase in signal corresponds to an inclusion. The system computer maintains a one to one relationship between the spatial location of the projectile and the detectors' currents. In this way, density dependent responses for the total volume of the projectile are obtained in three dimensions. Fig. 1 is a schematic of the AIDECS apparatus.

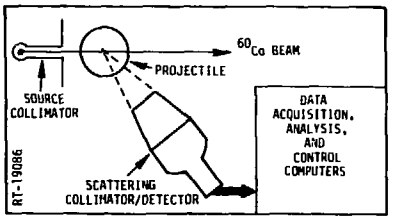


Fig. 1.

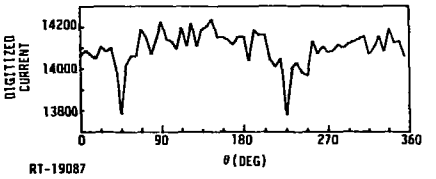


Fig. 2.

Fig. 2 shows a typical response curve obtained by rotating a 105 mm projectile in the gamma-ray beam. Two 0.16 cm diameter x 0.41 cm long cavities intercepted the beam at the detector inspection point and their effects are seen at $\theta = 45$ degrees and $\theta = 225$ degrees. The maximum signal change for each defect is 2.1 percent. AIDECS presently is capable of reliably detecting and identifying cracks smaller than 0.7 mm wide, porosity, and separation of the charge from the base smaller than 0.7 mm, in addition to the small cavities. The positions of the defects in the projectile may be specified to better than 0.8 mm.

In summary, the use of Compton scattering as described should, in some cases, provide a better means for nondestructive inspection than currently available as well as enable the nondestructive inspection of materials currently unresponsive to inspection.

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HIGH-SPIN STATES IN N=50 ISOTONES

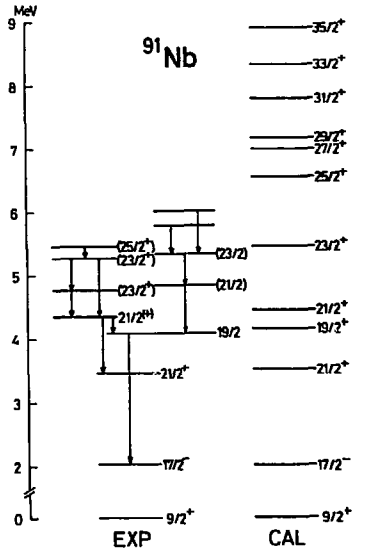
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Recently high-spin states have been observed in N=50 isotones.[1] In ^{91}Nb, the observed gamma-decay properties indicate positive parities for the high-spin states above 4 MeV and existence of two structures which are substantially different. They cannot be explained by the proton $(p_{1/2},g_{9/2})^3$ model, and neutron core excitation is suggested as a possible origin of these states.[1]

We tried a shell-model calculation as follows. In addition to the proton $(p_{1/2},g_{9/2})^{A-88}$ configuration, one proton or neutron is allowed to excite from the $p_{1/2}$ or $g_{9/2}$ shell to the $d_{5/2}$ shell. Effective interactions in the $p_{1/2}$-$g_{9/2}$ subshells are taken from ref 2). Matrix elements concerning the $d_{5/2}$ nucleon are taken from ref 3) and from the observed spectra of ^{90}Y, and are supplemented with the MSDI and phenomenological-potential interaction. The s.p.e. of $d_{5/2}$ neutron is set to the difference of binding energies of ^{89}Sr and ^{88}Sr.

The calculated level scheme of positive-parity states in ^{91}Nb is compared with the observed one in the figure. The lowest three members of the one structure above 4 MeV is satisfactory reproduced by the $g_{9/2}$-neutron excitation. The wave functions are quite well described by coupling of neutron particle-hole to the ^{91}Nb ground state. Negative-parity high-spin states appear above 5.8 MeV. Therefore, the other structure of the observed energy spectra may be attributed to Z=38 core excitation. It is also revealed that almost all the calculated levels have very small mixing of configurations.



Further experiments of high-spin states in this mass region will be requested.

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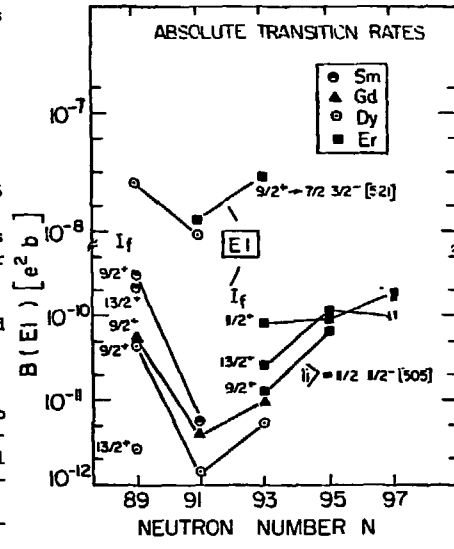
POSSIBLE ONSET OF THE ROTATIONAL-ALIGNED COUPLING SCHEME AT N = 89

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Transition strengths B(E1) in odd-neutron deformed nuclei surprisingly reveal a pronounced minimum at N = 91 which has not been understood so far[1]. The E1 transitions considered connect the almost unperturbed $11/2^-505$ state with members of the positive-parity band explained by the strong Coriolis mixing of i13/2 orbitals. The analysis showed that some known effects (e.g. pairing correlations) are not responsible for the strange minimum. Now, we propose a possible explanation for this behavior.



The E1 transitions in question are K-allowed to $9/2^+624$, $11/2^+515$ and $13/2^+606$ components in the wave functions (WF) of the final states With decreasing neutron number above the N = 82 gap, the admixture amplitudes of these orbitals decrease as confirmed by earlier calculations in odd-A Er isotopes. This explains the decrease of the B(E1) strengths from N = 97 to N = 91. The sudden strong increase of B(E1) between N = 91 and 89 indicates a new considerable increase of the $\Omega = 9/2^+$, $11/2^+$ and $13/2^+$ components in the WF.

Such an increase can be caused by a new coupling scheme [2] with the odd neutron aligned along the axis of rotation and the WF of the $\pi = (+)$ states represented by a strong mixing of all possible Ω-values. The onset of this coupling scheme can be associated with the smooth decrease of deformation [2].

*On leave from Institute of Nuclear Research, Sofia, Bulgaria.
†Supported in part by the National Science Foundation.

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Yrast Isomers in ^{152}Dy

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Some time ago[1]) the yrast states up to 12.7 MeV excitation in the ^{152}Dy nucleus have been observed, and the slope of its yrast line has been intensely[1-3]) discussed in terms of a fermigas model and (oblate) nuclear deformation. More recent $T_{1/2}$ and polarization measurements[4]) gave relative parities and confirmed the relative spins for the levels above the 60 ns isomer[5]) at E_x = 5 MeV. However, the data from different groups[1,5,6]) on the levels below 5 MeV so far are contradictory. In particular, disagreement [5,1,6]) exists about the occurance of a low-energy isomeric transition de-exciting the 5 MeV 60 ns isomer, and about the multipolarity[5,1]) of the next lower 604 keV transition (see fig.). The so far available data therefore would allow I^{π} = 15±, 16±, 17± or 18± for the 60 ns isomer, with equal uncertainties for all higher lying states.

We have reinvestigated ^{152}Dy in an (α,4n) four parameter γ-γ coincidence experiment. Application of a recoil shadow technique eliminated the intense K and L X-rays arising from target ionization. The data reveal a 53.3 ± 0.2 keV γ transition which is shown to be the 60 ns isomeric transition in ^{152}Dy. Its multipolarity must be determined from the coincidence data since in the singles spectra the transition is not resolved from the 53.5 keV Dy K_α X-ray and the 53.4 keV ($T_{1/2}$=1/2 sec) transition in ^{73}Ge. Three independent intensity ratios (see table) give E2 multipolarity for the 53.3 keV isomeric transition.

Intensity ratio	E1	M1	E2	M2	experiment
Dy KX/53	14	5.3	.56	.21	.48(16)
½(604+610)/53	1.0	2.7	26	67	21(6)
Dy KX/53	.04	.26	3.2	9.1	1.5(6)

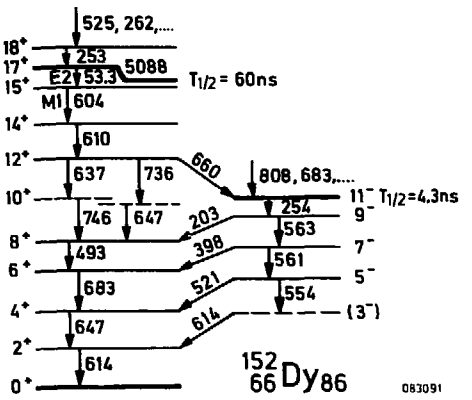
From these coincidence studies we also found that the lowest yrast isomer in ^{152}Dy is the 11^- level at 3161 keV. Its half life is $T_{1/2}$ = 4.3 ± 0.9 ns.

Conversion electron spectra measured between cyclotron beam bursts gave K values for the transitions below the 50 ns isomer, in particular the 604 keV transition is found to be of M1 character.

From the present work the spins and parities of the ^{152}Dy yrast states above 4.5 MeV are now determined, which makes detailed theoretical discussion of these data more meaningful.

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+++ Alex. von Humboldt fellow 78/80

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GENERALIZED OPTICAL MODEL FOR TRANSITIONAL NUCLEI BASED ON THE DYNAMIC DEFORMATION THEORY

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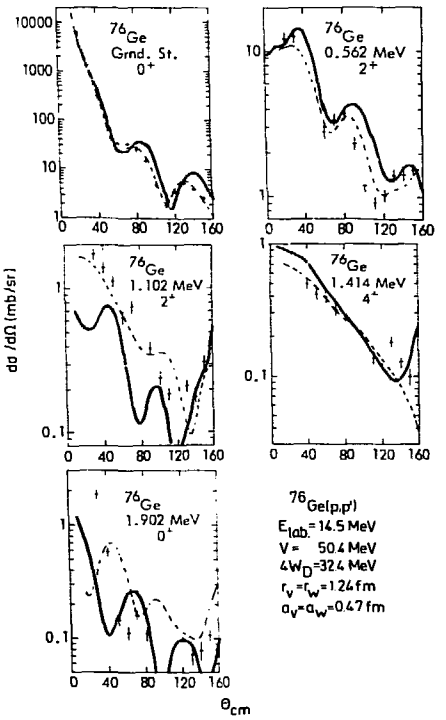
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The present formulation of the dynamic deformation theory (DDT)[1] has proven succesful in describing energy and electromagnetic properties of a wide range of nuclei with no need for parameter adjustments from one nucleus to the next. We are presently testing the quality of the DDT wave functions with respect to particel transfer reactions and inelastic scattering. Thus we have generalized the optical model for permanently deformed nuclei to become a dynamical model in the shape coordinates (β,γ). The general structure of the scattering form factors becomes

$$\langle n'I'||V_L(r)||nI\rangle =$$

$$\sum_{sKK'} G^{(s)}_{KK'}(II'L) \; \langle\langle n'I'K'|V_{LK_s}(r)|nIK\rangle\rangle$$

where $s = +,-$, G is a 3j-symbol and the double brackets symbolize an integration over the deformation coordinates, where the intrinsic form factors are weighted with the vibrational amplitudes for the states being connected. The intrinsic nuclear form factors correspond for each shape to a deformed Fermi function with equivalue surfaces of the Hill-Wheeler ellipsoidal type[1], so as to conserve the volume for all shapes.



The figure shows the result of a test calculation (coupled channels) for ^{76}Ge(p,p') with data from ref.[2]. A quite satisfactory overall description of the five lowest lying states is obtained. This is gratifying since a quite complicated nuclear structure is involved with rich variations from level to level. A similar quality fit in a phenomenological vibrational model (dashed curves) requires a large number of fitting parameters.

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BAND STRUCTURE OF ^{82}Sr AND THE INTERACTING BOSON MODEL *

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The excited levels of ^{82}Sr have been studied by means of γ-ray spectroscopy using the reactions ^{72}Ge(^{12}C,2n), ^{66}Zn(^{19}F,p2n), and ^{79}Br(^{6}Li,3n). It has been possible to identify three bands viz the g.s.b. up to 10^+, the quasi γ-band up to 14^+, and a band of negative parity whose level ordering is still uncertain.

By means of the Proton-Neutron-Interacting Boson Model (IBM-2) [1] we could well describe the states of the ground state band and those of the γ-band up to 7^+. Only two parameters have been varied compared to the description of the isotone ^{80}Kr. At spin 8^+ the γ-band displays backbending which exhibits the influence of the $(\nu g_{9/2})^{-2}{}_{8+}$ configuration. There is a great similarity between the family of states based on the 8^+_2 state up to 14^+ and the ground state band of ^{84}Sr up to 6^+ which could point to a $(\nu g_{9/2})^{-2}$ ⊗ ^{84}Sr (decoupled?) structure for these states, as suggested in the figure. This assignment must be considered tentative, however, as the band crossing is not very conspicuous. Measuring the B(E2) values will provide information on the degree of mixing with the states of the γ-band.

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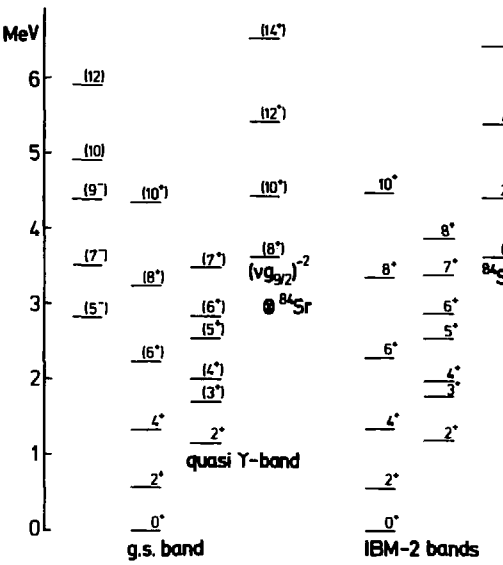


Fig. 1:

On the left side are given the experimental levels of ^{82}Sr.

* Supported by BMFT

CORRELATIONS BETWEEN MOMENTS OF INERTIA AND CLOSED-SHELL MASSES OF GROUND STATE BANDS IN EVEN-Z, EVEN-N NUCLEI

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Considerable information is now available on the ground state rotational bands and quasi-bands in even-Z, even-N nuclei. A representative sample of this data (A = 120-242) is plotted in Fig. 1. Two things are noted in a plot of this type. First, the data breaks up into groups based on their slopes. The breaks occur at the closure of major proton and neutron shells. The last closed proton and neutron shells for the upper group are Z = 50 and N = 50; for the middle group, Z = 50 and N = 82; and for the lower group, Z = 82 and N = 126, respectively. The second interesting feature is that although the slopes of the lines differ by factors of two between members of the same group at low spin, they become quite similar for all members of the group at higher spins ($I \gtrsim 8$). This trend can be more easily seen in Fig. 2 where the moment of inertia, $\mathcal{I}$, of each band (calculated from the energy spacing between the 8+ and 10+ levels) is plotted verses A, the atomic weight. The dependence of the moment of inertia of a rigid rotor on its mass, $\mathcal{I}$ = constant $\times A^{5/3}$, is indicated by the slanted line. The moment of inertia values within each group show no mass dependence. The average value for each group, however, does show a strong mass dependence that follows the predictions for a rigid rotor ($A^{5/3}$) quite closely (see horizontal lines) if one uses the mass of the closed-shell nucleons in each nucleus. In summary, the moment of inertia of an even-Z, even-N nucleus in this mass region appears to be correlated with the mass of its closed-shell nucleons and is affected only slightly by the nucleons outside closed shells and by its deformation.

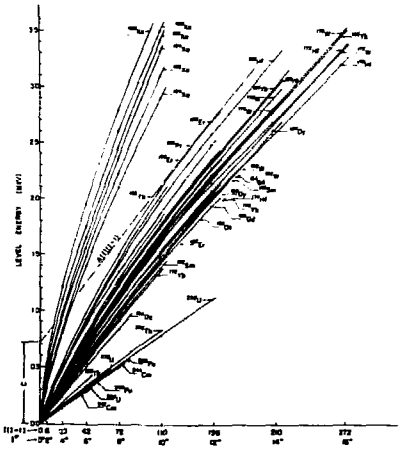


Fig. 1

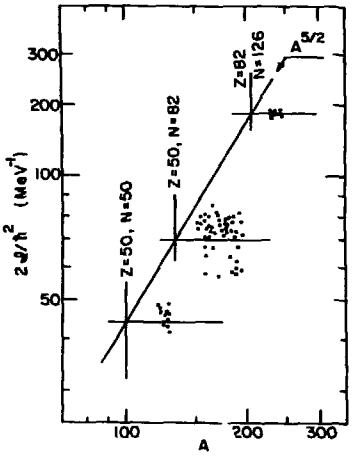


Fig. 2

*Work supported by the Nuclear Science Division of the U. S. Department of Energy.

A Quantitative Description of Band-crossing in $i_{13/2}$ Particles-Soft Rotor Coupling Model

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The backbend of rotational bands of deformed rare earth nuclei can be regarded as a manifestation of interaction between collective rotation and the internal degrees of freedom. Particles in the unique-parity orbits are most strongly influenced by the interaction and change their motion relative to the collective rotation very sharply at a certain spin. Based on these physical considerations, we have proposed[1] a model of $i_{13/2}$ particles coupled to a soft rotor which is described in terms of angular momentum projected states out of a coherent boson state. In order to be realistic it is important to take into account the pairing correlation and, therefore, the number of particles in $i_{13/2}$ is not fixed but allowed to take on various values equivalently to the BCS theory. In addition to the pairing and the quadrupole coupling, we have included $\alpha\vec{R}\cdot\vec{J}$ term where $\vec{R}$ and $\vec{J}$ are angular momentum operators of the rotor and the particles, respectively.

	g-band		S-band	
0^+	0	(0)	1688	
2^+	93	(92)	1763	
4^+	303	(300)	1916	
6^+	618	(614)	2084	
8^+	1025	(1024)	2219	
10^+	1516	(1518)	2355	
12^+	2082	(2082)	2553	(2518)
14^+	2723	(2700)	2829	(2874)
16^+	3443	(3410)	3253	(3261)
18^+	4225	(4120)	3759	(3767)
20^+	5004	(4867)	4359	(4344)

The purpose of our study is to quantitatively describe the backbending rotational bands. We have performed numerical calculations for a series of Er isotopes using the full space for $i_{13/2}{}^n$. The Lanczos method is used for diagonalization. We have obtained very satisfying fits to experiments. As an example the theoretical excitation energies are shown in the Table for ^{164}Er (experimental values are in parenthesis).

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BEHAVIOUR OF ^{156}Er AT HIGH ANGULAR MOMENTUM

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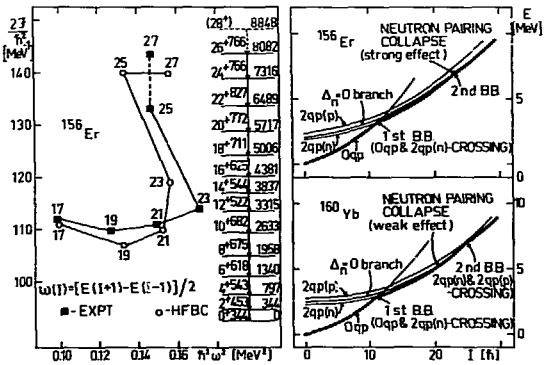
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A second anomaly in the moment of inertia has been observed in ^{158}Er [1] and ^{160}Yb [2] and explained as the alignment of an $h_{11/2}$ proton pair. The magnitude of the break in the backbending curve has been shown to be an oscillatory function with respect to Z. In order to study the role of the neutron number, we have investigated the yrast levels of ^{156}Er using the ^{141}Pr(^{19}F,4n) reaction. The experiments were performed with use of the 95 MeV ^{19}F beam from the Strasbourg MP tandem accelerator. High resolution γ-γ coincidence measurements, directional γ-γ correlation measurements and relative γ-ray yield measurements as a function of beam energy provided the information necessary to deduce the level scheme up to $I^{\pi}=26^{+}$ and tentatively up to $I^{\pi}=28^{+}$ (lefthand side of the figure). In a previous study [3] using an ^{18}O beam, the levels with spin up to 24 $\hbar$ were identified. The conventionnal $\mathcal{J}(\omega^2)$ plot, also represented in the figure, exhibits a strong backbending at $I^{\pi}=24^{+}$.

The data were analysed in terms of the HFB cranking method in its pairing self-consistent version of ref.4. The nuclear hamiltonian was represented by deformed Woods-Saxon and monopole pairing fields. Unlike the ^{160}Yb nucleus, the second anomaly for ^{156}Er is, in the present calculations, caused by the neutron pairing collapse (crossing of the nuclear "superfluid" and "non superfluid" (Δ_n=0) bands, righthand side of the figure). The second irregularities in both nuclei were obtained using the same method and a common set of parameters (see papers quoted in ref.4) at the Strutinsky equilibrium deformations. The alternative possibility that the second irregularity in ^{156}Er is caused by crossing with the two quasi particle proton band has not been completely excluded and possibly a sufficiently large variation of deformation will provide the appearance of a proton effect.



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LIFETIME OF YRAST LEVELS AND COMPOSITE SIDE FEEDING TIMES IN ^{76}Kr

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Earlier we reported[1] the energies, spins, and parities of levels populated in ^{76}Kr vis the ^{66}Zn(^{12}C,2n) reaction. One recent study[2] of the lifetimes in ^{78}Kr has reported a drop-off in the lifetimes of yrast levels at high spin (14^+-16^+). The drop-off was interpreted as evidence for the validity of the interacting boson approximation since the finite number of bosons results in just such a prediction. However, there is a serious question as to whether the yrast band at those high spins is a pure extension of the ground state band, or states with more complex structure. Our systematic studies[3] of this mass region have indicated that the yrast line can become quite complicated at high spin. Forking at the 8^+ level in ^{80}Kr is interpreted as arrising from the crossing of gsb by a rotation aligned band built on the $(g_{9/2})^2$ configuration[3]. We interpret the high spin 14^+ and 16^+ states in ^{78}Kr as members of a rotation aligned band. Also, the experimental situation in extracting lifetimes in ^{78}Kr is complicated by the fact that the 12-10 and 10-8 transitions have the same energy. In order to study the question of possible drop off in collectivity at high spin, we have measured the lifetimes of the yrast levels in the neighboring e-e nucleus ^{76}Kr using the DSAM.

The excited ^{76}Kr nuclei were produced via the ^{66}Z(^{12}C,2n) reaction and the line shapes at 0^o degrees in both singles and γ-γ coincidence modes were measured. By gating above and below the level of interest, one can extract not only the lifetimes of the levels but also composite feeding times for the side feeding to the levels. From singles data and from gates set on transitions below the levels of interest, we have extracted the lifetimes and B(E2) values given below. The lifetimes are still preliminary because we have assumed that the non-discrete side feeds have very short lifetimes. For the highest level observed, 12^+, we extracted only a composite lifetime which is longer than the lifetime for the 10^+ level. This longer lifetime suggests that there may be some delays in the sidefeeding times that could lower the lifetimes of the 10^+ and 8^+ levels and perhaps even the 6^+ level. We are in the process of extracting lifetimes for the levels and the side feeders by further analysis of our coincidence data. The lifetimes of the 2^+ and 4^+ levels have been measured by the recoil distance technique[4]. One is struck by the large collectivity, the largest for a yrast cascade in this region. From the Table clearly there is no loss in collectivity up to the 10^+ level. Since no feeding corrections were applied to the 12^+ level, this level lifetime is considerably shorter than the composite one. If the lifetime of the 12^+ feeder is ignored the 10^+ lifetime is comparable to the composite 12^+ lifetime. Lifetimes of other bands are being extracted.

I_i^π-I_f^π	τ	τ^4	B(E2)/B(E2)$_{sp}$
2-0		37(5)	85
4-2	3.2(10)	5.7(16)	121**
6-4	1.25(11)		90
8-6	0.33(5)		116
10-8	0.14(3)		129
12-10	0.21(4)*		60*

*Composite. **From average τ = 4.4 ps.

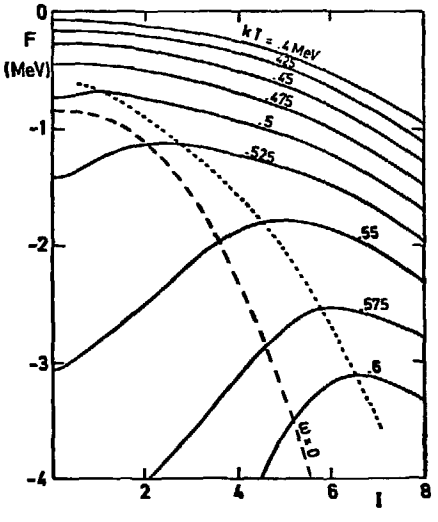
Work is supported by the U.S. Department of Energy.
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PREDICTION OF NEW PHASE IN DEFORMED NUCLEI[†]

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The self-consistent solution to the cranked temperature-dependent HFB equation with the pairing plus QQ-interaction indicates an existence of the new phase of deformed nucleus in the low spin and high temperature region. This phase is characterized by the antialignment of the spin relative to the angular velocity (i. e. $\omega<0$). The transition from the known phase (aligned, or ferromagnetic phase) to this "antialigned, or antiferromagnetic" phase is the first order phase transition across the "zero-rotation" line (i. e. $\omega = 0$), because the isothermal curve of the thermodynamical potential has its maximum close to this line (dashed line in the figure), and the physical quantities such as the specific heat dE/dT and the specific entropy dS/dt show the drastic enhancement in the vicinity of this line. The predicted critical temperature for ^{164}Er is kT = 0.5 MeV for the positive parity states in the projected statistics, and 0.45 MeV in the mixed statistics with Fermi distribution for quasiparticles. The corresponding excitation energy is about 3 MeV for spin 0 state in both statistics. The suitable choice of the order parameter will be $\eta = I_0(T) \equiv \langle \hat{J}_x \rangle$ for $\omega = 0$, and $\eta = I - I_0(T)$ for the two phases (i. e. $\eta < 0$ in the antialigned phase). This new phase is caused by the overcome of the entropy force as the manifestation of the temperature effect in the competition with the Coriolis force.



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THEORY OF TEMPERATURE-DEPENDENT HARTREE-FOCK-BOGOLIUBOV APPROXIMATION†

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In order to describe the average properties of the deformed nucleus in the not too highly excited region, where the effects of the pairing interaction and the deformation are still important, the framework of the HFB approximation with cranking model is extended by introducing temperature T as the parameter to take into account the excitations in statistical manner. The inadequacies of the theory based on the simple Fermi distribution in low temperature region are solved by introducing the projection operator P for the space parity and the number parities of proton and neutron quasiparticles. To derive the temperature-dependent (or thermal) HFB (THFB) equation including such projection, we proceed in the most general manner the variation of the thermodynamical potential, i. e.

$$F = \langle \hat{H} \rangle - \lambda \langle \hat{N} \rangle - \omega \kappa \langle \hat{J}_x \rangle - ST,$$

where the thermal average $\langle\ \rangle$ is taken with the trial density matrix

$$W = \frac{P \exp(-\beta \Sigma_\mu E_\mu \alpha_\mu^\dagger \alpha_\mu)}{\mathrm{Tr}[P \exp(-\beta \Sigma_\mu E_\mu \alpha_\mu^\dagger \alpha_\mu)]}$$

The quasiparticle operators α_μ and $\alpha_\mu^\dagger$ are introduced by the generalized Bogoliubov transformation. The THFB equation takes the form similar to the HFB equation, but the definitions

$$\rho_{kl} = \langle c_l^\dagger c_k \rangle = [B^*(1-f)B^T + AfA^\dagger]_{kl}$$
$$\kappa_{kl} = \langle c_l c_k \rangle = [B^*(1-f)A^T + AfB^\dagger]_{kl}$$

involve the quasiparticle distribution function defined by

$$f_\mu = \langle \alpha_\mu^\dagger \alpha_\mu \rangle .$$

It is shown that the derived stability condition for THFB equation yields the TRPA equation and this TRPA equation tends to the self-consistently blocked RPA equation in the limit of T = 0. New state density formula free from the enhancement at low temperatures and also the formula for the average electromagnetic transition rate are proposed in this paper.

†The work supported by the Bundesministerium für Forschung und Technologie (BMFT).

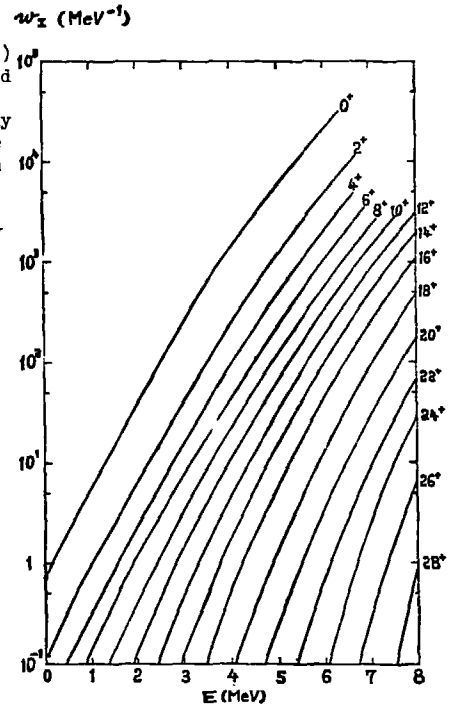
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THE PHASE TRANSITION AND STATE DENSITY IN THE YRAST REGION OF DEFORMAED NUCLEUS[†]

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The theory of the cranked THFB approximation developed in the preceeding paper is applied to the typical deformed nucleus ^{164}Er. The solution to the THFB equation is numerically solved by minimizing the thermodynamical potential with the use of steepest descent method. As the residual interaction the pairing plus QQ-interaction is assumed with the set of force constants which reproduces well the yrast level scheme. To study the structure change the calculations are carried out in the region of excitation energy below 8 MeV and temperature of $kT \lesssim 0.6$ MeV. Some aspects of our results are the following: (1) The cross-over of the contour lines of proton and neutron gap is predicted. The large difference exists between the changes of both gap values. Along the yrast line the neutron gap decreases due to the CAP effect, while the proton gap decreses quickly with increasing excitation energy. Thus the phase transitions in neutron shell and proton shell do not simultaneously occur. (2) The occupation numbers of the particles of the canonical basis are still like Fermi distribution due to the decrease of gap with increasing temperature. (3) The temperature effect on the deformation parameters β and γ are very small. (4) The existences of the proton-decoupled band and the neutron-decoupled band are predicted by the self-consistently blocked HFB equation for the negative parity levels. These bands cross each other at $I = 11^-$. (5) The predicted state density w_I vs. the excitation energy E for the separate spin-parity state without factor (2I+1) is shown in the figure.



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HIGH-SPIN NEGATIVE-PARITY STATES IN ^{109}IN VIA THE ^{108}Cd (α,2np) REACTION+

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The study of high-spin states in odd-mass In should yield valuable information for testing the hole-core coupling scheme in nuclei close to the spherical core limit. We have used the (α,2np) reaction and conventional in-beam spectroscopic method to investigate the high spin states in ^{109}In at the SF Cyclotron of the Institute for Nuclear Study, Tokyo.

The table shows a partial level sheme derived from the measurements. One finds that there are two distinct

Level Energy E(keV)	Assignment J^{π}	Level Energy E(keV)	Assignment J^{π}
0	9/2+	2957.3	19/2-
1026.5	11/2+	3091.3	19/2-
1428.3	13/2+	3121.7	21/2-
1900.5	13/2+	3201.4	21/2-
2101.7	19/2+	3409.5	23/2-
2195.2	15/2-	3461.4	23/2-
2270.5	13/2-	3799.5	25/2-
2530.8	15/2-	4037.4	27/2(-)
2867.3	17/2-		

types of states: the low-lying states of mainly postive-parity and the odd-parity higher lying rotation-like states. The former levels are interpreted as hole-vibrational coupling states whereas the latter states seem to belong to a different structure of more collectiveness, originating presumably from 3-quasiparticle(qp) excitations, and having a purer band-like structure. As in the adjacent Sn[1]), the importance of 3-qp configurations in the upper energy region ($\gtrsim$2.5.MeV) in which the particle-vibration coupling picture seems inadequate (e.g. it fails to reproduce the observed density of states), is apparent.

One is led to conclude that for odd-mass In, the fact that 2-qp on top of a core cannot be regarded as a new core could eventually account for the possibility that we have a kind of configuration mixing due to the combination of 1-qp (x) vibrational states of a core plus 3-qp states of a rotaion-like nature. Further interpretation with quantitative calculations[2]) in terms of a semi-microscopic model based on the Sn and Cd cores is in progress.

+ Work supported in part by the Japan Society for the Promotion of Science

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STRUCTURE OF THE NEGATIVE PARITY BAND AT HIGH SPIN IN ^{232}Th

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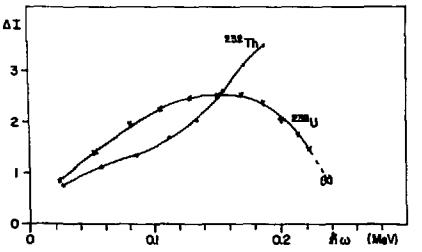
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In our previous work [1,2] on ^{232}Th Coulomb excitation with ^{84}Kr ions, using p ⊕ γ and γ ⊕ γ coincidence analysis of data, we pointed out that the behaviour at high-spin of the $K^{\pi} = 0^{-}$ octupole band is different from the ^{238}U and ^{180}W cases (see detailed references in ref.2)). We discussed the comparative trends of these bands considering the degree of alignment of the vibrational angular momentum along the rotation axis and the possible change from octupole to particle-aligned structure as suggested by Vogel [3].

In the simple assumption of a pure octupole alignment, assuming $\mathcal{J}_{oct}=\mathcal{J}_{gb}$, some nuclei follow rather nicely the expected limit of the ratio $(E_{I+3} - E_{I+1})_{oct} / (E_I - E_{I-2})_{gb} = 1$, up to a certain spin depending on the (Z,N) region, from the rare-earths to the uranides, and present then a smooth change to a different structure necessitating to take into account another kind of alignment, that is an individual particle alignment of angular momenta.

But ^{232}Th, as well as recently studied ^{178}W and ^{172}Yb [4], deviate from this simple octupole alignment limit (see fig. 3 of ref.2)). If one continues to assume the same moments of inertia, independently of the intrinsic structure, an alignment of more than 3 units of angular momentum would be involved.

This is illustrated for ^{232}Th and ^{238}U [5] on the figure which is based on the graphical method of Bohr and Mottelson for finding the degree of alignment between an excited-state band and the ground-state band.



However, we have plotted here ΔI (oct.b. - g.b.) as function of $\hbar\omega$ to show a strong difference of behaviour which could be related to the important role of the j15/2 neutron states in this region, if one consider that the main intrinsic component of the 0^{-}, 2 q.p. one-phonon states, issued from the semimicroscopic calculation [6] contains the 5/2 (j15/2) neutron state in ^{232}Th and the 7/2 (j15/2) in ^{238}U.

* The authors are indebted to I. Mikhaïlov and P. Vogel for helpfull discussions.

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HIGH SPIN STATES IN ^{30}Si FROM THE (α,p) REACTION

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In our previous paper [1]) we have shown that (α,p) reaction on sd shell nuclei excites selectively high spin states in the residual nucleus. In the present investigation high spin states in ^{30}Si have been located using the ^{27}Al$(\alpha,p)^{30}$Si reaction. Proton spectra have been measured at three α-particle energies 26.2,26.45 and 26.7MeV in the angular range from 20° to 170° LAB. Distinct peaks imposed on the continuous background of the evaporated protons were interpreted as proton groups populating high spin states in ^{30}Si nucleus. Angular distributions of these proton groups averaged over three incident energies (in order to smear out the effects of Ericson fluctuations) have been compared with Hauser-Feshbach theory. Level density and optical model parameters were taken from the existing data. The only adjusted parameter was the spin of the final state in ^{30}Si. We claim that it is possible in this way to determine the spin of the level with the accuracy of 1ħ unit. The validity of this method was checked for states of the known spin value. The obtained excitation energies and spin values of levels in ^{30}Si are collected in Table 1. Levels indicated by stars have been known previously.

Table 1

E_{ex} [MeV]	I [ħ]	E_{ex} [MeV]	I [ħ]	E_{ex} [MeV]	I [ħ]	E_{ex} [MeV]	I [ħ]
6.50*	4	9.11	5	10.91	7	14.69	8
6.87*	3	9.37	5	11.22	6,7	15.95	8
7.04*	5	9.84	5	11.46	7	16.70	9
7.22*	4	10.43	6	12.34	6		
8.66	4	10.72*	6	14.24	8		

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Comment on the Relation of Backbending Behavior of Even-even Nuclei with Odd A Neighbors

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Grosse, Stephens and Diamond (GSD)[1] stated that, the mechanism of backbending (bb) ($in\mathcal{J}\sim\omega^2$plot) for even-even(e-e) nuclei could be determined by an analysis of the bb behavior of odd A neighbors. However, there exist already difficulties, for instance:

1. The $\pi h_{11/2}$decoupled bands of $^{155,157,159,161}_{67}$Ho show bb, and the $\nu i_{13/2}$ decoupled bands of $^{157,159}_{69}$Er, $^{157,159}_{67}$Dy show no bb, then according to GSD, it seems to show the bb in $^{156,158,160}_{68}$Er, $^{156,158,160}_{66}$Dy etc. are caused by rotation alignment (RAL) of a $\nu i_{13/2}$ pair. But the $\nu i_{13/2}$ decoupled band of ^{156}Er shows bb too, it seems to state on the opposite hand, the bb in ^{156}Er is not caused by RAL of a $\nu i_{13/2}$ pair.

2. The $\pi h_{11/2}(1/2^-[541]$) bands of $^{163,165,167}_{69}$Tm, $^{167,169}_{71}$Lu show no bb, while the $\nu i_{13/2}$decoupled bands of $^{163,165,167}_{70}$Yb, $^{169}_{72}$Hf show no bb too. Then no cosistent conclusion can be obtained from GSD for the mechanism of bb in e-e neighbors (^{162,164}Er, ^{164,166}Yb, ^{168}Hf etc.).

3. The $\pi h_{9/2}$ decoupled band of $^{171}_{73}$Re shows no bb and the $\nu i_{13/2}$mixed bands of $^{171,173}_{76}$Os show bb. Then according to GSD the bb in e-e neighbors, ^{172}Os etc. are caused by RAL of a $\pi h_{11/2}$pair. However, the $\pi h_{9/2}$ decoupled band of $^{173}_{77}$Ir shows bb too, then we should say at the same time, the bb occuring in ^{172}Os is caused not by RAL of a $\pi h_{9/2}$ pair.

The above difficulties can be resolved by studying the properties of e-e nuclei themselves[2]. Because of the drastic retardation of B(E2) of ^{156}Er at critical angular momentum, the backbending of this nucleus is due to shape transition rather than RAL of a $\nu i_{13/2}$pair. From the comparison of theoretical result and measured average value of g factor of 8^+-16^+ states for ^{178}Hf, we can say the RAL is due to a $\nu i_{13/2}$pair instead of a $\pi h_{9/2}$pair. While based on the calculation of the aligned angular momentum $i(\omega)$, we can confirm the bb in ^{172}Os is mainly caused by RAL of $\nu i_{13/2}$pairs.

These facts seem to indicate, at least in certain cases, the e-e core of an odd A nucleus is not quite similar to the e-e neighbors. In fact, the addition of an odd nucleon to e-e core not only modifies the status of pairing correlation of whole nucleus, as mentioned by GSD [1], but also modifies the status of long -range interaction inside the nucleus. Thus, the shape, the moment of inertia ($\mathcal{J}$), the softness and the interaction strength between s- and G-band etc. would be changed to a certain extent to affect the bb behavior of an odd A nucleus.

Therefore the relation of the bb behavior of e-e nucleus with its odd A neighbors is not so simple as first expected. In exploring the bb mechanism of e-e nuclei, the indication given by the properties of e-e nuclei themselves seem to be more definite than that given by this relation.

I'd like to thank Prof. Xu Gong ou for valuable discussion.

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The Rotation Alignment Effects of $g_{9/2}$ Proton Pair and Neutron Pair in Nucleus ^{68}Ge

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The three forking phenomenon has been discovered in the plot of moment of inertia versus rotation frequency square for nucleus ^{68}Ge [1]. (Fig.1)

In HFB-cranking model,

$$H^{HFBC} = \sum_{\alpha}(\varepsilon_{\alpha}-\lambda)a_{\alpha}^{+}a_{\alpha} + \frac{\Delta}{2}\sum_{\alpha\beta}\delta(\alpha\bar{\beta})(a_{\alpha}^{+}a_{\beta}^{+}+a_{\beta}a_{\alpha}) - \omega\sum_{\alpha\beta}\langle\alpha|j_x|\beta\rangle a_{\alpha}^{+}a_{\beta} \qquad (1)$$

Through the Bogoliubov transformation, the HFB equation can be obtained as follows

$$\left.\begin{aligned}(\varepsilon_{\alpha}-\lambda)A_{\alpha}^{i}+\Delta B_{\alpha}^{i}-\omega\sum_{\beta}\langle\alpha|j_x|\beta\rangle A_{\beta}^{i} &= E_i A_{\alpha}^{i}\\ -(\varepsilon_{\alpha}-\lambda)B_{\alpha}^{i}-\Delta A_{\alpha}^{i}+\omega\sum_{\beta}\langle\alpha|j_x|\beta\rangle B_{\beta}^{i} &= E_i B_{\alpha}^{i}\end{aligned}\right\} \qquad (2)$$

Solving eg.2, we can get eigen spectra E_i and wave function A_{α}^{i} and B_{α}^{i} of quasiparticle. Then the aligned angular momentum $i(\omega)$ of two quasiparticle excitation band relative to gsb is

$$i(\omega) = \sum_{K=1}^{2}\langle J_x\rangle_K = \sum_{K=1}^{2}\sum_{\alpha\beta}\langle\alpha|j_x|\beta\rangle(A_{\alpha}^{K}A_{\beta}^{K}-B_{\alpha}^{K}B_{\beta}^{K}) \qquad (3)$$

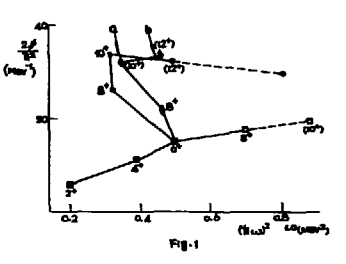


Fig.1

The results of calculation are shown in table 1, which are in agreement with experimental data.

It is stated out that [2], generally, the i_{exp} obtained from experimental energy spectra includes the contributions of CAP, shape transition effects and the RAL effect. While in our calculation the parameters of deformation and energy gap are constant (independent of ω), hence the i_{theo} obtained by calculation is mainly the contribution of the RAL effect. Therefore, based on the approximate coincidence of theoretical values and experimental data, we could say that the backbending in a-band and b-band are in truth mainly caused by the RAL of a $\nu g_{9/2}$ pair and a $\pi g_{9/2}$ pair. This conclution is in consistent with that of Hamilton's [1].

Besides, our calculations show yet an important role of RAL effect of both $\nu g_{9/2}$ pair and $\pi g_{9/2}$ pair will play in all the region of A≃70. Therefore, a further exploration of their effects are necessary both in theoretical and experimental aspect.

Table 1 ($\hat{\omega}_0 = 41A^{-1/3}$ Mev)

	i_{theo}	$\omega_c^{theo}/\hat{\omega}_0$		i_{exp}	$\omega_c^{exp}/\hat{\omega}_0$
$\nu g_{9/2}$ pair	6.37ħ	0.064	a-band	~7ħ	~0.065
$\pi g_{9/2}$ pair	7.99ħ	0.050	b-band	~7ħ	~0.061

Authors would like to thank Prof.J.H.Hamilton for his sending the parameters for calculating the Nilsson levels in A ≃ 70 region.

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LARGE QUADRUPOLE MOMENTS OF 7^- ISOMERS OF ^{66,68}Ga

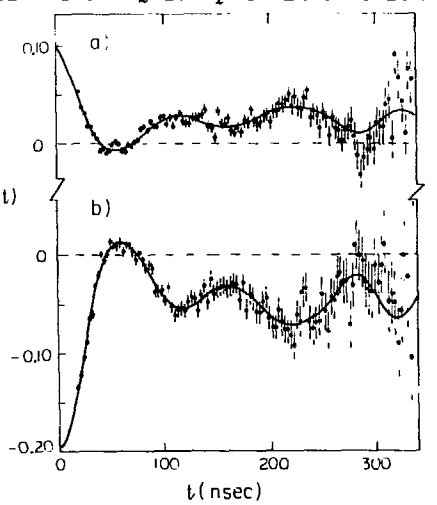
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The 7^- isomeric states in ^{66}Ga(E_x=1464 keV, $T_{1/2}$=54 nsec) and ^{68}Ga(E_x=1229 keV, $T_{1/2}$=62 nsec) were excited in ^{16}O induced reactions on natural Mn and Cr targets using pulsed beams from the Rutgers-Bell Tandem Accelerator. The nuclei were recoil implanted into cooled (77K) metallic gallium backings where the nuclear quadrupole interaction was observed using the time differential perturbed angular distribution of gamma rays. The Figure shows the observed modulation of the intensity of the (a) 125 keV (anisotropy a>0) and (b) the 201 keV (a<0) gamma rays following the decay of the 1229 keV isomeric level of ^{68}Ga. The solid curves are theoretical fits to the data using the perturbation factor appropriate to I=7 and an asymmetry parameter η=0.179 for α-Ga. A similar set of data were obtained for the gamma rays depopulating the isomeric state of ^{66}Ga. Quadrupole interaction constants were derived from these fits. From the ratio of these values to the coupling constant[1] for the ground state of ^{69}Ga in α-Ga and using $Q(^{69}Ga)$ =0.168 b, the quadrupole moments of the isomers are determined to be $|Q|(^{66}Ga,7^-)$=0.78(4) b and $|Q|(^{68}Ga,7^-)$=0.72(2) b.



With the $(\pi f_{5/2}, \nu g_{9/2})7^-$ maximum stretch configuration for the state and using effective charges e_p=1.5 and e_n=0.5, a shell model estimate leads to too small a value for both $Q(7^-)$ and $B(E2:7^- \rightarrow 5^-)$ ($\sim$1/3 and $\sim$1/20 respectively). Good agreement for the quadrupole moment is obtained using a neutron effective charge consistent with the measured quadrupole moment of (-)0.55 b for the ^{67}Zn($9/2^+$) state; the corresponding B(E2) however is too small. A rotational model estimate, on the other hand, gives the ratio $B(E2)/Q^2$ too large. Thus the experimental data indicate a surprising new regime.

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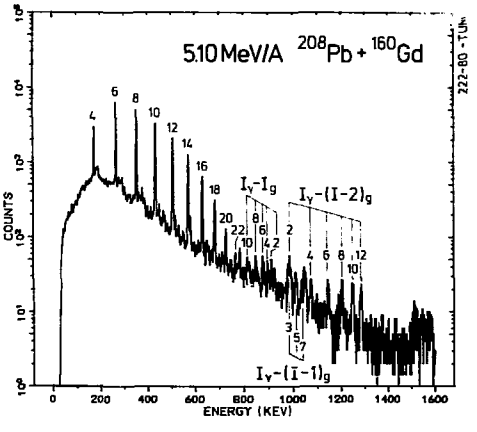
HIGH SPIN STATES IN NEUTRON RICH RARE EARTH NUCLEI*

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In performing a systematic study of the behavior at high angular momentum in neutron rich rare earth nuclei we investigated high spin states in ^{160}Gd, ^{170}Er, and ^{176}Yb. Since these nuclei cannot be populated by the usually applied fusion-type reactions we excited them via multiple Coulomb excitation employing a ^{208}Pb-beam from the UNILAC. Thin, highly enriched targets were bombarded at beam energies between 4.73 and 5.10 MeV/A. Taking advantage of the inverse reaction kinematics the γ-decay has been detected in coincidence with the scattered particles in a special set-up[1].

As an example the figure shows a Doppler-shift corrected Ge(Li)-spectrum for ^{160}Gd obtained at 5.10 MeV/A. This γ-spectrum is coincident to recoils scattered into the whole angular range ($17^0 \leq \Theta_{Lab} \leq 58^0$) accepted by the particle detectors. Spectra of comparable quality are obtained for the other two nuclei investigated. Up to now information on the ground state band (g.s.b.) and other bands was scarce and concentrated on low spin states only, except for ^{176}Yb where excitation of the g.s.b. up to 18^+ was observed recently, employing lighter (^{86}Kr, ^{136}Xe) projectiles[2]. We observe excitation of the g.s.b. up to $I^\pi = 22^+$ in all three nuclei studied. In addition we observe excitation of the γ-band, for ^{160}Gd and ^{176}Yb as high as spin 12. For all three nuclei the moment of inertia of the g.s.b. only rises slowly with increasing rotational frequency in contrast to the behavior for the more neutron deficient nuclei. This rather rigid rotation is most pronounced for ^{160}Gd and ^{170}Er compared to their neighbouring even isotopes.



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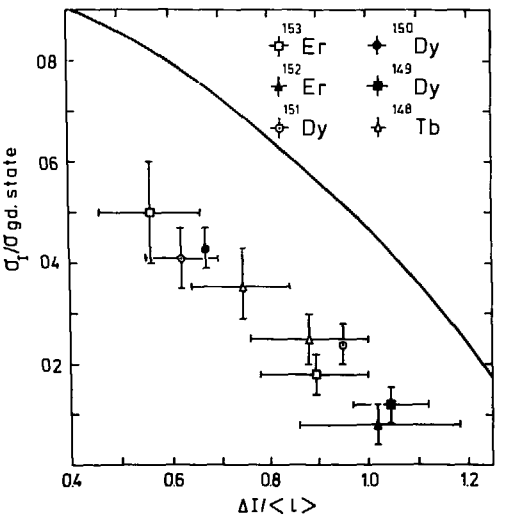
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SYSTEMATICS OF THE ISOMERIC RATIOS IN NUCLEI CLOSE TO N = 82

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The isomeric ratios have been determined for a number of high spin isomers produced in ^{12}C and ^{14}N bombardment of targets close to N = 82. The presently available data seem to fall on a common curve (see figure) if the isomeric ratios are plotted vs. $\Delta I/\langle I \rangle$ where ΔI is the difference between the isomer and ground state spin and $\langle I \rangle$ is the average entry angular momentum. The latter quantity was determined from the prompt multiplicity for the lowest lying gamma transitions in the reaction channel in which the isomer was observed. The relation $\langle I \rangle = 2(\langle M \rangle - 4)$ was assumed. The validity of this assumption for nuclei in the region close to N = 82 was preliminary checked for the reaction $^{12}C + ^{144}Sm$ where the total fusion cross sections [1] and the gamma ray multiplicities were measured.



The continuous line on the figure is calculated from a subroutine of the evaporation code ALICE assuming that the particle emission does not change the angular momenta distribution of the compound nucleus and that the gamma transitions from the entry line to the yrast line also preserve the I distribution. With the assumption that the isomers lie on the yrast line, the difference between calculated and observed populations may reflect the "tilting" of the gamma flow (in the E - I plane) from the entry line to the yrast line,

The relation between the isomeric ratios and the average angular momentum reported here implies that in the search of the yrast traps of a very high spin in this region, the ΔI value close to $\langle I \rangle$ should be considered as the practical experimental limit.

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SYSTEMATICS OF YRAST LEVELS IN NUCLEI*

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When it is possible to look at a large collection of data, it sometimes becomes possible to identify general features and systematic trends that are much more elusive when only a few data items can be considered. The Evaluated Nuclear Structure Data File (ENSDF) now contains reasonably complete and up-to-date information on properties of 41,000 nuclear levels. Although only about a quarter of these levels have well-established spins, it is nonetheless possible to demonstrate many general relationships between energy and spin. As a further illustration of the potential of such a data base, we have extracted the subset of levels consisting only of the yrast sequences in even-even nuclei. A standard parametrized three-dimensional display shows dramatically the transition from deformed to spherical shape as pairs of nucleons are added or removed. Characteristics of rotational bands and quasi-bands also lead to suggestions of shape transitions near the ends of the region of strong deformation.

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EVIDENCE FOR NEAR-SPHERICAL SHELL MODEL STRUCTURE IN THE HIGH SPIN STATES OF N=86 ISOTONES

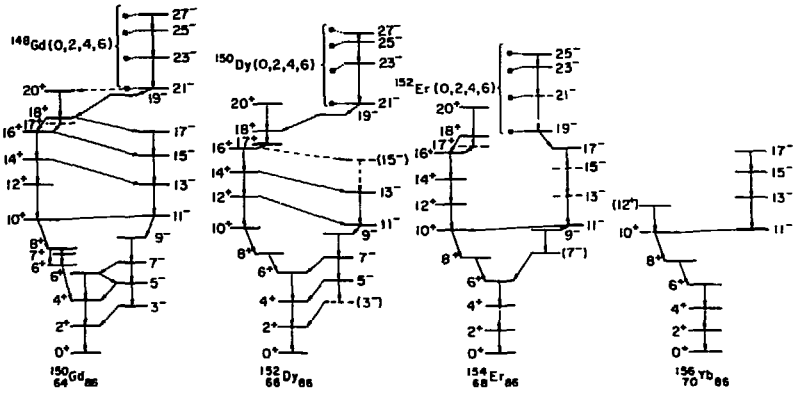
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In a recent study, we have established the yrast structure of ^{150}Gd to spin 36$\hbar$ and ≈12.5 MeV excitation energy.[1] The level scheme of ^{150}Gd and its neighboring N=86 isotones ^{152}Dy [2], ^{154}Er [3] and ^{156}Yb [4] exhibit systematic trends which include: (i) a smooth decrease of the excitation energy of the 2^+ to 8^+ states with increasing proton number, (ii) the presence of low-lying negative parity 3^- to 9^- states whose excitation energy increases as one moves away from ^{150}Gd, and (iii) the regular occurrence of close lying 10^+ and 11^- states fed by cascades extending to 16^+ and 17^-, respectively. Extending the extreme single particle approach of Kleinheinz[5], these features may be described as $(f_{7/2}^2)$ or $(f_{7/2}h_{9/2})$ neutron configurations coupled to: (i) the ground, (ii) a 3^- octupole phonon, and (iii) to $(i_{13/2}^2)_{10^+}$ or $(i_{13/2}h_{9/2})_{11^-}$ configurations. The near equality of the transition energies, however, may indicate admixture of some quadrupole vibrations in their wave functions.

Since maximal alignment of 4 neutrons in this region cannot generate more than ≈20$\hbar$ units of angular momentum, proton excitation becomes necessary for states with $\ell \geq 20\hbar$. Interestingly, in ^{150}Gd, ^{152}Dy (^{154}Er), starting with $I=21^-(19^-)$, a sequence of transitions, decreasing in energy, establishes a quasi-band structure up to $I=27^-(25^-)$. Moreover, the energy spacings within these structures closely resemble the $(\nu f_{7/2}^2)_{0^+,2^+,4^+,6^+}$ energy spacings of their corresponding N=84 isotopes (shown by full circles in the Fig.). Such a correlation is suggestive of coupling a $(\nu f_{7/2}^2)$ two-neutron structure to bandheads composed of $[(\pi h_{11/2}^2)_{8^+,10^+} \otimes (\nu h_{9/2}\, i_{13/2})_{11^-}]$ aligned shell-model configurations. The presence of readily recognizable (j^2) configurations in this region suggest that even at spins up to $\ell \approx 30\hbar$, relatively pure and near-spherical shell model states are the dominant mode of excitation.

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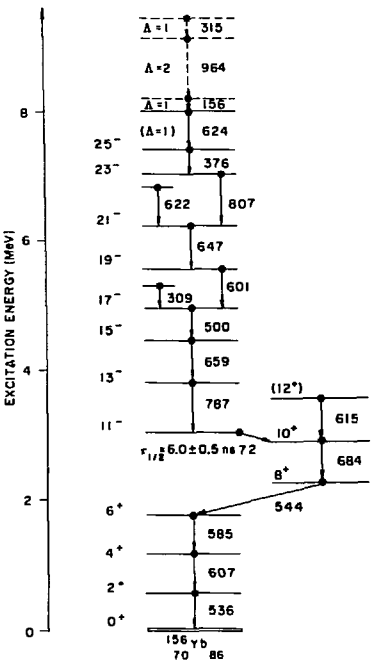
HIGH SPIN STATES IN ^{156}Yb (N=86)

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The observation of isomeric and very high spin states in ^{152}Dy and ^{154}Er has stimulated a host of experimental and theoretical studies to try to elucidate their structure.[1] Many of these features appear to arise from relatively simple single-particle configurations in a near-spherical nuclear potential. In order to extend the experimental information and identify systematic trends across the N=86 isotones, ^{156}Yb has been investigated using the reactions ^{144}Sm(^{16}O,4n)^{156}Yb(E=70-120 MeV) and ^{113}In(^{46}Ti,p2n)^{156}Yb (E=190-210 MeV). Several competing reactions were observed, so particle-gamma, gamma-gamma, and X-gamma coincidence experiments were done to identify transitions from ^{156}Yb. Measurements of gamma-ray excitation functions, linear polarizations and angular distributions were also made. The resulting decay scheme is shown in the figure; assignments are firm to the $J^{\pi}=17^{-}$ state. From the 17^{-} state to the 25^{-} state similar transition intensities leave some doubt on level ordering.

The following interesting features may be noted. The low-lying level sequence is similar to ^{154}Er, although the population of the positive parity sideband is considerably less, while 7^{-} and 9^{-} states are not seen. The unconverted γ-ray intensity and angular distribution of the 72 keV decay from the $T(1/2)=6.0\pm0.5$ns isomer give $\delta=-0.1$ and rigorously establishes the isomer as $J^{\pi}=11^{-}$. Presumably this state is an $(h_{9/2}i_{13/2})_{11^-}$ aligned neutron configuration. The sequence of levels to $J^{\pi}=17^{-}$ has a typical j^2 energy spacing and appears to be due to further neutron alignment, culminating in $\left[(f_{7/2})_6^{+} \otimes (h_{9/2}i_{13/2})_{11^-}\right]_{17^-}$, above which one would expect yrast states of both proton and neutron excited configurations.



This research was supported by the Division of Basic Energy Sciences, U.S. Department of Energy, under contract # DE-AC02-76CH00016.

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STRONGLY-DEFORMED STATES IN THE NEUTRON-DEFICIENT ODD-MASS Au AND Hg NUCLEI[†]

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The well-established[1] onset of deformation in ^{185}Hg and the lighter odd-A Hg isotopes raises the question of where these strongly deformed states ($\beta \sim 0.27$) are located in ^{187,189}Hg and in the neighboring odd-mass Au nuclei.

In the course of studying the radioactive decay schemes of ^{189m}Tℓ (ref. 2), ^{187m,g}Tℓ (ref.2), ^{187m,g}Hg (ref.3) and ^{185m_1,m_2,g}Hg (ref.4) at the UNISOR facility, a number of excited states were observed at low energy in ^{189,187}Hg and ^{187,185}Au that were not seen in the heavier odd-mass Hg and Au isotopes. These "additional" excitations have been studied in order to ascertain if they are strongly deformed states. This was done by lifetime measurements which can locate isomeric states (shape isomers); and by conversion electron spectroscopy which reveals low-energy transitions (rotational structure) and de-excitation by the EO process (an indication of large changes in the mean square charge radius of the nucleus).

In ^{187}Hg we have located an isomeric state ($T_{1/2} \sim 30$ns) that de-excites by a 161 keV transition, most probably to the $i_{13/2}$ isomeric state. We have observed low-energy transitions feeding this state. In ^{187}Au we have located two bands of states that evidently result from the coupling of an $h_{9/2}$ proton to a ^{186}Pt core. The lowest band was previously established in a study[5] of the ^{187m}Hg decay scheme and by in-beam reaction gamma-ray spectroscopy[6]. The band head of the upper band is located 323 keV above that of the lower band. A number of EO transitions between these bands have been observed. The further characterization of these and similar states in ^{189}Hg and ^{185}Au is in progress.

[†]This work is supported in part by the U.S. Department of Energy, and is conducted at the UNISOR facility at the Oak Ridge National Laboratory.

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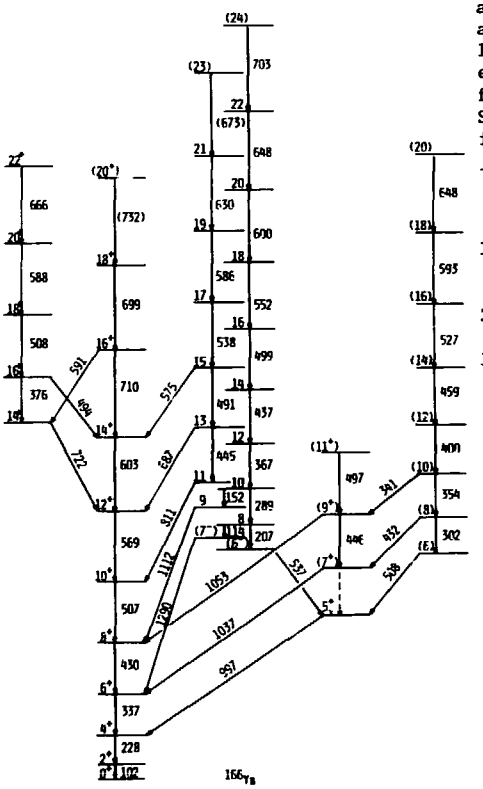
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HIGH SPIN BAND STRUCTURE OF ^{166}Yb†

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The high-spin band structure in ^{166}Yb was studied via the ^{162}Dy(^{9}Be,5n) reaction at 60 MeV beam energy in order to follow to neighboring isotones the systematics of the rich band structure found in ^{164}Er.[1] A tentative level scheme is shown in the figure. Despite a remarkable number of similarities to ^{164}Er, notable differences include the absence of the negative parity band built upon the [404,7/2; 523,7/2]$_7$- two-proton configuration.[2] Further, a weakly populated band with even spin members from (8) to (22) in ^{164}Er, suggested[3] as the band built upon the two-neutron (642,5/2; 505,11/2)$_8$- configuration, begins here at spin 6, thereby clouding the K=8 interpretation in ^{164}Er. As in ^{164}Er, the continuation of the ground state band (gsb) is observed beyond the backbend to a possible spin 20. The pair of odd and even spin bands built on the known levels of 7$^-$ and 6$^-$ are in identical relation to the gsb. The gamma band is populated relatively weakly, the tentatively assigned 7$_\gamma^+$ level being in disagreement with that given in the literature. Of particular interest is the reverse transition from the gsb at 16$^+$ to the Stockholm band at 14$^+$ not seen in ^{164}Er.



†Research sponsored by the U. S. Department of Energy under Contract No. DE-AC02-76CH00016.

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MULTIPLICITY OF THE STATISTICAL γ-RAYS FOLLOWING (HI,xn) REACTIONS

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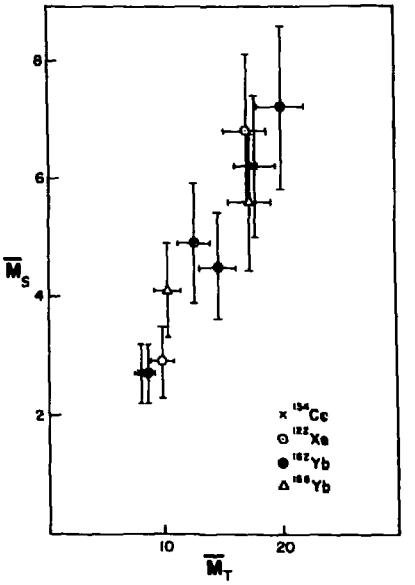
The average number $\bar{M}_S$ of statistical γ-rays emitted following (HI,xn) reactions has been deduced to be about 4, a number which has been used extensively in analysis of continuum γ-rays[1].

We have found evidence for a rather large variation in $\bar{M}_S$, which in our case appears to be correlated with the total γ-multiplicity $\bar{M}_T$ of the reaction. The reactions studied were $^{122}Sn(^{16}O,4n)^{134}Ce$, $^{110}Pd(^{16}O,4n)^{122}Xe$, at 65 and 83 MeV bombarding energies, and $^{149}Sm(^{16}O,3n)^{162}Yb$, $^{150}Sm(^{16}O,4n)^{162}Yb$, $^{154}Sm(^{16}O,4n)^{166}Yb$ at 73 and 85 MeV. The γ-rays were detected in coincidence with discrete lines from the residual nucleus; data analysis was similar to that of ref.(2). Clear evidence for the variation can be seen in the numbers of γ-rays above 1.9 MeV, well beyond the range of the yrast cascade. To estimate $\bar{M}_S$, we have assumed that the shape of the statistical spectrum has the form $E^x e^{-E/T}$. The values for x = 3 are shown in table 1 and plotted against $\bar{M}_T$ in fig.1. Values for x = 5, which fits the shape less well, are about 10% higher. Assuming that the remaining γ-rays are stretched E2 and that the statistical γ-rays carry no angular momenta (a.m.), the quantity $\bar{\ell}_\gamma = 2(\bar{M}_T - \bar{M}_S)$ should be the mean input a.m. $\bar{\ell}$. In table 1, $\bar{\ell}_\gamma$ is compared with $\bar{\ell}$ calculated with the IWB Bass model, and Sikkeland's method of partitioning into the various xn channels[3]. The usual values $\bar{M}_S = 4$ would give poorer agreement, again suggesting that $\bar{M}_S$ varies with $\bar{M}_T$.

The observed variation in $\bar{M}_S$ depends on the variation of average excitation energy above the yrast line for different bombarding conditions. The quantitative relationship between $\bar{M}_S$ and $\bar{M}_T$ depends on the target, projectile and final nucleus and therefore a clear relationship as seen in fig.1 will only be expected for similar systems.

TABLE 1

Final nucl. (xn)	E_{lab} (MeV)	$\bar{\ell}$	$\bar{\ell}_\gamma$	$\bar{M}_S$
^{134}Ce	65	10.6	12	2.7
(4n)	83	24.3	23	6.2
^{122}Xe	65	12.6	14	2.4
(4n)	83	25.2	21	6.8
^{162}Yb	73	10.7	16	4.9
(3n)	85	23.8	26	7.2
^{162}Yb	73	9.1	11	2.7
(4n)	85	19.3	20	4.5
^{166}Yb	73	11.0	14	4.1
(4n)	85	22.6	21	5.6



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HIGH SPIN STATES IN ^{119}Te

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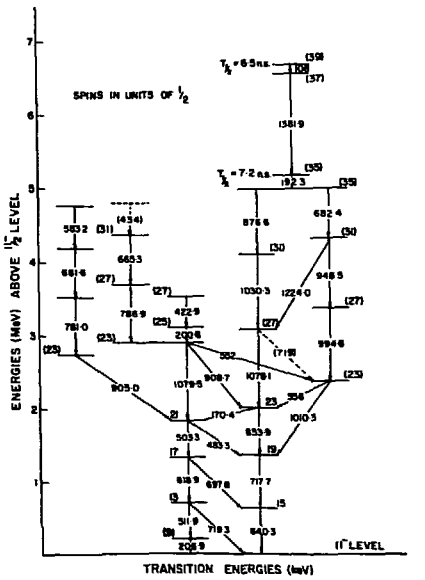
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The structure of the doubly even Z = 52 nucleii is not well understood, though the levels of low angular momentum are similar to those of a spherical vibrator. Study of the odd mass nuclei may throw further light on the nature of the Te nuclei. There is some evidence[1]) for rotational bands based on low lying even parity one quasiparticle states. We report here on odd parity levels, based on the unique parity $h_{11/2}$ orbital in ^{119}Te, which decay finally to the $11^-/_2$ isomeric level. ($T_{\frac{1}{2}}$ = 4.7 days, E_{ex} = x ≈ 300 keV).

The nucleus was formed in the ^{110}Pd (^{13}C,4nγ) ^{119}Te reaction with bombarding energies between 53 and 75 MeV. Gamma ray angular distributions, γ-γ, n-γ and x-γ coincidences, and conversion electrons were measured at 59 MeV, and γ-γ and n-γ coincidences at 75 MeV.

The level scheme shown is based on γ-γ coincidence measurements and supported by accurate energy sums. Levels with spins up to J = (39/2) and excitation energies up to ∿ 8 MeV have been observed. Isomeric states at excitation energies of (5187 + x) keV ($T_{\frac{1}{2}}$ = 7.2 ns, J = (35/2)) and (6677 + x) keV ($T_{\frac{1}{2}}$ = 6.5 ns; J = (39/2)) were observed. Conversion electron measurements confirmed the negative parity of all levels up to [2012 + x] keV excitation.

The triaxial rotor model with rigid core[2]) (γ = 28°, β = .21) gives qualitative agreement with the observed levels up to (2012 + x) keV excitation. The agreement would be improved if the core softness was included. Several possible collective bands based on 3 quasiparticle configurations are seen. The high lying isomeric levels are probably 5 quasiparticle states.



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CONTINUUM γ-RAY STUDIES FOLLOWING LOW ANGULAR MOMENTUM REACTIONS

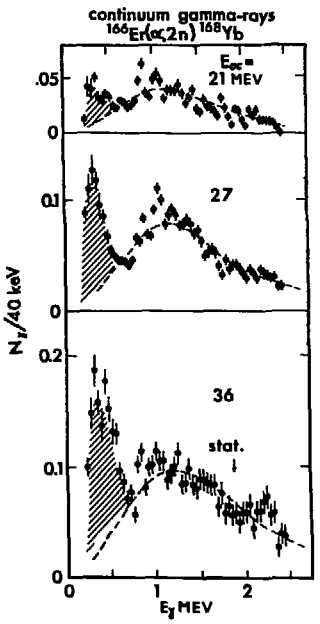
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We have studied the continuum γ-rays following the reaction $^{166}Er(\alpha,2n)^{168}Yb$ at bombarding energies 21, 27 and 36 MeV. The γ-rays were detected in a 7.6 × 7.6 cm NaI detector, at 40 cm from the target, in coincidence with the discrete γ-rays from the ground state band in the residual nucleus, observed in a Ge(Li) detector. A second Ge(Li) detector, in coincidence with the first, and set alternately with the NaI detector at 32° and 90°, measured the discrete γ-rays. Neutron induced events in the NaI detector were subtracted out. The continuum spectra were obtained after removal of the discrete line contributions. The γ-ray spectra, obtained by unfolding the net continuum spectra are shown in fig. 1. The multiplicity of the statistical spectrum increases with bombarding energy, and the shapes follow an $E^3e^{-E/T}$ dependence fairly well, as shown by the dashed lines in Fig. 1. The total multiplicities M_S of the statistical γ-rays, derived assuming the above form, are listed in table 1, together with the mean angular momentum $\bar{\ell}$ calculated using the IWB Bass model and Sikkeland's method for xn channel partitioning[2]).

A low energy component, shown shaded, was also observed. This component may be the counterpart of the "yrast bump" seen in the continuum spectra obtained by heavy ion, hence higher angular momentum, reactions[1]). The mean energy of the bump is roughly consistent with that expected for transitions in bands with the rigid body moment of inertia, suggesting that these transitions may occur in the low spin extension of the superbands.

These transitions, observed for the first time here, may account for the apparent deficiency in the angular momentum carried by the discrete lines when compared to the total input angular momentum[3]). The angular distributions of these bumps are consistent with the stretched E2 value.



† Lawrence Berkeley Lab., CA 94720.

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Table 1
$^{166}Er(x,2n)^{168}Yb$

Ex (Mev)	$\bar{\ell}$	M_S
21	6.0	1.2(0.7)
27	9.0	3.1(.3)
36	12.6	4.0(0.2)

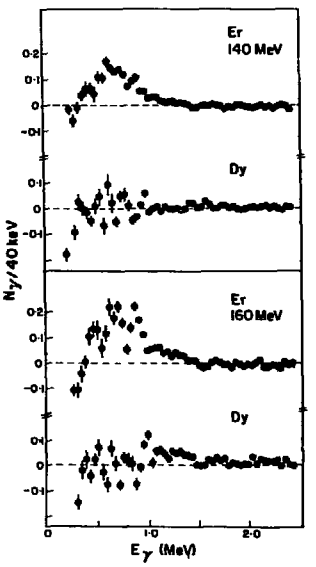
CONTINUUM γ-RAYS FROM THE NUCLEI $^{150-152}$Dy AND $^{156-158}$Er

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The ^{152}Dy Nucleus has been proposed as an example of the oblate-coupling scheme, suggested to occur at high spin.[1] Discrete γ-rays from ^{152}Dy and also from the deformed nucleus ^{158}Er are seen up to unusually high spins (∿30). We have studied the continuum spectra from these and adjacent nuclei in order to obtain additional information. The γ-rays were detected in 7.6 × 7.6 cm NaI and Ge(Li) detectors in coincidence with neutrons. The reactions studied were ^{124}Sn(^{32}S,xn)$^{156-x}$Dy and ^{130}Te(^{32}S,xn) $^{162-x}$Er at 140 and 160 MeV bombarding energies. Measurements were carried out at angles of 32°, 55° and 90°. The neutron contributions to the NaI spectra were distinguished by time of flight. Data analysis was similar to that of ref. 2; the continuum spectra were obtained by removing the discrete line contributions.

The unfolded spectra showed an yrast bump, typical of rotational nuclei, superimposed on a statistical spectrum, for the Er case but not for Dy. An yrast bump consisting of stretched E2 transitions should show clearly in the 32°-90° spectrum since the statistical cascade is usually nearly isotropic. As seen in fig. 1 such a bump is evident for Er; further its angular distribution coefficient A_2 is consistent with that for stretched[2] E2 transitions. There is no clear evidence for an E2 bump in Dy, except possibly for the Eγ ∿1.25 Mev region at 160MeV. These results are consistent with those of ref. 3.



The absence of a strong E2 bump in Dy is consistent with rotation about a symmetry axis, in which case there is little correlation between γ-ray energy and angular momentum. Also the rapid cooling to the yrast line in this case enhances the possibility of populating yrast states of very high spin as is observed. The somewhat weak evidence for an E2 bump at high Eγ may indicate a change to collective rotation at high spin. The reason why ^{158}Er is populated to such unusually high spin is not clear from these data.

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NUCLEAR SHAPES AND THE CONFIGURATION ($i_{13/2}$,$h_{9/2}$) IN A ∿ 150 NUCLEI

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Variations in the nuclear shape with increasing spin in transitional nuclei with A∿150 and N = 82-88 neutrons recently have attracted considerable interest. From several calculations it was deduced that nuclei at I≤20 possessed oblate shapes with $\beta \approx -0.1$ and at I>20, $\beta \approx -0.3$ for N=84 and N=86, and prolate shape with $\beta \approx +0.2$ for N=88. At higher I, β is expected to be a complex function of spin.[1] However, these calculations failed in some specific predictions, so the nuclear shape is more sensitive to collective and particle features of nuclear structure than thought previously.

From an analysis of two configurations we demonstrate the sensitivity of extracting information on the nuclear shape from details of the level structure of a nucleus. One can make a definite choice between spherical and deformed shapes and between prolate (β>0) and oblate (β<0) deformation. In N = 84-88 nuclei the lowest particle states with large j involve primarily levels with small Ω if β>0, and with large Ω if β<0. Because of their stronger Coriolis coupling, the β>0 rotational bands should have a decoupled (aligned) character with ΔI=2 for adjacent levels, whereas the β<0 bands should be strong-coupled bands with ΔI=1. For a spherical shape the band is expected to be a multiplet of a two-particle configuration (j^2) with ΔI=2 between adjacent levels and ΔE(I → I-2) decreasing with increasing I.

Convenient band heads for such analysis are high spin states with configurations that involve nucleons with large intrinsic spin, e.g. ν $i_{13/2}$, and $h_{9/2}$ and π $h_{11/2}$. The energies of the lowest Nilsson components of these levels are very sensitive to the magnitude of the nuclear deformation. Consider the bands based on the band head with the simplest 2-particle configuration ν($i_{13/2}$,$h_{9/2}$), $I^{\pi}_{0} = 11^{-}$ as identified in even-even nuclei with N=84 (ref. 2), 86 (ref. 3), and 88 (ref. 4). In the Gd nuclei it is seen that the character of this band changes from $^{148}_{64}Gd_{84}$ where a strong coupled band with ΔI=1, as expected for significant oblate deformation $\beta \approx -0.15$ to -0.20 is observed[5], to one typical for spherical nuclei with a multiplet of a (j^2) configuration with ΔI=2 and decreasing ΔE in $^{150}_{64}Gd_{86}$ (ref. 3), on to an aligned rotational band with ΔI=2 and increasing ΔE, as expected for a significant prolate deformation[4] ($\beta \approx +0.2$) in $^{152}_{62}Gd_{88}$. Similar β<0 and β>0 rotational bands based on the same configuration are known in other N=84 and N=88 nuclei. However, in contrast, the bands based on the $\pi(h_{11/2}{}^2)_{10^+}$ configuration have ΔI=2 and decreasing ΔE even in N=84 nuclei[5] as expected for spherical nuclei. More complex structures that include the above two configurations show a similar behavior.

In summary we conclude that in N=83, 84 nuclei the levels which include the configuration $\nu(i_{13/2},h_{9/2})_{11^-}$ are the lowest ones that are significantly oblate $\beta \approx -(0.15\text{-}0.20)$ with their lower ones spherical. In N=86 and possibly N=85 nuclei the same levels are spherical (β≈0), and in N=88 significantly prolate ($\beta \approx +0.2$). The important conclusion follows that for N=86 (at least in $^{150}_{64}Gd$, $^{152}_{66}Dy$) all states with $I^{\pi} \leq 27^{-}$ are spherical.

This work was supported by the U.S. Department of Energy.

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HIGH SPIN ISOMERS IN ^{151}Ho

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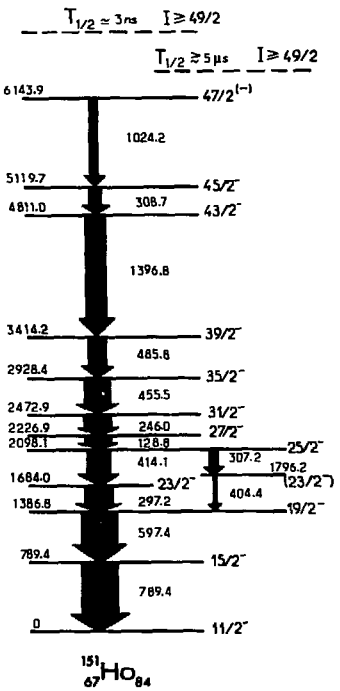
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Levels in ^{151}Ho have been populated in the ^{12}C + ^{144}Sm and ^{16}O + ^{141}Pr reactions with beams from the Grenoble cyclotron. The nucleus ^{151}Ho is identified by the excitation functions and cross-bombardments. The partial level scheme shown in the figure results in the analysis of prompt and delayed singles spectra, angular distribution of γ-rays and four dimensions coincidence events. Complementary data were obtained for some transitions by measuring the linear polarization of γ-lines with a Compton polarimeter made of five Ge(Li) detectors placed in the same cryostat[1].

All the lines shown in the scheme are associated with a high-spin short-lived isomer ($T_{1/2} \simeq 3 \pm 1$ ns) found by means of a multiplicity filter consisting of 14(2"x2") NaI detectors. The delayed multiplicity (12±1) of this yrast isomer is deduced from the ratios of γ-intensities in the x-fold Ge(Li) spectra. These lines appear also, but very weakly, several hundreds of ns after the prompt peak in Ge(Li)-NaI coincidence spectra but not in the spectra recorded 200 μs after the beam shut-off. This indicates the existence of a long-lived isomer (5% $T_{1/2} \lesssim$ 200 μs).

The coupling of a fully aligned $h_{11/2}$ proton to the ^{150}Dy states[2] reproduces most of the configurations of the ^{151}Ho yrast cascade. The level schemes of both nuclei have many analogies. So, the four lowest states of ^{151}Ho have a $\pi h_{11/2} \otimes \nu f^2_{7/2}$ configuration. The low energy part of the level structure reflects a vibrational nature. The $27/2^-$, $25/2^-$ and a second $23/2^-$ level at 1796 keV result very likely in the coupling of $\nu f_{7/2}$ $\nu h_{9/2}$ core states with an $h_{11/2}$ proton. A third $h_{11/2}$ proton coupled to $(\pi h^2_{11/2})_{10} \otimes \nu f^2_{7/2}$ core states could account for the $39/2^-$, $35/2^-$ and $31/2^-$ levels. Comparisons with core level spacings support the $\pi h^3_{11/2} \otimes (\nu f_{7/2}\ \nu h_{9/2})_8$ configuration for the $43/2^-$ state. Indeed, the energy difference (2584 keV) between the $43/2^-$ and $27/2^-$ levels is almost equal to the spacing (2669 keV) between the 18^+ and 8^+ states in ^{150}Dy.

The two isomers are placed above the $47/2^{(-)}$ state but their excitation energies remain unknown because of missing transitions. Their spins are at least equal to I = 49/2.



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SEARCH FOR HIGH SPIN ISOMERS IN THE Er AND Ho REGION

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Since the first systematic search for high spin isomers in the region near the N = 82 shell closure[1] many uncertainties still remain in this field. Indeed, in many cases the final nuclei in which these isomers have been found are not yet surely known[2]. Simultaneously with other groups[3-5], we have undertaken an experimental study to explore this region of deformed nuclei.

10-20 mg/cm^2 targets of ^{141}Pr, ^{144}Sm and ^{147}Sm were bombarded with 70-130 MeV ^{12}C, ^{14}N and ^{16}O beams from the Grenoble cyclotron. The Ge(Li) γ-ray spectra were recorded between the beam bursts in coincidence with gammas detected by a multiplicity filter consisting of 14 NaI detectors.

Short half-lives (up to ∿ 20 ns) were measured in Ge(Li)-RF coincidence experiments and long ones deduced from Ge(Li)-NaI coincidences. The ^{151}Er long half-life was obtained from γ decay using a mechanical beam chopper. The average delayed multiplicities $\bar{M}_d$ are determined from the ratios of γ-intensities in the x-fold coincidence spectra. The excitation energies in column 4 are obtained by summation of the individual γ-rays energies, taking into account the γ-γ coincidences relationships. When no precise informations are available, the spins are estimated by the relation $I_{is} = 1.7\,\bar{M}_d + I_o$ where I_o is the spin of the ground state or of a lower isomeric level.

The identification of Er and Ho final nuclei which contain high spin isomers was achieved through excitation function measurements and cross-bombardments. The assignments of the $^{150-153}$Ho isotopes which were previously uncertain by one mass unit are unambiguously established for the first time by our experimental results. The case of ^{151}Ho has been studied in detail and its level structure is known up to 6.1 MeV

	$T_{1/2}$	$\bar{M}_d$	E_{is}	I_{is}
^{153}Er	450±50 ns	5.6±1.0	≥2.75	25/2
^{152}Er	350±50 ns	8.6±1.0	≥5	37/2
^{151}Er	3.5±1.0ns	9±2	≥4.29	14
	35±10 ns	14±2	≥7	24
	6±2 ns		1.14	13/2
^{153}Ho	0.62±0.02s	3.0±0.5	>2.5	27/2
	40±10 ns			
	240±20 ns	≥4.8		>27/2
^{152}Ho	340±20 ns			
	10±3 ns			
	55±10 ns	6.5±1.0	≥2.87	20
	70±10 ns	4.5±0.5	≥2.8	16
^{151}Ho	2≲T≲200 µs			
	3±1 ns	12±1	>6.14	≥49/2
	5≲T≲200 µs	11±1		
^{150}Ho	20±10 ns			11
	80±15 ns	7±2	≥2.5	23
^{149}Dy	25±5 ns	8±1	>6.1	53/2
^{148}Tb	1.3±0.5µs	11.8±1.0	>6.6	29

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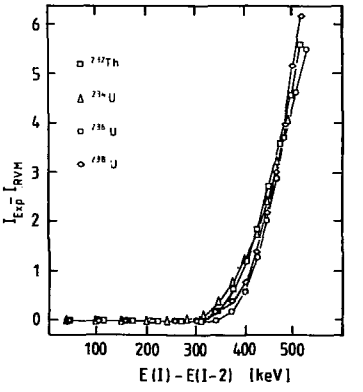
HIGH SPIN ROTATIONAL STATES IN ACTINIDE NUCLEI[Δ]

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High spin states in ^{232}Th and ^{234,236,238}U have been studied via multiple coulomb excitation with 5.3 MeV/u ^{208}Pb-ions supplied by the UNILAC at GSI. De-excitation γ-rays were observed with Ge-detectors and corrected for the large Doppler broadening by detecting in coincidence the recoiling target nuclei and/or the scattered Pb-projectiles over a large angular range in two position-sensitive parallel plate counters.

The ground state band is observed up to spin 28^+ in ^{232}Th and ^{234}U and 30^+ in ^{236,238}U. High spin levels of the $K=0^-$ band were also identified. The level energies deduced for the ground band of all four nuclei show a tendency to be too low above spin 14^+ as compared to energies extrapolated from low spin states. This corresponds to an 'upbending' of the apparent moment of inertia, which is also observed in ^{248}Cm studied recently at GSI[1]. Our data is consistent with the assumption that the ground band is crossed by a strongly interacting excited band based on rotational aligned $\nu j_{15/2}$ or $\pi i_{13/2}$ pairs[2]; The figure shows that a rotational aligned angular momentum of 4 to 5 ħ at spin 26 can be deduced for these nuclei if the rot-vib model[3] is used to describe the collective rotation of the core.



The experimental γ-ray yields within the ground band are compared with results of semi-classical coulomb excitation calculations using matrix elements based on the rigid rotor, interacting boson[4] , and rot-vib model[3], and including E1- and E4-excitations as well as octupole, β- and γ-bands. In view of the uncertainties of the inter-bands matrix elements used in these calculations, an at least reasonable description of the observed ground state yields is obtained assuming rigid rotor values for the inband matrix elements. Thus it seems unlikely that the 'upbending' is caused by a crossing of the ground band with a band of much larger deformation. The interacting boson-model, which predicts a cut-off of the ground bands at spin 24^+, 26^+, 28^+, 30^+ for ^{232}Th, ^{234}U, ^{230,238}U, respectively, and a strong reduction of the γ-yields in the high-spin region, is in contrast to our data. It is felt that this discrepancy cannot be solved by including two-quasiparticle bands into the model. Calculations employing the rot-vib model are still in progress.

[Δ]supported by Bundesministerium für Forschung und Technologie

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Effective and Collective Moment of Inertia in Cranking Model

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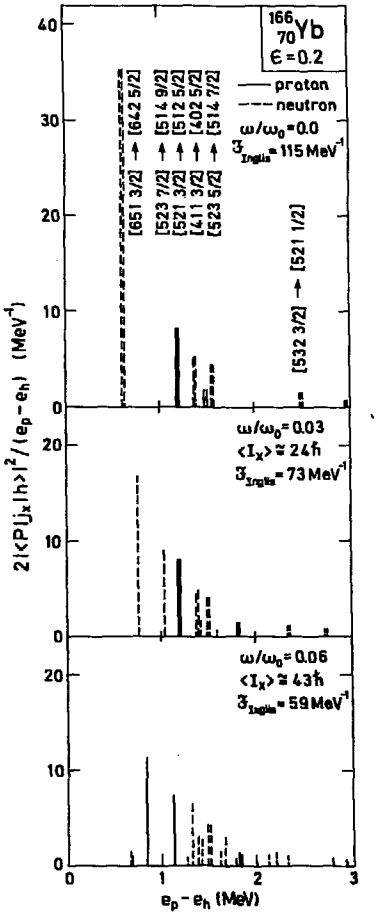
Recent γ-spectroscopy experiments[1] have given us new information about rotational bands up to very high angular momentum ($I \sim 45\hbar$) in rare earth nuclei. The energy of a band, as function of angular momentum, can be expanded around a certain value I_0:

$$E_{band}(I) = E_{band}(I_0) + \frac{\hbar^2}{\mathcal{J}_{eff}} I_0 (I - I_0) + \frac{\hbar^2}{2\mathcal{J}_{coll}} (I - I_0)^2$$

The effective moment of inertia, $\mathcal{J}_{eff}$, is close to rigid body value[2] in accordance with theoretical predictions based on the cranking model. The collective moment of inertia, $\mathcal{J}_{coll}$, shows a reduction up to 50% relative to $\mathcal{J}_{eff}$, this reduction increasing with increasing angular momentum. The cranking model gives the following expression for $\mathcal{J}_{coll}$:

$$\mathcal{J}_{coll} = \left(\frac{\partial^2 E'}{\partial \omega^2}\right)_\beta + \left(\frac{\partial^2 E'}{\partial \omega \partial \beta}\right) \Big/ \left(\frac{\partial^2 E'}{\partial \beta^2}\right) = \mathcal{J}_{Inglis} + \delta\mathcal{J}$$

Here $E'(\omega, \beta)$ is the energy in the rotating frame for the configuration of the band, as function of frequency ω and deformation β. The first term of $\mathcal{J}_{coll}$ is the Inglis moment of inertia in the rotating frame, and the second term, $\delta\mathcal{J}$, is due to the deformation change along the band. In the figure we show the single-particle contributions to $\mathcal{J}$ Inglis for yrast configurations of the nucleus 166Yb at three different frequencies. The main contributions to $\mathcal{J}$ Inglis comes from high-j_3 orbitals as indicated in the figure. These orbitals have a strong tendency to align their angular momenta along the rotating axis, thereby decreasing the non-diagonal matrix-elements of j_x. The figure in a natural way explains why $\mathcal{J}_{coll}$ decreases as function of angular momentum.



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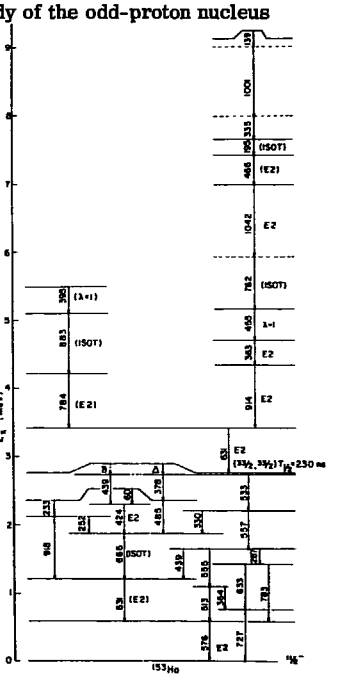
HIGH SPIN STATES AND A 230-ns ISOMER IN ^{153}Ho†

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Recently much attention has been devoted to rare-earth transitional nuclei, particularly following the observation of very high spin states and high spin yrast isomers in ^{152}Dy [1] and ^{154}Er [2]. We have begun a study of the odd-proton nucleus ^{153}Ho using standard γ-rays spectroscopy techniques and the reactions ^{141}Pr(^{16}O, 4n) and ^{122}Sn (^{35}Cl, 4n). Only the decay of ^{153}Ho had previously been observed, [3] so transitions were isotopically assigned on the basis of their excitation functions.

A preliminary level scheme is given in the figure. An yrast isomer with a half-life of (231 ± 4) ns and a spin of about 33/2 is observed at an excitation of approximately 2.8 MeV. This isomer is hypothethised to decay via at least one unobserved low-energy transition. Due to the presence of a 439 keV doublet, the energy sums for the states feeding the 439 and 378 keV transitions are not sufficiently accurate to remove the possibility of two low-energy transitions.


E_x (MeV)
^{153}Ho
E2
(ISOT)
(E2)
(E2)
(E2

CONFIGURATION ASSIGNMENTS IN DOUBLY ODD DEFORMED NUCLEI FROM RESIDUAL INTERACTION STUDIES

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In view of the sparse data on the excitation spectra of odd-odd nuclei, it is of interest to have reliable estimates for the location of the various two quasi-particle states with a view to assign appropriate spin-parities. On the other hand, for levels with known spin and parity, one is interested in determining the nature of the state and to assign deformed orbital configurations to the same. The usual procedure[1] is to build up the two quasi-particle states by superposition of the single particle configurations from the neighboring odd-mass nuclei and, while invoking the Gallagher-Moszkowski rule (which places the state with parallel spin projections out of the G-M pair with $K^{\pm} = |\Omega_p \pm \Omega_n|$ lower in energy), add a constant n-p residual interaction contribution to split the GM pair. This procedure has however been found[2] to be inadequate to describe even the ground state in several rare earths and actinides; these anomalies could be explained with the proper inclusion of the residual interaction effects.

In common with other studies[3] we adopt a zero range interaction and obtain[2] for the residual interaction energy contribution to the K band

$$\Delta E_{int}(K) = (1-\alpha)W\, A_W(K) + \alpha W\, A_\sigma(K)$$

where A_W and A_σ are the matrix elements of the Wigner (spin independent) and the spin-dependent $\bar{\sigma}_p \cdot \bar{\sigma}_n$ terms, α being the relative strength of the spin dependent part and W the potential strength. The matrix elements have been evaluated analytically using Nilsson wavefunctions and the interaction parameters W and αW determined[4] from the atomic mass data and the splitting energy of the ground state GM pair. The calculations show that the inclusion of the residual interaction contribution results in reordering of the two-quasiparticle spectra in several cases as compared with the predictions of the simple superposition approach. We have made detailed comparison and predictions over a wide range of nuclei wherever enough information is available. For example comparison with the experimental results for Americium isotopes[5] is seen to lead to appropriate configuration assignments to the states with same spin-parity and also to the approximate location of missing combinations. The calculations further predict the corresponding two quasi-particle spectra involving the excited proton single particle states.

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THE NEW TYPE OF COLLECTIVE EXCITATIONS IN NUCLEI

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The microscopic theory of the collective motions in nuclei[1], based on the clear distinction between the collective and internal degrees of freedom, gives the method for the expansion of an arbitrary microscopic Hamiltonian in series, the first term of which gives the collective hamiltonian H_{coll}. The eigenstates of H_{coll} give the most general description of the collective features of the nuclei. Most of them are the new ones, not similar to those, which follow from the traditional phenomenological approach. In particular, the following new effects, connected with the microscopic collective degrees of freedom, have been discovered.

The collective excitations of a new type are equally important in even and odd nuclei and the spectrum of H_{coll} is similar to the traditional rotational-vibrational picture only in special cases of some even nuclei. The new picture of the collective spectrum, not known in the phenomenological theory, is created by the vectorial and tensorial terms of H_{coll}.

The new microscopic theory provides the possibility of the investigation of the dependence of the collective effects on the form of the potential of the nucleon-nucleon interaction. Wide variety of the potentials has been studied from this point of view including the realistic potentials, as well as some characteristic interactions, such as δ - forces and central multipole interactions.

The spectrum of H_{coll}, using the simplified version of the theory, has been studied in the region of the mass numbers $A \leq 40$. The collective effects, as well as the effects opposite to the collective ones, give rise to a very definite scheme, similar to the experimental one, including the description of the observed level density.

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ALPHA CLUSTER WITH HIGH ANGULAR MOMENTUM

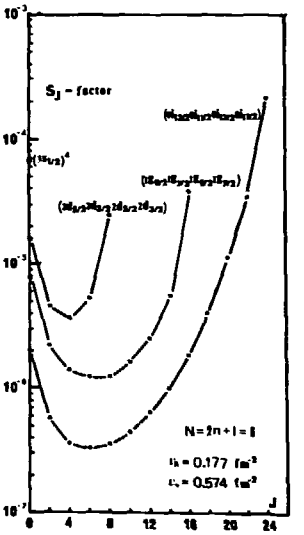
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Recent experiments[1] on the heavy ion nuclear reaction show that α-particles having larger energies and angular momenta than those anticipated from the evaporation model are emitted considerably. Data have been analysed in terms of the pre-equilibrium model in which the formation probability of α-cluster is assumed to be one.

In order to examine how much the α-cluster with a high angular momentum can be formed in a medium heavy nucleus, we have calculated α-reduced width amplitudes $y_J(a)$ with the angular momentum J for four-particle shell model states around an assumed residual nucleus. The square norms $S_J = \langle y_J^2 \rangle$ for some configurations with $N = 2n + \ell = 6$ oscillator quanta are shown in the figure as a function of J.

In each configuration, the S_J-factor grows larger in the region of high angular momentum, especially in the configuration with nodeless orbits. The S_J-factor can be factorized as $S_J = C_J T_J$. The C_J represents angular and spin overlaps between the α-particle and the four particles, and T_J the radial overlap. In contrast to the decreasing inclination of the C_J, the T_J-factor shows a severe increase as J increases. The rising nature of S_J in the region of high angular momentum is a consequence of the strong increase of T_J which overcompensates the decrease of C_J in that region. The increasing nature of T_J as a function of J can be regarded as the finite size effect of the α-particle, since one easily observes that the T_J-factor remains constant irrespective of J if one takes the zero-size approximation for the α-particle. On the contrary, if one assumes $\nu_\alpha = \nu_A$ the ratio of T ($J = J_{max}$) to T ($J = 0$) amounts to 10^7 for $0i^4$ configuration. Because of the property of the C_J-factor in the larger J region, the growth of S_J for the $(\ell+1/2, \ell-1/2)$ type configuration is more remarkable than that for the $(\ell\pm1/2)^2$. Unlike the α-decay between the ground states, the phase of each configuration will become at random in the highly excited states, and the destructive interference will lead to a small α-reduced width, in particular for lower J. For high spin states, however, a few configurations are involved in and the corresponding S_J-factors have large values. Therefore, it is conceivable that α-clusters with large angular momentum are preferably formed in highly excited states.



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MULTIPLE COLLECTIVE EXCITATIONS VIA BOSON EXPANSIONS

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The finite boson expansion technique is particularly useful for the investigation of problems associated with the description of highly excited nuclear states in terms of multiple collective excitations. Apart from the normal Pauli anharmonic effects in multiple boson states, it is also important to study the decoupling of non-collective degrees of freedom, as well as the influence of other types of collective excitations. The decoupling is complete in the schematic model with constant particle-hole (ph) interactions and a degenerate ph-basis.

A *semi-schematic model* was investigated in which the degeneracy is split. The effect on the decoupling is slight. As function of the ratio between the energy splitting and the interaction strength, the ratio of 2→1 phonon to 1→0 phonon transition probabilities, as well as the ratio between 2 phonon and 1 phonon excitation energies show a gradual change from the schematic model values as modified by the exclusion principle in the larger active space to those for the active space which remains when some of the ph states have moved out of range.

An example of the influence of one type of collective excitation on another is obtained by introducing particle-particle (pp) and hole-hole (hh) interactions, which lead to collective pairon (pp) and holon (hh) excitations. The interaction which generates these excitations must then *inevitably* mix pairon-holon excitations into two-phonon states in close proximity. This of course also shifts the energies and fragments the transition strengths strongly.

The bi-fermion operators for ph, pp and hh collective states are elements of a Lie algebra associated with the group Sp(4). This algebra was analysed by means of a finite boson expansion similar to the Dyson-Maleev formulation (1) for the generators of SU(2). Ideal fermions (2) and non-collective bosons can also be incorporated in this new expansion. They enter essentially in a number operator capacity for the respective excitations and thus *in effect* they monitor the available space for the collective states.

The finite boson expansion method was also used to derive the phenomenological IBA model for even and odd nuclei for a microscopic hamiltonian with monopole and quadrupole pair interactions. The IBA hamiltonian thus obtained is non-hermitian and it remains difficult to visualize the existence of a finite hermitian boson hamiltonian.

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SYMPLECTIC SHELL MODEL OF COLLECTIVE MOTION+

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The Symplectic model is a microscopic theory which provides a practical technique for identifying the shell configurations necessary for the description of quadrupole and monopole vibrations as well as collective rotations of the nucleus. The model is based on the symplectic algebra sp(3,R) and is a natural generalization of both the Bohr-Mottelson collective model and Elliott's su(3) model to include many major oscillator shells in addition to core excitations. The sp(3,R) algebra includes the quadrupole and monopole mass moments, the kinetic energy, the harmonic oscillator Hamiltonian and the angular and vibrational momenta. In contrast to the su(3) algebra, the sp(3,R) algebra makes no $\hbar\omega$ approximations and treats all observables in the algebra exactly, thereby achieving a theory of collective motion applicable to large amplitudes.

Numerical results are reported for ^{20}Ne using an $8\hbar\omega$ truncation and a phenomenological potential $V(\beta,\gamma)$. Satisfactory agreement with experiment is obtained for the absolute B(E2) rates without resorting to an effective charge. A 10^+ state is predicted extending the yrast band beyond the su(3) cutoff with a large transition rate to the 8^+ state, $B(E2{:}10\rightarrow 8) \approx 16$ w.u.

A projection technique is used to determine the two-body part of the many-body potential $V(\beta,\gamma)$. Results for the two-body projection differ only slightly from the many-body potential. Hence, in the symplectic shell model, one has achieved a collective model with two-body forces.

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VELOCITY CURRENT DISTRIBUTION FOR FAST ROTATING NUCLEI

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It is of current interest to investigate the structure of rotational currents. In all previous studies on this problem the perturbation methods were used, so that the results were limited to the small rotational frequencies (small ω). In addition, so far, there exist two kinds of self-consistency conditions for the calculation of current distributions 1,2).

In this work the velocity current distribution is calculated on the basis of exact solution of cranked anisotropic harmonic oscillator by including $\Delta N=2$ at various rotational frequencies ($\hbar\omega$=0.001, 0.15, 1.5, 2.25 in MeV unit). Only for the cases of $\hbar\omega$=0.15, 2.25 are plotted (see. Fig.1-2). It is found that a large number of circulations appeared in the case of small ω and gradually disappeared as the ω increased.

Our calculation also shows that based on the different self-consistency conditions the results are the same for the small ω and quite different for large ω although the general tendency indicated above is still the same.

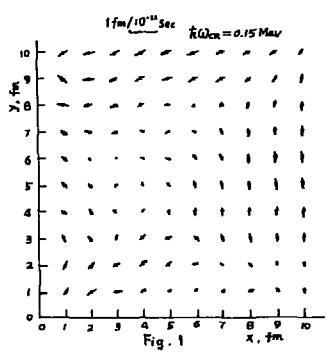


Fig. 1

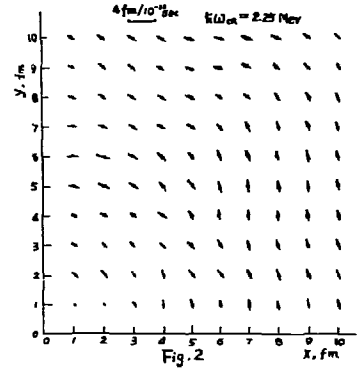


Fig.2

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SELF-CONSISTENT COLLECTIVE COORDINATE METHOD FOR LARGE AMPLITUDE NUCLEAR COLLECTIVE MOTION

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A new microscopic theory capable by itself to select the "optimum" collective path (or more generally, the "optimum" collective submanifold in many particle Hilbert space), consistent with the spacified boundary condition on the collective motion, is developed.[1-3]

In order to describe the large amplitude collective vibration about the Hartree Fock ground state $|\phi_0>$, we introduce a generalized moving frame called as a vibrating frame[2,3] (which corresponds to the rotating frame for the rotational nuclei) by a time dependent unitary transformation, with complex parameters $\eta_r(t)$ and their complex conjugate $\eta_r^*(t)$ spacifying the collective variables,

$$|\phi(\eta^*(t),\eta(t))> = U^{-1}(\eta^*(t),\eta(t))|\phi_0>.$$

On the basis of a simple fundamental principle called as the "invariance principle of the Schrödinger equation"[1] to spacify the time variation of the collective variables $(\eta^*(t), \eta(t))$,

$$0=\delta<\phi_0|U(\eta^*(t),\eta(t))\{i\frac{\partial}{\partial t} - H\}U^{-1}(\eta^*(t),\eta(t)|\phi_0>,$$

it is shown that the "maximal decoupled" collective Hamiltonian $\mathcal{H}_c(\eta^*,\eta) \equiv <\phi_0|U(\eta^*,\eta)HU^{-1}(\eta^*,\eta)|\phi_0>$ is determined selfconsistently.

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ADIABATIC TIME-DEPENDENT HARTREE-FOCK CALCULATIONS FOR THE OPTIMAL PATH, THE POTENTIAL AND THE MASS PARAMETER FOR LARGE AMPLITUDE COLLECTIVE MOTION

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Microscopic theories of large amplitude collective motion in the spirit of ATDHF aim to reduce the many body problem to a simpler one in terms of one (or few) collective coordinate, q, thereby using concepts like collective masses, M(q), and potentials, V(q); refs. 1-4. One of these approaches[1]) has been shown to be particularly appropriate for a numerical application since it results[5]) in a simple differential equation for the collective path, $|\phi(q)>$, from which V(q), M(q) together with all relevant quantum corrections can be extracted:

$$\frac{\partial}{\partial q}|\phi(q)> = c(q)\left[H,H_{ph}(q)\right]_{ph}|\phi(q)> \qquad (1)$$

Here the $c = M(\partial V/\partial q)^{-1}$ and ph indicates the 1p-1h part w.r. to $|\phi(q)>$. The resulting $|\phi(q)>$ is optimal in the sense that it minimizes the coupling between the collective coordinate q to the noncollective ones. The initial value $|\phi(q_{in})>$ for eq. (1) can be uniquely fixed by the validity condition of the Goeke-Reinhard approach.

In praxi, eq. (1) is solved in a 3-dimensional coordinate- and momentum-space on a grid of 9x9x9 points with step size of 1 fm. The theory is first applied to the $^8Be \rightarrow \alpha+\alpha$ system using a simplified Skyrme-force without Coulomb part. Fig. 1 shows equidensity plots for various points of $\{|\phi(q)>\}$ being equivalently labeled by the deformation β of ^8Be and the distance d of the α-particles. The curves reveal features like polarization of the fragments, neck formation, etc. Fig. 2 shows V and B = 1/M. For large d the M approaches the reduced mass from which it strongly deviates in the overlapping region.

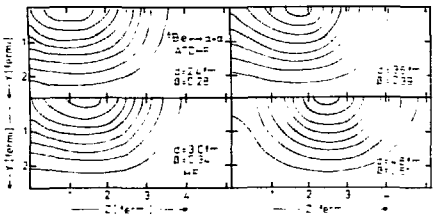


Figure 1

Although the calculations are fully dynamic and evaluate the optimal path they are much faster than ordinary Hartree-Fock with a guessed constraint.

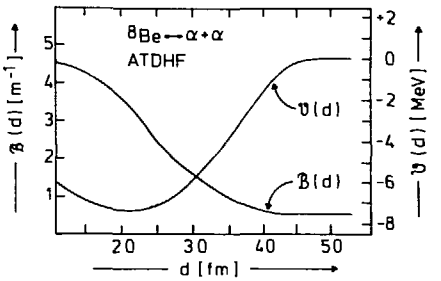


Figure 2

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MAGNETIC HIGH SPIN STATES IN ^{208}Pb

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The magnetic high spin states discovered recently in ^{208}Pb [1] are especially interesting because the number of single particle hole excitations which can contribute is highly restricted. The experimental excitation energies are very close to the shell model energies for the neutron $j_{15/2}\, i^{-1}_{13/2}$ and proton $i_{13/2}\, h^{-1}_{11/2}$ configurations. The cross section measured in inelastic electron scattering, however, is only 50 % of the shell model prediction.

We show that the coupling of phonons to the single particle states is largely responsible for this discrepancy. The collective 3^- state at 2.61 MeV alone reduces the single particle strength of the neutron $j_{15/2}$ orbit to Z = 0.65. Apart from the first 5^- state at 3.19 MeV, the influence of the other phonons can be neglected.

Since the form factors have maxima above q = 2 fm^{-1}, it is definitely required to take into account the one pion exchange potential and the rho meson exchange. We show that in the important q-range the effective interaction becomes weakly attractive. This explains the coincidence with the shell model predictions. Results of a 2p2h-calculation with one pion and rho exchange are shown in the table.

	$E(12^-_1)$ [MeV]	$E(12^-_2)$ [MeV]	$E(14^-)$ [MeV]
shell model	6.49	7.18	6.49
1p1h	6.60	7.52	6.81
2p2h	6.54	7.37	6.63
exp.	6.43	7.06	6.75

The large Landau parameter g'_0 = 0.75 employed here is incompatible with "precritical phenomena" related to pion condensation.

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MAGNETIC MOMENTS IN THE BACKBENDING REGION

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Backbending is understood as the crossing of the collective groundband (g-) with the s-band containing two aligned intrudes quasiparticles. This simple two band picture well accounts for the spectra [1].

In the cranked shell model [1] the total angular momentum I and magnetic moment μ at the frequency ω are given by

$$I(\omega) = I_g(\omega) + i(\omega) \quad \mu(\omega) = g_R\, I_g(\omega) + g_i\, i(\omega)$$

where I_g is the collective angular momentum and $i(\omega)$ the aligned angular momentum of the excited quasiparticles. The gyromagnetic ratio is

$$g \equiv \frac{\mu}{I} = g_R + (g_i - g_R)\, i(\omega)/I(\omega)$$

where $i(\omega)$ may be obtained from the experimental spectrum [1].

The relevant matrixelements of the magnetic moment for the intruder states do not very strongly deviate from the spherical shell model limit. Using this and reducing g_s by a factor of 0.7 one obtains g_i = 1.26, -0.20, 1.22, -0.18 for $h_{11/2}{}^p$, $i_{13/2}{}^n$, $i_{13/2}{}^p$ and $j_{15/2}{}^n$, respectively. We take g_R = 0.35.

In the g-band i = 0 and g = g_R. The first backbend in the light rare earthes is the crossing of the $i_{13/2}$ neutron s-band with g-band. Assuming a sharp crossing at I_1 = 14 and i_{sn} = 8, g drops from 0.35 to 0.04 and then slowly increases again. The second backbend is due to the $h_{11/2}$ protons. With I_2 = 28 and i_{sp} = 6, respectively, g jumps from 0.20 to 0.39. The backbend in Os^{184} is also interpreted as neutron alignement. Accordingly g should drop from 0.35 to 0.08 at I = 14. In Os^{186} g would decrease to -0.03 at I = 12 if the backbend is caused by the neutrons but increase to 0.83 if the $h_{9/2}$ protons are responsible. In most nuclides there is some mixing between g- and s-band leading to a gradual growth of $i(\omega)$. In Er^{164} one finds g = 0.35, 0.35, 0.34, 0.10, 0.12, 0.14 and in Yb^{168} g = 0.27, 0.25, 0.22, 0.20, 0.18, 0.16 for I = 10, 12, ..., 20 respectively. The values for other N = 96 and 98 isotones should be similar.

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COMPETITION OF PROTON AND NEUTRON ALIGNEMENT IN ROTATING HEAVY NUCLEI

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Backbending in heavy deformed nuclei is interpreted as the crossing of the ground state band (g-) with the s-band containing two aligned intruder quasiparticles ($h_{11/2}$, $i_{13/2}$, $j_{15/2}$). The cranked shell model [1] (CSM) is able to account for the crossing frequency ω_c the amount of aligned angular momentum i_s and the interaction matrixelement V controlling the band mixing and thus the rapidity of the backbend.

If the deformation is prolate i_s decreases and ω_c increases with the filling of the intruder shell. Thus the position of the chemical potential determines whether the proton or the neutron s-band crosses first, where due to the larger pairing gap the protons are slightly disfavoured.
In the light rare earthes the $h_{11/2}$ p shell is half filled whereas the lowest $i_{13/2}$ n levels are being filled. Correspondingly CSM gives $\omega_{CN} \approx 0.3$ MeV and $\omega_{cp} \approx 0.4$ MeV, what is born out by the data on the first ($i_{13/2}$) and second ($h_{11/2}$) backbend observed in the spectra of the Z = 66 - 72 nuclids. The rapidity of the crossing is well correlated with the oscillations of V calculated in the CSM.

In the heavy rare earthes the $i_{13/2}$ n shell is half filled. The competing protons are in the $h_{9/2}$ shell the 1/2 level of which beeing close to the Fermi surface. However CSM calculations for A $\approx$ 182 give $\omega_{CN} = 0.25 - 0.30$ MeV and $\omega_{cp} \approx 0.40$ MeV. The spectra of odd A - nuclids around Os^{184} are consistent with the neutron alignment being first. In heavier Os and Pt isotopes ω_{CN} and ω_{cp} come close.

In the light actinides the chemical potentials lienear the 7/2 level of the $j_{15/2}$ n shell end the 5/2 level of the $i_{13/2}$ p shell. As a consequence $\omega_{CN} \approx \omega_{cp} \approx 0.20$ MeV. The spectra of the U-isotopes, Th^{232} and Np^{237} are consistent with a simultaneous alignement of protons and neutrons.

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BOSON EXPANSION THEORY APPLIED TO THE ANALYSES OF Os AND Pt NUCLEI†

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The boson expansion theory, as formulated earlier[1]), has recently been applied in describing the transition from the spherical to deformed elements of the Sm isotopes[2]). Analyses of Ru and Pd isotopes have also been made[3]). We report here on more recent work for the Os and Pt isotopes. Part of the results have already appeared[4]).

It is seen in Fig. 1, that the theory agrees well with the experimental spectra, in fact reproducing the more deformed nature of Os and the more γ-unstable nature of the Pt isotopes. The difference between the Os and Pt isotopes can, however, be seen more clearly in some branching ratios. Two examples presented in Fig. 2, do in fact reveal a dramatic difference; and it is seen that the theory reproduces this.

The results may be understood from the following. The four proton holes in the Pt isotopes favor an oblate shape and compete with the opposing tendency exerted by the larger number of neutron holes. Furthermore, it is to be expected that a transition from prolate to oblate deformation induces γ-instability in the nuclear system. This occurs in Pt. A similar feature is also true in Os, but the six proton holes favor an oblate shape more weakly than in Pt. Thus the Os isotopes, particularly the lighter elements, tend to have a prolate deformation. Our theory, due to its construction of the bosons from the underlying proton and neutron single particle degrees of freedom can reproduce these transitions.

Currently we are working on the Ge and Se isotopes, and the results of this new work may also be discussed, together with further details of the Os-Pt analyses.

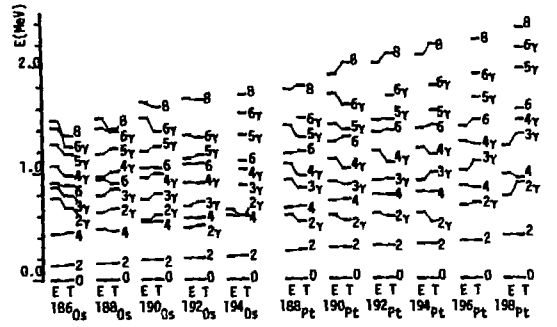


Fig. 1 Theory(T) and experiment(E) for the ground and gamma bands.

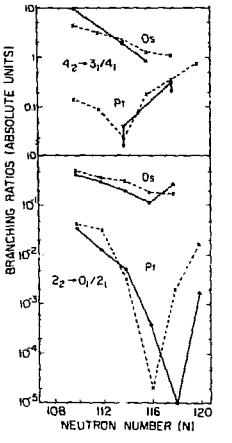


Fig. 2 Theoretical (x) and experimental (•) B(E2) ratios.

† Supported in part by the U.S. Department of Energy.

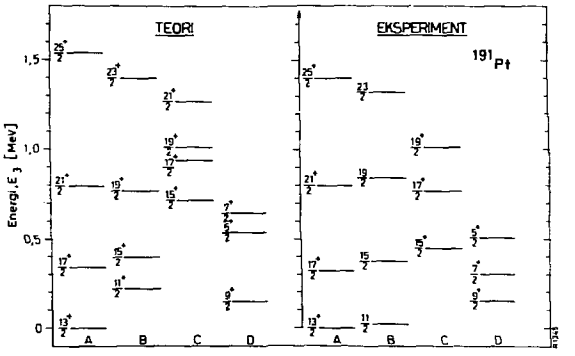
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PARTICLE-CORE COUPLING IN ^{191}Pt USING A DDT-DESCRIPTION OF THE EVEN-EVEN CORES.

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Conventional core-particle coupling models do not consistently describe the transitional shape and particle-hole structure of odd-A transitional nuclei. In an approach developed by F. Dönau and S. Frauendorf [1] the wave functions are formed from particle-like states with a particle coupled to the collective states of the A-1 even neighbour, and hole-like states with a hole coupled to the A+1 even neighbour. The resulting equations for the (spectroscopic) amplitudes are those earlier derived by the Philadelphia-group [2], but in the Dönau-Frauendorf approach the iterative procedures required for self-consistency are dropped and the core-field (static monopole pair-field + collective dynamic quadrupole field) is considered to be known. An approximative procedure for selecting the physical states excists. [1].



$\lambda = \varepsilon_{13/2} + 1.5$ MeV, $\varepsilon_{9/2} - \varepsilon_{13/2} = 4.15$ MeV

In our calculations we have combined this coupling model with a Dynamic Deformation Theory (DDT)-description of cores [3]. Results for ^{191}Pt are shown in the figure. For the quadrupole coupling strength we have used the Bohr-Mottelson value. The two model parameters are given in the figure, the Fermi level is constrained to conserve the average particle number to within 80%. The single-particle basis consists of two levels ($1i_{13/2}$, $2g_{9/2}$) while 16 states were included in each core nucleus. The Quality of the fit is comparable to what is obtained with simpler core models but requires much fewer parameters. The sensitivity of the odd-A energy sequence to the core model seems to be fairly weak. A more detailed test of possible improvements is expected to result from comparisons with transfer and scattering data, such calculations are in progress.

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MICROSCOPIC TRIAXIAL DESCRIPTION OF ODD AND EVEN EVEN NUCLEI IN Os AND Pt REGION

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The study of the structure of nuclei in the Os-Pt region has raised a vital question regarding the occurance of rigid triaxial shape. While the model study of odd A nuclei favours the view of static triaxial shape for the even-even core, the potential energy surface study of such nuclei shows them to be γ-soft. Thus a controversy has been raised. We have developed a fully microscopic model to describe both the odd and even-even nuclei in a consistent manner starting from pairing plus quadrupole interaction of Baranger and Kumar[1]. This theory[2] for even-even nuclei is based on variation after angular momentum projection from a triaxially symmetric intrinsic wave function obtained in the frame work Hartree-BCS theory and provides a simultaneous description of both the ground and γ-bands. We have applied[2] this theory to ^{188}Os and ^{188}Pt. We have chosen a core consisting of 40 protons and 70 neutrons. For the protons N = 4 and 5 and for neutrons N = 5 and 6 oscillator shells are the active shells. We find that the triaxial minima are more bound than the corresponding axial minima by 0.714 MeV and 0.724 MeV respectively. Level energies up to J = 10 in ground band and up to J = 4 in γ-band and the electromagnetic properties are in good agreement with experiment.

The odd A nuclei like ^{187}Ir, ^{187}Os, ^{189}Ir, and ^{189}Pt are now described in terms of the quasiparticle coupled to the core whose wave functions are the ones obtained above. Level energies of both the positive and negative parity bands and the electromagnetic properties calculated for these nuclei are in reasonably good agreement with experiment. Keeping the parameters of the force fixed at the values determined by Baranger and Kumar and without any other adjustable free parameters, a coherent description of the both the odd and even-even nuclei have been attempted with reasonable success.

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HARTREE-FOCK-BOGOLYUBOV CALCULATION OF THE ^{240}Pu FISSION BARRIER INCLUDING NON AXIAL AND LEFT-RIGHT ASYMMETRIES

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Purely microscopic approaches are potentially able to give definite answers to several open questions in the nuclear fission field, such as the existence of new extrema in barriers and the trend of nuclear properties at large deformations. In recent years, various attempts in this direction have confirmed the existence of a second minimum in actinide fission barriers. However, many approximations were introduced in order to reduce the size of the calculation, and unrealistic barrier heights were obtained. In this work, we present the results of a self-consistent evaluation of the ^{240}Pu fission barrier, where special attention has been given to a realistic treatment of *short range correlations, asymmetry effects* and zero-point *energy* (ZPE) corrections. It is shown that reasonable values for the fission barrier can then be obtained.

In this calculation the full Hartree-Fock-Bogolyubov (HFB) formalism has been used in order to treat the pairing effects on the same footing as the average field aspects. We emphasize that this was possible because we employed a finite range effective two-body interaction[1]). The HFB equations have been solved in finite oscillator basis of one and two-centres types. Despite the large bases used, the convergence in the dimensionality of the basis is a delicate point that we are still checking carefully. The potential energy curve was first computed in axial and left-right symmetry by constraining the total quadrupole moment of the system. The axial symmetry was then relaxed at the first barrier, revealing a strong γ-instability. The left-right asymmetry has also been explored by using an additionnal constraint on the octupole moment of the system in the region of the second barrier. A deep valley was found for values of the mass asymmetry parameter compatible with the experimental data on mass yields. Finally the microscopic wave functions thus obtained have been used to compute the ZPE corrections associated with the spurious rotation-vibration modes of the system and with the spurious relative motion of the fission fragments.

	E_A-E_I	E_B-E_I	$E_{II}-E_I$
HFB axial left-right symm.	10.7	23.2	6.9
HFB γ-asymmetry	8.5	-	-
HFB mass-asymmetry	-	15.8	-
ZPE corrections added	6.8	9.8	3.7
from experiment	6.0	5.4	2

Table 1

The table 1 shows preliminary results obtained for the barrier heights (E_A-E_I and E_B-E_I) and the position of the isomeric well ($E_{II}-E_I$) for the various types of symmetry and after the ZPE corrections have been added. It is likely that the second barrier will be noticeably reduced after full convergence in the basis dimension.

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NEUTRON CROSS SECTION CALCULATIONS FOR THE EVEN SAMARIUM ISOTOPES USING DEFORMATION DEPENDENT WAVE FUNCTIONS

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The microscopic wave functions obtained[1-2]) from the diagonalization of the collective hamiltonian using the numerical method of Kumar and Baranger[3]) are used in a generalization of the coupled optical model. These wave functions have the following form : $|IM,n\rangle = \sum_{K,\alpha} A^{n}_{IK}(\beta_\alpha,\gamma_\alpha)\Phi^{I,n}_{MK}$, and the half-value radius of the optical potential is parametrized as usual for triaxial quadrupole deformation $(\beta_\alpha,\gamma_\alpha)$. The different multipoles of the potentials are computed using these wave functions via two dimensional integration over the angles (θ,φ). This formalism avoids the choice of deformation parameters and allows us to take into account the possibility of shape coexistence for various ground and excited states. The calculations of neutron cross sections were performed using the previously determined[4]) optical potential parameters and the wave functions calculated from the dynamic deformation theory[1]) for ^{148,150,152,154}Sm and from Hartree-Fock-Bogolyubov methods[2]) for ^{150,152}Sm. The calculated total cross section for ^{148}Sm is in fairly good agreement with the experimental data[4]). The calculated total cross section differences between ^{150}Sm (^{152}Sm) and ^{148}Sm are presented in Fig. 1a (Fig. 1b) together with experimental values of Ref.4. For these calculations the wave functions for ^{148}Sm have been taken from the work of Kumar[1]).

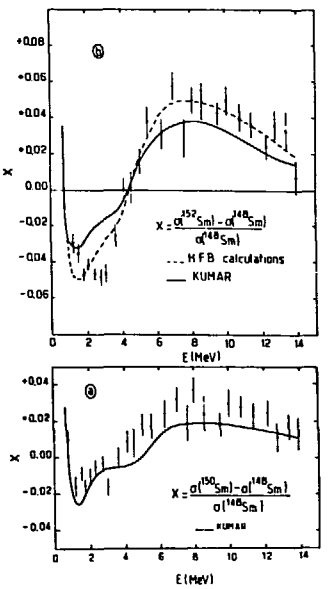


Fig. 1

The angular distributions computed using the present optical model parameters and wave functions are in good agreement[1]) with recent data for these Sm isotopes[5]).

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THE PARTICLE-ROTOR MODEL WITH PARTICAL NUMBER CONSERVATION -EXACT SOLUTION FOR $i^{13/2}$ SINGLE MODEL

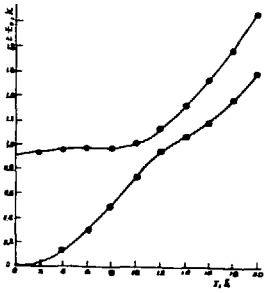
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In this article, we present a particle-rotor (PR) model with particle number conservation. The model is solved in i13/2 single j model and comparisons with the results of HFBC and PR model with BCS approximation are made. For two dimensional rotation,

$$H = H_0 + \alpha (I - J_x)^2$$

$$H_0 = \sum_\alpha \epsilon_\alpha a_\alpha^+ a_\alpha - G \sum_{\alpha\beta} a_\alpha^+ a_{\bar{\alpha}}^+ a_{\bar{\beta}} a_\beta$$



First, the exact solutions of H_0 give the bases with particle number conservation. In case of 4 particles, there are 21 pair exitation states, 210 states with one pair broken, 210 states with two pairs broken, altogether 441 states. H can be diagonalized with these bases for each I and the ground band and S-band obtained here are shown in Fig.1. The aligned angular momentum $\langle Jx \rangle$ of valence particles, the $\langle \Delta Jx^2 \rangle$, the pairing energy and components of wave function of ground band and S-band are also calculated. The results show that $\langle Jx \rangle$ increases rapidly at I=12, but pairing energy decreases rapidly. The $\langle \Delta Jx^2 \rangle$ here has large value, indicating the break down of the HFBC at this I.

The comparisons with the results of HFBC and PR model with BCS approximation are made in table.

The calculation shows that when the energy truncation of bases is made, (particle number still conserved), the satisfactory result can also be obtained, indicating this model can be used to caculate real nucleus.

	ω_c	I_c	j_{max}	IVI
HFBC	0.09(K)	12(ħ)	9.5(ħ)	0.045 (without recoiling) 0.09 (with recoiling)
BCS-PR	0.09(K)	12 (ħ)	9 (ħ)	0.08 (K)
present work	0.09(K)	12 (ħ)	6 (ħ)	0.2 (K)

CONTINUUM γ-RAY SPECTRA AND EXCITATION FUNCTIONS OF YRAST STATES IN ^{152}Dy*

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Beams of ^{34}S from the Argonne superconducting linac booster have been utilized to populate states in ^{152}Dy in an attempt to study the nature of the γ-ray transitions connecting the entry region with the yrast line and to understand in detail the population process of the yrast line.[1]

Two series of experiments have been done. In one, the population intensities of yrast states in ^{152}Dy were studied as a function of bombarding energy with $144 \leq E_S \leq 184$ MeV. In the other, continuum γ spectra were measured at E_S = 150 and 162 MeV with a 25 cm diam. × 30 cm NaI crystal with a 7.5 cm diam. central collimator. The γ rays in both experiments were observed in coincidence with a sum-spectrometer consisting of two 33 cm × 15 cm NaI crystals; enhancement of high-ℓ events was obtained by selecting higher sum energies.

For bombarding energies ≥ 160 MeV, corresponding to $\ell_{max} \gtrsim 57\,\hbar$, states with spins of up to 29 ħ receive close to 100% of the $(^{34}S,4n)^{152}$Dy cross section, indicating little or no side-feeding below this spin. The population of states with higher spin does not increase even at higher bombarding energies (corresponding to higher angular momentum input). In contrast, a monotonic decrease in yrast population with spin is usually observed in studies on prolate deformed nuclei.

The NaI spectra exhibit an enhanced yield between 1.2 and 1.6 MeV, well separated from any known discrete lines. Anisotropy measurements of this energy region suggest that it consists of many unresolved stretched quadrupole transitions.

These results imply that the deexcitation of high-ℓ events ($\ell \gtrsim 35\,\hbar$) is not feeding the yrast line directly via statistical transitions, but is diverted by continuum cascades of E2 character, and only reaches the yrast line at $\ell \sim 29$-$37\,\hbar$. The fact that the high energy edge of the "bump" remains fairly constant over a large range of incoming ℓ-values implies a moment of inertia which seems to increase with spin.

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**Supported by the Danish National Science Research Council.

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GAUGE INVARIANT PERIODIC QUANTIZATION METHOD†

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Recently, the gauge invariant periodic quantization (GIPQ) method has been formulated[1] for the special case of the time-dependent Hartree-Fock (TDHF) approximation. We here generalize this method to all time-dependent descriptions which follow from the variational principle,

$$\delta\int\langle\Psi|(H - i\hbar\partial_t)|\Psi\rangle dt = 0 \qquad (1)$$

where the trial many-body wave function Ψ is varied both in direction and in magnitude inside a fixed but arbitrary manifold in the Hilbert space. This variational principle leads to (a) norm and energy conservations, (b) definite time evolution for the phase[2] of Ψ, so that

$$\Psi = \Phi_G \exp\{-i\langle H\rangle t/\hbar\}, \quad \Phi_G \equiv \Phi \exp\{i\int^t\langle\phi|i\partial_{t'}|\phi\rangle dt'\}, \qquad (2)$$

and (c) an equation of motion for the uni-modulous ϕ.

The wave function Ψ in (2) is structurally analogous to the exact time-dependent Schrödinger eigensolution, consisting of an energy phase factor and a gauge invariant part Φ_G, analogous to the exact eigenfunction, which is invariant under arbitrary (time-dependent) changes of the zero point of the energy.

The GIPQ method identifies those Ψ for which Φ_G is periodic as the proper analogs of the bound eigenstates of the many-body system. This leads to the following quantization condition for any periodic ϕ in (2),

$$\int_0^T\langle\phi|i\partial_{t'}|\phi\rangle dt' = 2n\pi, \text{ with integer n and period T.} \qquad (3)$$

In the particular case of TDHF where the variational manifold is the determinantal manifold, the quantization condition (3) reduces to that of ref. [1] and to that of Reinhardt[3] and Levit, et al.[4]

Some applications and tests of this GIPQ method can be found in refs. [1,3-5] for TDHF approximation, and in ref. [6] for non-determinantal wave functions. We report here two new results which support the validity of the method at a deeper level. First, for the system of one particle in an harmonic oscillator potential, the GIPQ method with the oscillating minimum wave packets not only predicts the exact energy spectrum, but also maximizes the packets' overlap with the exact eigenstate. This exemplifies the method's capability of predicting good wave functions as well as energy eigenvalues.

Secondly, for collective rotations confined in a plane, the GIPQ method utilizing a many-body wave function assumed to be constant in a body-fixed frame, but otherwise arbitrary, yields quantization of the angular momentum $\langle L\rangle = I\hbar$ (integer I) and quantization of the rotation energy $E_{rot} = I^2\hbar^2/2\mathcal{I}$, in agreement with the exact quantum results for rotation in a plane. The GIPQ method therefore implies the nonperturbative cranking theory, except that the angular momentum is here already quantized and requires no additional assumption.

†Work supported in part by U. S. Department of Energy.

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DEFORMED NUCLEI AS A BOSON CONDENSATE

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In order to obtain a qualitative understanding of the structure of the ground state of deformed nuclei we consider a schematic hamiltonian (monopole and quadrupole pairing plus quadrupole particle-hole[1] hamiltonian) in a single shell with j=15/2. This hamiltonian was treated within the Nuclear Field Theory framework using the Principal Serie Approximation[2]. In this approximation the ground state of the system is considered as a boson condensate. The microscopic structure of this boson is obtained in terms of the fermionic excitations which are themselves dependent on the boson structure. These sets of nonlineal equations turn out to be equivalent to the selfconsistent Nilsson-BCS equations for this force.

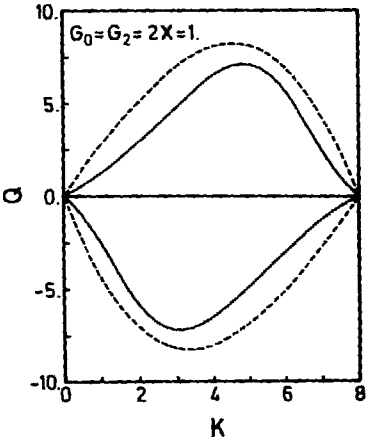
In the figure we show the selfconsistent expectation value of r^2Y_{20} (Q) obtained for different number of pairs (K) in the shell, in full line, while the dotted line correspond to Q for the normal system. There exist also a solution for Q=0. It is seen that the influence of the quadrupole pairing force is important in the description of the system, comparing with results of ref. 3). The relative strength of this force as compared to the usual pairing force, is the one used in ref. 1) for the ^{208}Pb region. The ground state of the system is formed by a condensate of bosons, each of which does not have a well defined angular momentum. However, it is possible to proyect out from them bosons with good angular momentum, with amplitudes:

$$A_J \approx \sum_{m>0} V_m \sqrt{\frac{2}{K}} \langle jj m\bar{m} | J0 \rangle \quad (-)^{j-m}$$

The corresponding probabilities for different K are shown in the Table. The sign in brackets refers to the corresponding sign of Q for the selfconsistent solutions. For Q=0 the only nonvanishing amplitud is for J=0.

The Table shows that the only relevant bosons, to a high degree of approximation are the s and d bosons, which can be considered as a justification for the use of the I.B.M. as a good approximation in the deformed region.

K \ J	0	2	4	6
1(+)	.9221	.0737	.0040	.0002
2(+)	.8687	.1141	.0166	.0006
3(+)	.8346	.1337	.0301	.0015
4(+)	.8165	.1391	.0403	.0036
1(-)	.6636	.2695	.0602	.0005
2(-)	.5785	.3252	.0854	.0085
3(-)	.6510	.3012	.0432	.0011
4(-)	.8618	.1217	.0149	.0001



[+]Fellow of the CONICET, Argentina

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PARTICLE-PHONON COUPLING MODEL APPLIED TO ^{89}Y AND ^{90}Y +

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Within the framework of the particle-phonon coupling model the ^{89}Y and ^{90}Y nuclei are considered to be a ^{88}Sr core coupled to a proton, and to a proton and a neutron, respectively. The interaction Hamiltonian for ^{89}Y is extended to include quasiparticles in the orbitals $1f_{5/2}$, $2p_{3/2}$, $2p_{1/2}$, $1g_{9/2}$ and $2d_{5/2}$. On the other hand, for ^{90}Y the proton space is restricted to the $2p_{1/2}$ and $1g_{9/2}$ orbitals. The neutron orbitals are $2d_{5/2}$, $3s_{1/2}$, $1g_{7/2}$ and $2d_{3/2}$. We considered core states up to two quadrupole phonons. The values of the diagonal matrix elements of the proton-neutron interaction Hamiltonian are considered adjustable parameters. The strengths of the dipole-dipole and quadrupole-quadrupole interactions were determined from the requirement that the calculated eigenvalues were the best fitted to the experimental states of both nuclei. In Fig. 1 the calculated energy sequences of both parities are compared with the experimental data of ^{89}Y. The calculated negative-parity states for ^{90}Y are compared with experiment in Fig. 2. It is to be noted that the high-spin states of ^{89}Y recently found[1] were omitted since they cannot be calculated at this stage of the model. Therefore we are now developing an extension of this model to include: (i) quadrupole and octupole core vibrations; (ii) anharmonicities of the core; and (iii) 2p-1h modes of excitation. The pertinent formalism is in progress.

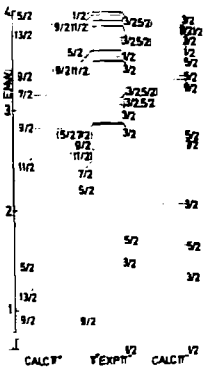


Fig. 1

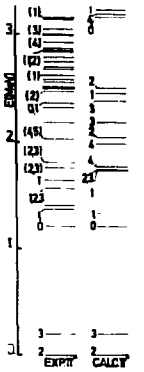


Fig. 2

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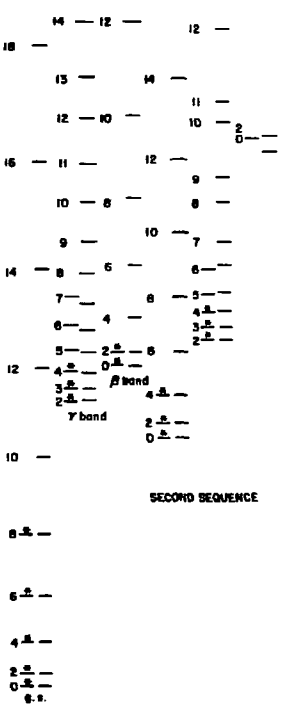
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THE ROTATION VIBRATION STRUCTURE OF ACTINIDE NUCLEI

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The extended rotation vibration model Hamiltonian consists of an asymmetric rotor coupled to deformation (β) vibrations together with an additional degree of freedom, regarded as quasi-boson, which is assumed but not treated explicitly. We have previously employed this model with success to explain the structure of the even-A Pd isotopes[1], and that of ^{196}Pt[2]. The assumed additional degree of freedom results in a spectrum which consists of several rotation vibration sequences which are very similar to the sequence containing the ground state. Such excited sequences were identified in the earlier applications. We undertook the study of several actinide nuclei to look for such sequences. We have been able to clearly identify a second sequence in all four U isotopes. The figure shows the most well-developed case, that of ^{234}U. The left-most line is the experimental level and the right is the theoretical prediction; the angular momenta are indicated. Starred levels were used in fitting to determine the five model parameters. The second sequence is rather well developed showing 5 levels of the γ band and the β band head. Both sequences were assumed to have the same stiffness, but it appears that the 2nd sequence should be slightly stiffer since the β band head is predicted slightly too low.



This model does remarkably well in predicting the locations of the high spin members of the yrast band. The predicted energies depend entirely on 3 of the 5 model parameters. The most well known experimentally is that for ^{238}U. The table shows the remarkable agreement between theory and experiment. The left column is the spin, next is the experimental energy in KeV, and last the theoretical energy in KeV.

0	0.0	0.0
2	44.9	44.9
4	148.4	148.4
6	307.2	307.5
8	517.8	517.4
10	775.7	776.4
12	1076.5	1076.8
14	1415.3	1415.7
16	1788.2	1786.0
18	2190.7	2186.9
20	2618.7	2613.9
22	3067.2	3064.3
24	3534.5	3535.8

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INTERACTING BOSON-FERMION MODEL OF COLLECTIVE STATES IN ODD-GOLD NUCLEI[†]

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Recently, an interacting boson-fermion model of collective states in odd-A nuclei has been proposed[1]. This model contains as limiting cases both the particle-vibration (weak-coupling) and Nilsson (strong-coupling) models. It also contains a new coupling scheme[2] which appears to be valid for describing the spectra of odd-A nuclei towards the end of major shells. These three limiting cases correspond to the SU(5), SU(3), and O(6) boson symmetries, respectively. We have explored the ability of this model to describe the $h_{9/2}$ bands in the odd-mass gold isotopes, where the boson structure is intermediate between O(6) and SU(3).

The calculations for this intermediate situation were performed using the code ODDA[3], which diagonalizes the model Hamiltonian given in ref.1. The boson part was fixed by requiring its eigenvalues to describe the adjacent even-even platinum nucleus. The boson-fermion interaction is particularly simple for an odd-proton in the $h_{9/2}$ (intruder) orbital since in this case the exchange term[1] is zero; and, the $j = 9/2$ states are not mixed with states of other j. The trend in the level sequence of the $h_{9/2}$ bands through the isotopes $^{185-193}$Au is described well (compared to ~40 experimental levels) with a single parameter Γ[1] (the boson-fermion coupling strength), which is equal to 300 keV for the entire region. This is the first successful description of the very neutron-deficient odd-mass nuclei in this extremely complicated[4] region of nuclear structure.

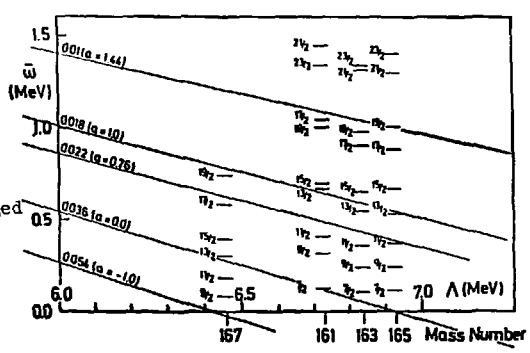
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RENORMALIZATION GROUP APPROACH TO THE ATTENUATION OF CORIOLIS COUPLING†

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The attenuation of the Coriolis coupling term in the rotational level is interpreted in terms of the scaling behavior of the coupling constant as the general consequence of the renormalizable field theory with cutoff.[1] The functional dependence of the coupling constant on the excitation energy and the cutoff energy is derived by applying the renormalization group method. On this systematics not only the attenuation factor but also the transition from the rotational to vibrational-like behavior are comprehensively understandable.[2] The linear dependence of the cutoff energy Λ on ϵ is assumed as $\Lambda = \hbar\omega(\epsilon)(0.156\epsilon + 0.42)$ MeV for Er isotopes. The attenuation factor, $a = 2\text{-}g^{inv}/g$, is calculated from the renormalized Coriolis coupling g^{inv}. The contour map of g^{inv} (or a) calculated for the odd-mass Er isotopes with the bare values $g = 1/\mathcal{J} = 0.018$ MeV and $g_z = 1/\mathcal{J}_z = 0.343$ MeV is shown in the figure. The abscissa stands for the value $\bar{\omega} \equiv g[I(I+1) - I_0(I_0+1)] - \omega_{exp}$, where ω_{exp} is the level energy measured from the band head at $I = I_0$; and the ordinate the cutoff energy Λ. The experimental levels of the corresponding isotopes are also indicated. The line of a = 0 stands for the measure of the strong coupling, a = 1 the decoupled band, and a = 0.76 the averaged attenuation factor over $Er^{161, 162, 163}$.[3] It is predicted that the Coriolis coupling is less attenuated with increasing excitation energy[4], and the decoupled bands are expected at the high spin states in ^{164}Er. In case of ^{167}Er the strong coupling is predicted at low value of $\bar{\omega}$.



† The work supported by the Bundesministerium für Forschung und Technologie (BMFT).
†† On leave from Department of Physics, Saitama University, Urawa, Saitama, Japan 338.

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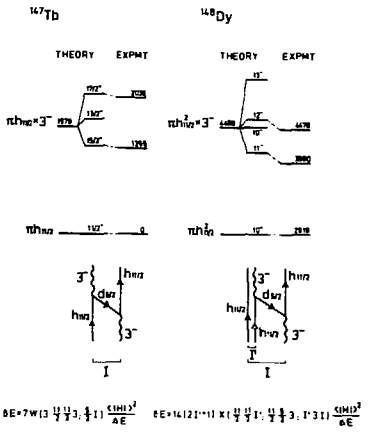
TWOPARTICLE-PHONON EXCHANGE COUPLING IN YRAST STATES OF DYSPROSIUM NUCLEI

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In-beam γ-ray and e^- studies of the N=82 and N=83 nuclei ^{148}Dy and ^{149}Dy have shown that their 10^+ and $27/2^-$ isomers, both involving two fully aligned $h_{11/2}$ protons, are mainly fed by E1 transitions of ∿1MeV. The relevant portion of the ^{148}Dy level scheme is shown in the figure. At I=10, the ^{148}Dy valence spin is exhausted, and the yrast line is expected to continue by excitation of an octupole multiplet built on the $\pi h_{11/2}^2$ 10^+ state. The ΔI=1 multiplet member at 3980 keV lies lowest because of the Pauli interference between the dominant $\pi h_{11/2} d_{5/2}^{-1}$ component of the ^{146}Gd core octupole and the two aligned $h_{11/2}$ protons.

Recently we have analysed[1] the related but simpler situation in the one valence proton nucleus ^{147}Tb. The figure shows the appropriate particle-phonon exchange diagrams and, for each nucleus, the equation giving the energy shifts δE(I) for individual multiplet members as a product of geometrical and energy factors. The crucial point is that the energy factor $\langle|H|\rangle^2/\Delta E$ containing the interaction matrix element is identical in the two cases. Using for that energy factor the empirical value 856 keV, derived from the $17/2^+$ to $15/2^+$ energy separation in ^{147}Tb, we have calculated the energy shifts for the highest spin members of the ^{148}Dy $\pi h_{11/2}^2 \times 3^-$ multiplet. The good agreement with the experimental 11^-, 12^- energies provides strong support for the interpretation of these states as octupole multiplet members. This type of exchange coupling involving two particles seems not to have been observed previously; it is encouraging that the empirical coupling strength derived from the one-particle case describes the more complex situation so well.



A $29/2^+$ yrast level in ^{149}Dy at 3645 keV, which de-excites to the $27/2^-$ isomer, is interpreted in an analogous way, and similar ΔI=1 octupole excitations are also identified in the yrast lines of heavier Dy nuclei. In all cases they are built on yrast states in which all available $\pi h_{11/2}$, $\nu f_{7/2}$ and $\nu h_{9/2}$ valence spins are exhausted and fully aligned. The fact that octupole core excitation competes successfully with lifting of a neutron into the $i_{13/2}$ single particle state indicates that the $\nu i_{13/2}$ single particle energy is rather high, and has implications for the yrast spectroscopy of many nuclei in this interesting region.

†Supported by the U.S. Department of Energy

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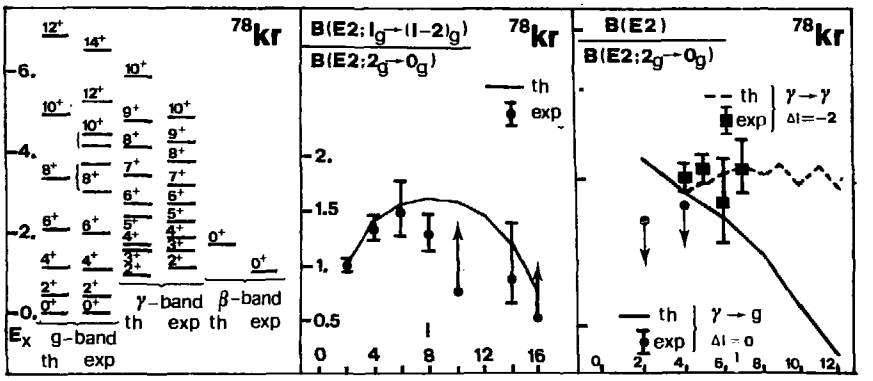
MICROSCOPIC TREATMENT OF THE INTERACTING BOSON MODEL IN THE FRAMEWORK OF THE NUCLEAR FIELD THEORY †

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* INFN, Laboratori Nazionali di Legnaro, Italy
** University of Padova and INFN, Padova, Italy

The nuclear field theory is extended to complex nuclei showing strongly anharmonic spectra, aiming at a better understanding of the dynamical interplay of pairing and quadrupole degrees of freedom and of the mechanism of formation of different bands. The building blocks used to describe the spectra of even-even nuclei are the monopole and quadrupole pairing modes, obtained in a single j shell and determined by their energies and particle vibration coupling strengths and interacting via a quadrupole particle-hole interaction. All the lowest order graphs in the expansion parameter $1/\Omega$ (where Ω is the total degeneracy of the valence shell) leading to the interaction between the bosons have been considered. In case that the d-bosons do not interact in lowest order with the s-bosons, the next order graphical contributions have been included. The fermion degrees of freedom are taken into account as intermediate states, and Pauli principle corrections and overcompleteness of the basis are systematically treated. It is shown that this approach is equivalent to diagonalizing the pairing plus quadrupole hamiltonian in the fermion collective subspace built up from L=0 and L=2 nucleon pairs.

The model is able to exhibit the main characteristic features of transitional nuclei, as the structure of the ground- and γ-bands and associated excitation pattern, while the poor results for the excited 0^+ indicates that the many-j shell structure is important for the formation of the β-band. As an example in the figure the calculated spectrum and selected electromagnetic transition probabilities for ^{78}Kr are compared with the experimental data.



As the model treats bosons and fermions on par, the extension to odd nuclei is natural. The problems connected with the use of a large single j value (unpracticable in the case of the odd particle) is overcome by using a schematic model with many degenerate j shells.

† Part of a common project carried out in collaboration with R.A.Broglia, K. Matsuyanagi and H.M. Sofia.
For a survey of the Interacting Boson Model, see "Interacting Bosons in Nuclear Physics", ed. F. Iachello, Plenum Press, 1979.
For the Nuclear Field Theory cf. P.F.Bortignon, R.A.Broglia, D.R.Bes and R. Liotta, Phys. Rev. 30C (1977) 305, and references therein.

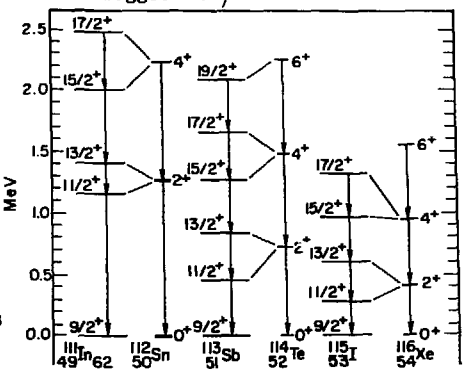
THE SYSTEMATICS OF THE ΔJ=1 BANDS IN THE Sn-REGION, EVIDENCE AGAINST THE PARTICLE + DEFORMED ROTOR MODEL *

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The pioneer work on high spin yrast states in odd-A nuclei carried out at Berkeley revealed a simple connection between the band structure of the odd-$_{57}$La isotopes and their $_{56}$Ba even-even cores. For these slightly deformed nuclei, a particle + rotor model was suggested by them. [1] However, it can be shown that the systematic study of odd-A nuclei with $49 \leq Z \leq 57$ carried out at Stony Brook [2] is inconsistent with this model. In this short note we deal with one more [3] simple illustration of the inapplicability of this model to slightly deformed nuclei. In the particle + rotor model one is forced to assume that the ΔJ=1 bands built on the $g_{9/2}$ hole state in this region involve a different core than the ΔJ = 2 band. A deformed core with multiple particle two hole structure has also been suggested. [2]

For the discussed ΔJ = 1 bands, it is easy to see [4,5] that, in first order, the coupling of a core angular momentum $-J_c$ to that of the single particle $-j_\pi$ yields a multiplet of states in which the $j_\pi + J_c - 1$ state appears below the J_c core state and the $j_\pi + J_c$ state appears above the J_c core state. This is clearly manifested in the figure. For the nuclei discussed, this first order statement arises from trivial angular momentum algebra. [4]



The ground state of ^{111}In arises mainly from a $g_{9/2}$ proton hole coupled to the ground state of a ^{112}Sn core. These ΔJ=1 bands follow the energy of the Z + 1 core smoothly. The observation of a ΔJ = 1 band in In isotopes built on the $g_{9/2}$ hole ground state is inconsistent with the assumption of a deformed band. Furthermore, the smooth systematic behavior of these $49 \leq Z \leq 53$ isotones with respect to their Z + 1 cores is inconsistent with the assumption of a special deformed core for Sb and I isotopes.

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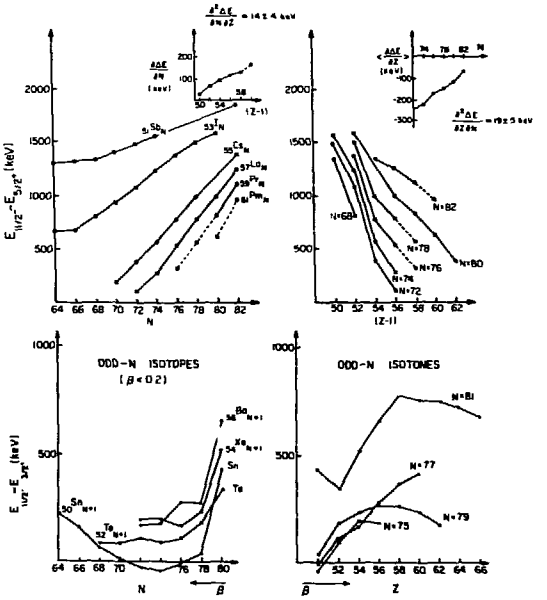
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IS THE NILSSON MODEL APPLICABLE FOR SLIGHTLY DEFORMED NUCLEI?*

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The $h_{11/2}$ intruder state in the $Z \geq 50$ region, is characterized by a large RMS radius, non normal parity and in some cases a large single particle energy. Hence, a systematic study of the variation of the energy of this state is important to the understanding of the structure of this state and the high spin bands built on the top of this state. The systematic behavior of the energy differences of this state relative to a reference state (usually the ground state) is shown in the figure. Derivatives of the experimental ΔE curves for the proton states yield an empirical linear behavior: $\Delta E = a_0 + an + bz + cnz$. This behavior is well understood in terms of the generalized seniority scheme.[1] For the neutron holes states, all the isotopes and isotones show a strikingly different dependence of the energy on the deformation. Indeed, no single dependence of single particle energies on the deformation parameter can be assumed for these four related trends of single particle energies, in contradiction to the assumption of the first order particle-deformation approximation.[2] The deformation parameter is estimated[2] to be $\beta \leq 0.2$ for these nuclei. In the pioneer study of the structure of high spin states in odd-La nuclei carried out at Berkeley it was suggested that the particle + symmetric rotor model can be applied to slightly deformed nuclei.[3] In this model the particle is assumed to occupy a Nilsson orbit with unique Ω value.[3] The systematics of the $11/2^-$ state in the region considered here contradict this assumption. A resolution of this apparent contradiction is required in order to understand the structure of slightly deformed nuclei and the phenomena of high spin band which are built on top of these single particle states with high j value.



* Supported by the U.S. Department of Energy and the National Science Foundation

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MICROSCOPIC LOOK AT BACKBENDING IN THE Ge REGION*

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Shell-model calculations of high-spin phenomena in ^{68}Ge, assuming ^{56}Ni as an inert core with $f_{5/2}$ $p_{3/2}$ $p_{1/2}$ negative parity (normal, N) and $g_{9/2}$ (abnormal, A) valence orbitals, are reported. Further truncation of the basis is achieved by assigning the N orbitals pseudo angular momentum and spin labels via the mapping $(f_{5/2}\ p_{3/2}\ p_{1/2}) \rightarrow (\tilde{d}_{5/2}\ \tilde{d}_{3/2}\ \tilde{s}_{1/2}) = (\tilde{ds})$ with $\ell + s = j = \tilde{\ell} + s$ and restricting the basis to leading representations of pseudo SU(3).[1] The mapping carries physical significance for H and is strongly correlated with $\tilde{Q}\cdot\tilde{Q}$, an invariant of pseudo SU(3).[2] A five-dimensional quasispin classification scheme is used in the A space with the basis restricted to states of seniority zero and two.[3]

The effective interaction is of the form

$$H = A \sum_i \ell_i^2 + \epsilon_{9/2}\, n_A + G_N H^N + G_A H^A + G_M H^M + G_P H^P$$

where the first two are one-body terms and the last four two-body interactions. For the latter a surface delta interaction is used. While H^N and H^A are interactions in the N and A spaces, respectively, H^M and H^P are multipole and pair scattering terms coupling the two.

Results with the number of nucleons in the N and A spaces fixed ($G_P \rightarrow 0$) are available. In this limit the observed backbending between spins 6^+ and 8^+ of the yrast band in ^{68}Ge can be reproduced but only one of the two forks to other 8^+ states is found.[4] A plot of the probability of finding the $g_{9/2}$ nucleons coupled to nonzero spin as a function of total spin shows that the dynamics responsible for the phase transition is pair realignment. A calculation which allows for pair scattering (neutrons or protons) between the N and A spaces is under investigation.

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* Supported in part by grants from the U.S. NSF.

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YRAST STATES IN ^{211}Rn: INFLUENCE OF THE NEUTRON HOLE ON THE 4-PROTON STATES

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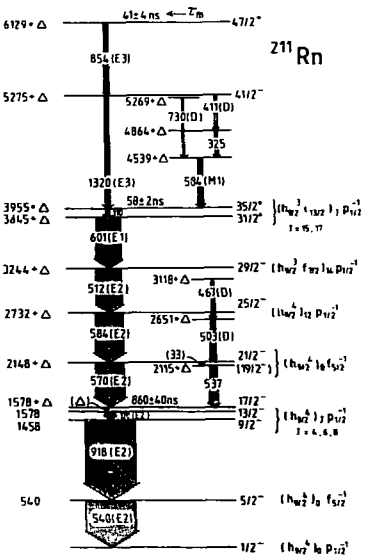
and

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We have established the properties of the yrast levels of ^{211}Rn up to $J^{\pi} = 47/2^{+}$ and to an excitation energy of over 6 MeV. The ANU 14UD pelletron accelerator provided beams of ^{11}B ions (E ~ 70 MeV) and ^{18}O ions (E ~ 95 MeV) which were used to initiate the ^{205}Tl (^{11}B, 5n)^{211}Rn and ^{198}Pt(^{18}O,5n)^{211}Rn reactions respectively. Standard γ-ray spectroscopic techniques which were used included γ-γ, γ-neutron, γ-x-ray and n-x-ray coincidence and delayed coincidence measurements, excitation function - , angular distribution - and conversion coefficient measurements. The level diagram summarises the results of the investigations. Relative γ-ray intensities as observed in the ^{11}B bombardment are indicated by the widths of the arrows. Multipolarities and spin changes are indicated in brackets after the γ-ray energy. (The symbol, D, indicates a dipole transition with the parity change undetermined). Level spins are consistent with all the different measurements performed. Three isomers have been detected and their mean lives determined while suggested configurations, consistent with the known systematics and with the assigned J values are given on the right of the diagram. The configurations giving rise to the highest states are at present uncertain. Shell model calculations are being undertaken. When plotted against I(I + 1), the yrast state energies scatter about a straight line whose slope corresponds to an effective moment of inertia $2\hbar^2$ of 105 MeV^{-1}. This is larger than that observed in the 4-proton nucleus ^{212}Rn[1]) at low spin, and there is no indication (at least up to the highest spin observed here) of a transition to a moment of inertia close to the rigid body value, as was seen in ^{2} n.



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GAMMA SPECTROSCOPY OF HIGH SPIN STATES IN ^{40}K, ^{42}Ca, ^{55}Fe AND ^{56}Fe

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Extending our recent gamma-spectroscopic work on high spin states in $^{34,37}Cl$ [1]) we have investigated high spin states in ^{40}K, ^{42}Ca, ^{55}Fe, ^{56}Fe by the reactions $^{27}Al(^{19}F,xyz\gamma)$ and $^{46}Ti(^{13}C,xyz\gamma)$ at the Heidelberg MP tandem. Using an Anticompton spectrometer device $\gamma\gamma$ coincidences and angular distributions were measured at E_{lab} = 72 MeV and 49-55 MeV, respectively. An excitation function was measured for $^{27}Al(^{19}F,xyz\gamma)$ between E_{lab} = 50 and 110 MeV. The bombarding energies at which the coincidence measurements have been performed were expected, on the basis of CASCADE calculations, to give the highest selectivity for the excitation of high spin states (see e.g. [2])). Figure 1 shows the level scheme obtained for ^{42}Ca. In ^{40}K J = $(8)^-$ is assigned to the

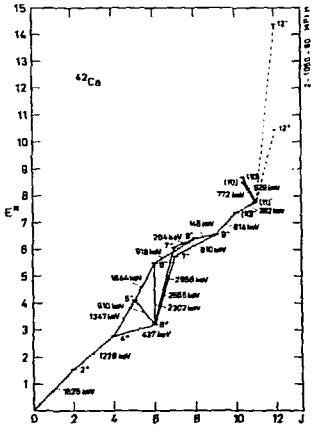


Figure 1 (left): Level scheme of ^{42}Ca. The dashed lines show predictions of weak coupling calculations.

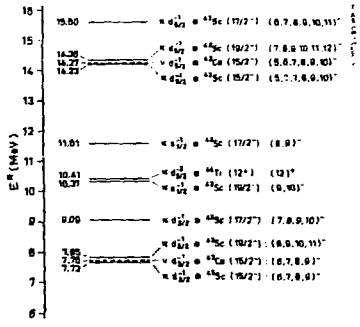


Figure 2 (l.): Level scheme of ^{42}Ca expected from weak-coupling calculations.

6.23 MeV state and J = (9) to a new state at 7.48 MeV. In $^{55,56}Fe$ two new states at E^* = 7.60 MeV (decaying to the 6.52 MeV (J = 21/2) state) and E^* = 7.08 MeV (decaying to the 6.11 MeV state), respectively, have been identified up to now. The fact that experimentally higher lying states in ^{40}K and ^{42}Ca are not seen might be understood as follows. Figure 2 shows predictions of simple weak coupling calculations for ^{42}Ca. Multiplets from one-nucleon excitation generating spins less than 9 are dropped. The lowest J^π=12$^-$ state in this configuration is expected at $E^* \approx$ 14.4 MeV. Three-nucleon excitations lie $\sim$3 MeV higher than the corresponding one-nucleon excitations. The lowest lying J^π=12$^+$ state which is produced by the $(\pi d_{3/2}{}^{-2})_{0^+} \otimes {}^{44}Ti(12^+)$ configuration is expected at $E^* \simeq$ 10.4 MeV. However, the matrix element for an E1 transition to the 11$^-$ state vanishes. The J^π=9$^+$ yrast state in ^{40}K, at E_{lab} = 100, is fed by more than 90% from unobserved high spin states.

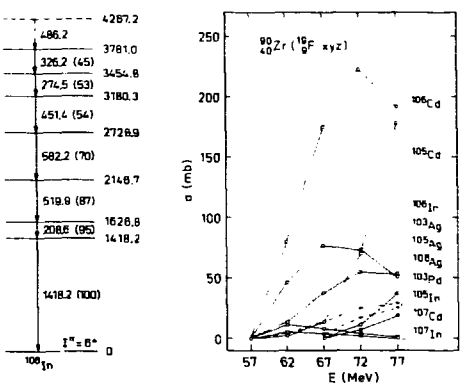
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INVESTIGATION OF HIGH SPIN STATES IN ^{106}In AND ^{106}Cd

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High spin states in odd $^{101-105}$Pd and even $^{102-106}$Pd isotopes are well understood[1,2]) by a one(two)-quasiparticle plus rotor model. This was somewhat surprising because the deformation of the cores of the Pd nuclei is very small. In this context an investigation of high spin states in ^{106}Cd and ^{106}In is of interest to study the influence of approaching the Z=50 proton shell closure on the coupling scheme. The reaction ^{90}Zr(^{19}F,xyzγ) was studied by measuring γγ coincidences, γ-angular distributions and excitation functions (for E_{lab} = 62-82 MeV) with three Ge(Li) detectors one of which had an Anticompton shield. In ^{106}Cd rotational bands built on the ground state and the $(\nu h^2_{11/2})_{10^+}$, $(\nu h_{11/2}d_{5/2})_{8^-}$, $(\nu h_{11/2}g_{7/1})_{9^-}$ band heads were observed[3]). To the state at E^+ = 3044 keV we assign $I^\pi = 6^+$ instead of the 8^+ assignment of ref. [4]). For ^{106}In there existed only information[5]) from the β^+ decay of the ground state ($I = 0^+$) of ^{106}Sn, i.e. on low spin states which were not excited in the heavy ion reaction. From the strongest γ transitions the level scheme shown in Fig. 1 (l.) is constructed. The assignment of these lines to the nucleus ^{106}In was made by comparing the measured excitation functions with CASCADE calculations (the latter are shown in Fig. 2 (r.)). An additional argument for strong population of ^{106}In in this reaction comes from the observed strong β^+ feeding of ^{106}Cd [3]). The level scheme of ^{106}In differs qualitatively from that of the neighboring even-even Pd and Cd isotopes and probably can better be explained by a two-quasiparticle phonon model with an Sn core.



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SEARCH FOR THE GAMMA DECAY BRANCH OF THE SHAPE ISOMER IN MUONIC ^{238}U[†]

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The possibility of excitation of the ^{238}U shape isomer by the atomic cascade of a negative muon has been investigated by a search for the gamma decay branch. Delayed gamma rays from muon capture in uranium were suppressed by requiring the candidate gamma ray to be followed by another gamma ray within a time interval typical of the nuclear muon capture lifetime. Backgrounds were further reduced through the use of a muon beam from which the pions and electrons had been electrostatically separated. From a sample of 10^{10} muon stopping we observed 2×10^{7} candidate gamma ray followed by a second gamma, of which 5×10^{5} occurred in a time interval 5 ns to 35 ns after the muon stopping. No evidence, at a yield level of 0.2% per muon-stopping, was seen for the 2215 kev and 3131 kev gamma rays reported by Fromm et al.[1])

[†]This work was supported by the Natural Science and Engineering Research Council of Canada under grant IEP-11, and by the U.S. Department of Energy under contract W-7405-ENG-48.

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NUCLEAR FISSION INDUCED BY ATOMIC TRANSITIONS OF THE MUON IN ^{235}U AND ^{238}U[†]

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When a negative muon is captured into the atomic orbit of a uranium nucleus it undergoes an atomic cascade, ordinarily reaching the muonic K shell through radiative transitions. Prompt nuclear excitation also occurs, arising from non-radiative atomic transitions by some of the cascading muons. Approximately 1% of the atomically captured muons produce prompt fission by this process.[1])

Teller and Weiss[2]) have recently pointed out that it would be interesting to know the specific atomic transition, or transitions, responsible for such prompt fissions, inasmuch as absolute rates from particular transitions (i.e. 2p-1s, 3p-1s, 3d-1s) can give both quantitative measurement of electromagnetic coupling to the giant dipole and giant quadrupole resonances and, if combined with careful model calculations of the muon-perturbed fission barrier, may permit improved determination of the barrier height, and therefore also improved estimates of the likelyhood of such excitation also populating the second well.

We have measured the time correlation between muon-induced fission (detected in a multiplate fission chamber) and muonic x-rays (detected with three large, 5in D x 6in, NaI crystals). Very preliminary analysis on the ^{238}U data appears to show that the prompt fissions are all missing when fissions are correlated with K_α x-rays; but all, or nearly all are present when correlated with L_α x-rays. These preliminary results suggest therefore that it is the electric-dipole interaction between the atomic muon and ^{238}U that plays the major role in producing prompt fission.

Full quantitative results together with interpretations for both ^{238}U and ^{235}U will be presented.

[†]This work was supported by the Natural Science and Engineering Research Council of Canada under grant IEP-11, and by the U.S. Department of Energy under contract W-7405-ENG-48.

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PARITY VIOLATION EFFECTS IN FISSION

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ABSTRACT

P-odd asymmetry of fission fragments has been observed in polarized thermal neutron induced fission of ^{233}U, ^{235}U and ^{239}Pu. The asymmetry coefficients turned out to be:

$$a(^{234}U) = (3.8 \pm 0.2) \cdot 10^{-4}$$
$$a(^{236}U) = (1.1 \pm 0.2) \cdot 10^{-4}$$
$$a(^{240}Pu) = (-7.4 \pm 0.5) \cdot 10^{-4}$$

The positive sign of the asymmetry means that the light fragments are predominantly emitted in the direction of neutron-spin orientation.

A possible mechanizm of appearing P-odd angular correlation in fission is discussed.

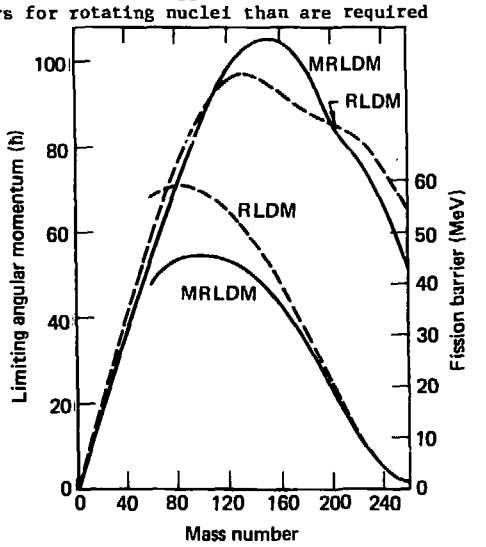
MODIFIED ROTATING LIQUID-DROP MODEL: FISSION BARRIERS, ANGULAR MOMENTUM LIMITS, AND FUSION-FISSION YIELDS*

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We report on the differences in the predictions of our modified rotating liquid-drop model (MRLDM) and the rotating liquid-drop model (RLDM) of Cohen, Plasil, and Swiatecki[1]. We compare fission barriers and the angular momentum limits, where fission barriers go to zero. The implications of these results to the understanding of fusion-fission yields in heavy-ion reactions are discussed with calculations for selected reactions. Unlike RLDM, our model incorporates the effects of finite range of nuclear force and the diffuse nuclear surface, as in the Yukawa-plus-exponential model of Krappe, Nix, and Sierk[2].

The motivation for our work comes from the suggestion that RLDM may be calculating higher fission barriers for rotating nuclei than are required to understand fusion-fission data[3]. In addition, this study provides an alternate and perhaps an improved macroscopic model for rotating nuclei.



We have calculated fission barriers of rotating nuclei in this modified model. The calculation covered the mass range from 20 to 260 and the angular momentum range from zero to the limiting value.

Some of the results of our calculation are compared in the figure with the predictions of RLDM. The two upper curves (left-hand scale) represent the limiting angular momentum of beta-stable nuclei. The two lower curves (right-hand scale) compare fission barriers at zero angular momentum. The results are summarized as follows: Our model predicts a lower value for the limiting angular momentum for $A < 110$ and $A > 200$. The fission barriers are also lower in our model, except near the limiting angular momentum for $110 < A < 200$. We find up to 25 per cent difference in the predictions of the two models. This uncertainty limits our present ability to reproduce fusion-fission yields in heavy-ion reactions. We shall show calculated yields for selected reactions.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.
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DYNAMICAL EFFECTS IN THE NEUTRON INDUCED FISSION OF ^{232}Th

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The fission fragment properties - total kinetic energy, mass distribution and average number of prompt neutrons emitted per fission ($\bar{\nu}_p$) - were investigated for the fission of ^{232}Th by neutrons near threshold. In this energy region, the fission cross section exhibits large resonances, interpreted as due to vibrational states probably located in a third well of the fission barrier [1].

The experiments were performed using the 4 MV Van de Graaff accelerator of BRC as a monoenergetic neutron source, with an energy resolution of about ± 20 keV. The fission fragment kinetic energy and mass distributions were determined according to the method of Schmitt. A very high relative accuracy - about 0.05% - was obtained for the kinetic energy [2]. The average number $\bar{\nu}_p$ of neutrons emitted per fission was measured in a separate experiment using a large gadolinium loaded liquid scintillator [3].

The data from both experiments are very consistent. They reveal a sharp change in behaviour near the neutron energy E_n = 2.4 MeV. This energy also corresponds to a minimum in the fission cross section above which the well resolved resonant structure disappears.

Below E_n = 2.4 MeV, one observes variations of the kinetic energy and the number $\bar{\nu}_p$ correlated with the structures observed in the fission cross section and the fission fragment angular distribution. This feature leads us to look for an interpretation in terms of a fission channel effect.

For this purpose, a channel analysis of the fission cross section and the fission fragment angular distribution has been performed with a simultaneous calculation of all the neutron cross sections (total, elastic and inelastic scattering and capture). The calculation code used is based on the Hauser-Feshbach formalism. The fission penetrabilities are calculated in the framework of a triple humped barrier shape, assuming that the first hump is well below the neutron binding energy and thus does not have any influence. From these calculations the correlations between the fission channels and the measured fission fragment characteristics will be discussed.

In the final conclusion, we propose an explanation of all these results based on the hypothesis of a nearly adiabatic behaviour of the ^{233}Th fission process.

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STUDY OF THE ENERGY DISSIPATION IN THE FISSION INDUCED BY THE $^{233}U(d,pf)$ REACTION

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Dynamical descriptions of the fission process deal with the coupling of internal and collective degrees of freedom of the system on the descent from saddle to scission points. The former are associated with the intrinsic excitations of the fragments (E_{int1}, E_{int2}); the latter with the pre-scission kinetic energy E_{Kpre}. Three quantities can be determined experimentally : the total kinetic energy TKE* and the excitation energies (E_{X1} and E_{X2}) of the fragments prior to neutron emission. For a pair of primary fragments with masses and deformation parameters at the scission point m_i^*, β_i (i=1,2), we can write :

$$E_{Xi} = \Delta V(\beta_i) + E_{inti} \qquad \text{and} \qquad TKE^* = E_{CR}(\beta_1,\beta_2) + E_{Kpre}$$

where the $\Delta V(\beta_i)$ are the deformation potential energies of the fragments relative to their ground states and $E_{CR}(\beta_1,\beta_2)$ the coulomb repulsion energy.

The energy balance in the fission of ^{234}U has been investigated on the basis of experimental results from the $^{233}U(d,pf)$ reaction [1]). Taking into account the neutron evaporation we have deduced the total kinetic energy TKE* and the excitation energy distributions of the primary fragments as functions of the masses and the ^{234}U excitation energy ($5.7 \leqslant E_{exc} \leqslant 9.7$ MeV).

Assuming spheroidal fragment shapes at scission, $\Delta V(\beta_i)$ and $E_{CR}(\beta_1,\beta_2)$ were calculated in the framework of the droplet model and including the semi-empirical shell corrections of Myers and Swiatecki [2]). An adjustable neck distance between the spheroids was kept constant and equal to 1.2 fm for all the mass divisions and the whole ^{234}U excitation energy range.

Since the fission process is, even during the last stage, very slow, the nuclear temperature of both fragments are equal ; it may be expected that $E_{int1} \simeq E_{int2} \simeq \eta/2$.

Assuming, in a first step , that E_{Kpre} does not vary with E_{exc} we have deduced the variation of $\delta\eta/\delta E_{exc}$ as a function of the heavy fragment mass m_H^* (fig.1). It appears that this slope is very close to unity except in two mass regions $117 < m_H^* < 125$ and $132 < m_H^* < 136$. The large value of the slope reflects a large dissipation to internal excitation. Furthermore for any hypothesis on the variation of E_{Kpre} with E_{exc}, both fragments from these two mass regions presents large changes in β_1 and β_2, tending to reduce shell effects.

In conclusion, it has been shown that, in low energy fission, a part of the excess of excitation energy of the fissionning nucleus is dissipated to internal excitation energy involving a fast decrease of shell effects for fragments in the vicinity of closed shell nuclei.

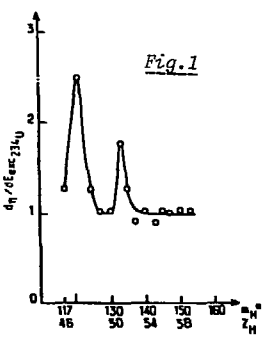


Fig.1

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INFLUENCE OF FRAGMENT SHELL EFFECTS IN THE FISSION OF THE ^{240}Pu COMPOUND SYSTEM.

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Energy correlation measurements were performed for ^{240}Pu s.f., $^{239}Pu(n_{th},f)$ and the photofission of ^{240}Pu with 12, 15, 20 and 30 MeV bremsstrahlung.The photofission cross section for ^{240}Pu was determined up to 30 MeV,enabling the calculation of the average excitation energy of the compound nucleus. For photofission of ^{240}Pu,in which predominantly $J^{\pi} = 1^-$ states are excited, the variation of the average total fragment kinetic energy $\langle E_k \rangle$ with the average excitation energy of the compound system $\langle E_{exc} \rangle$ shows an identical decrease as found in $^{239}Pu(n,f)$ at lower excitation energy. The $\langle E_k \rangle$ value for ^{240}Pu s.f. is 1.1 ± 0.5 MeV higher than the value for $^{239}Pu(n_{th},f)$. From an analysis of the different $\langle E_k \rangle(m^*)$ curves,giving $\langle E_k \rangle$ as a function of the fragment mass m^*, follows that the decrease of $\langle E_k \rangle$ in photofission can be attributed to a diminution of the influence of the spherical N=82 neutron shell at higher excitation energies, leading to fragments with more deformed shapes as pointed out in the scission point model of Wilkins et al.[1] The observed constancy of $\langle E_k \rangle(m^*)$ with $\langle E_{exc} \rangle$ for strongly asymmetric mass splits,where shell effects are of minor importance,is consistent with a weak coupling of the fission mode to quasiparticle excitations. The values of $\langle E_k \rangle(m^*)$ in $^{239}Pu(n_{th},f)$ are systematically about 1 MeV higher than for ^{240}Pu s.f. except in the region around the heavy mass 134, where a 2 MeV lower value is observed. An apparent asymmetry (coefficient of dissymmetry $\mu_3/\sigma^3 = -0.52$), present in the kinetic energy distribution for ^{240}Pu s.f. for these mass splits, is strongly reduced in $^{239}Pu(n_{th},f)$ ($\mu_3/\sigma^3 = -0.35$). This can be explained in the scission point model of Wilkins et al[1] by a slight increase of the intrinsic temperature, reducing shell corrections. This is also confirmed by the strong decrease in $^{239}Pu(n_{th},f)$ of the structures observed in the overall mass distribution for ^{240}Pu s.f. This mass distribution shows an abnormally high peak yield(7.3%) around heavy mass 134 and a prominent shoulder around mass 142, which can be attributed to the spherical N = 82 and deformed N=88 neutron shell respectively.

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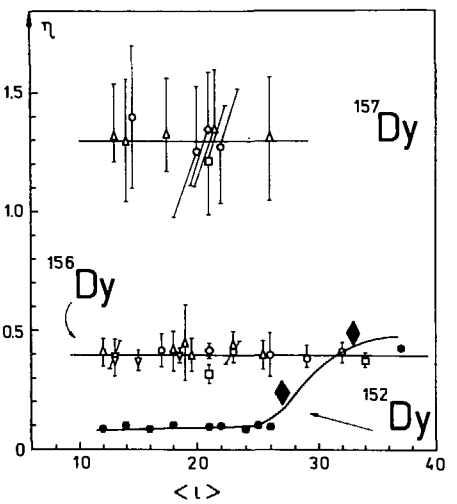
K-SHELL IONIZATION YIELDS FOR (h.i, xn) REACTION PRODUCTS

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The ionization yields, η, expected from the K internal conversion of observed discrete γ-ray transitions, are analyzed as functions of the average angular momentum, $\langle l \rangle$, in the exit channel of several (h.i, xn) reactions. Fig. 1 shows the results for the ^{152,156,157}Dy final products. The $\langle l \rangle$ values are taken from the measured [1] average γ-ray multiplicities, $\langle M \rangle$, assuming $\langle l \rangle = 2\langle M \rangle - 4$. Alternatively, they are obtained from the calculated l_{max} values assuming the relationship $\langle l \rangle$(exit channel) = 2/3 l_{max}(total) to hold for bombarding energies corresponding to the maximum cross-section for the exit channel considered. The two points marked with ◆ are estimates from published data, the remaining ones are from this work. It is seen that for the nuclei with regular rotational level spacings, ^{156,157}Dy, the ionization yields are practically independent of the reaction used. In contrast, a sharp increase in η with $\langle l \rangle$ is observed for the ^{152}Dy nucleus which has irregular yrast line and several low energy transitions at high spins.

In most cases studied the values summed over all the possible (h.i, xn) exit channels exhaust the total K-X-ray yields. This fact can be used to set upper intensity limits on all the unobserved ionizing processes [2], especially such as the low energy magnetic dipole transitions in the quasi-continuum γ-ray cascades.



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THE POPULATION OF FISSION ISOMERS IN (γ,n) and (γ,2n) REACTIONS *

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The low angular momentum transfer in photonuclear reactions is favourable for the investigation of fission isomers. In particular for even-odd nuclei, where low lying single particle excitations may cause spin isomers in the second well of the double humped fission barrier, a measurement of the population of these isomers in photonuclear reactions provides information on the spins of the levels involved[1].

The experiments were performed at the bremsstrahlung facility of the Giessen electron accelerator (E_{BS}=45 MeV) using pulsed beam techniques (pulse width variable between 6ns and 2µs) and large area transmission parallel plate avalanche detectors (PPAD). The results are summarized in table 1.

A statistical model analysis of the relative populations of the double isomers in the odd Pu-isotopes gave the following results. For ^{237}Pu a most probable spin assignment 11/2-5/2 for the long and shortlived isomer was evaluated. In ^{239}Pu a fission decay of the shortlived isomer[2] ($(2.6^{+4.0}_{-1.2}$ns)) could not be observed definitely in our experiments. The analysis for ^{241}Pu is complicated because of the unknown branching ratio of the electromagnetic and fission decay of the 34ns isomer.

Cross sections for isomeric fission were evaluated using absolute cross sections for prompt photofission or extrapolations. The results are compared with a systematic reported by Borggreen[3] to get information on the barrier parameters E_B and E_{II}.

Reaction	Isomer	Halflife	Yiso / Ypr.	Detect.
^{232}Th(γ,xn)	-	-	< 10^{-6}	PPAD
^{235}U (γ,xn)	-	-	< 10^{-7}	PPAD
^{238}U (γ,2n)	^{236}U	(115±5) ns	(2.02±0.16) · 10^{-5}	Si
		(118±7) ns	(2.10±0.16) · 10^{-5}	PPAD
^{239}Pu(γ,2n)	^{237m1}Pu	(77±16) ns	(6.4±1.7) · 10^{-6}	Si
		(87±11) ns	(4.9±0.7) · 10^{-6}	PPAD
	^{237m2}Pu	(1050±400) ns	(0.83±0.22) · 10^{-6}	Si
^{240}Pu(γ,n)	^{239m1}Pu	(6.5±0.4) µs	(7.9±0.4) · 10^{-5}	PPAD
	^{239m2}Pu ?	(4.5±1.5) ns	< 1.1 · 10^{-4}	PPAD
^{242}Pu(γ,n)	^{241m1}Pu	(20.5±2.5) µs	(9.2±0.8) · 10^{-5}	PPAD
	^{241m2}Pu	(34±7) ns	(3.7±0.7) · 10^{-5}	PPAD

Table 1: Populations of fission isomers measured at Giessen

* supported by the Deutsche Forschungsgemeinschaft
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STUDY OF HIGH-SPIN STATES IN THE NICKEL REGION WITH THE (d,α) REACTION AT 80 MeV†

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It is well known that in two-nucleon transfer reactions, like (α,d)[1] or (d,α),[2] stretched-configuration, high-spin states are preferentially excited because of the geometrical coefficients in the structure factor[3] and momentum mismatch conditions between the entrance and exit channels. This feature has been used in the present (d,α) reaction on ^{58,60,62}Ni to locate high-spin states in ^{56,58,60}Ni in which a transferred proton-neutron pair in the $(1f_{7,2})^2_{7,0}$ configuration is coupled to the unperturbed target nucleus as a core. Such transitions are characterized by an orbital angular momentum transfer of L=6.

A 80 MeV deuteron beam from the Indiana University Cyclotron Facility was used for carrying out the present experiment. The outgoing α-particles were momentum analyzed with the QDDM magnetic spectrograph. An energy resolution, FWHM = 50 keV, was achieved. Angular distributions from 6° to 50° to the strongly excited states in the final nuclei up to an excitation energy of 5.5 MeV were measured. Besides the transition to the known 7^+ state at 2.28 MeV in ^{56}Co, which served to identify an experimental L=6 angular distribution, states at 2.36 and 3.53 MeV in ^{56}Co and at 2.69 MeV in ^{58}Co are quite strongly excited with a characteristic L=6 angular distribution. The transitions to the 2.36 and 3.53 MeV states in ^{56}Co show approximately 10% of the strength of the 2.28 MeV transition. No similar strong L=6 transitions in ^{58}Co besides that to the 2.69 MeV state were observed.

Since the spins of these states are not known unambiguously, the observed L=6 angular distribution can be explained by either a $(1f_{7/2})^{-1}_{7,0}$ or a $(1f_{7/2}{}^{-1}, 1f_{5/2}{}^{-1})_{6,0}$ pickup. Therefore, without knowing the spin of the transferred proton-neutron pair, it is not possible at present to infer the predominant configuration of most of these states. Based on the intensity of the (d,α) transition to the 2.69 MeV state in ^{58}Co and the small occupation[4] of the $1f_{5/2}$ orbital in ^{60}Ni, this state is most probably a $[^{60}\text{Ni(g.s.;}0^+) \times (1f_{7/2})^{-2}_{7,0}]$ configuration 7^+ state.

†Work supported in part by the U.S. National Science Foundation.

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SEMICLASSICAL THEORY OF LARGE AMPLITUDE COLLECTIVE MOTION

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In recent years there has been an increasing interest in the study of large amplitude collective motion. Typical examples for such a motion are vibrations in very soft nuclei, nuclear fission and heavy ion reactions. During a large amplitude collective motion the action changes substantially and we expect a semiclassical description to be valid.
Starting from the path integral representation for the time evolution operator we have derived the TDHF equation

$$i\dot{\varrho} = [h[\varrho], \varrho]$$

from a stationary phase condition [1]. In this sense the TDHF equation can be considered as the classical equation of motion of many-fermion systems. Besides giving more insights into the spirit of the TDHF approximation the path integral approach allows to go beyond this classical approximation. This is of crucial importance for the treatment of quantum effects. In ref. [2] we have evaluated the leading order quantum corrections to the TDHF approximation. This has given a simiclassical quantization prescription for ...ar amplitude oscillations. Application of the semiclassic... ...neory to some schematic models haa given ver... encouraging results [3,4]. Analogously to the semiclassical treatment of bound states one can get a microscopic description of nuclear fission by continuing the time variable t to imaginary values $t = -i\tau$ (τ real) [4]. The solutions of the TDHF equation continued to imaginary times give a dynamical picture of the fission process. They describe the time-evolution of the fissioning nucleus from the static Hartree Fock ground state to the scission point. Evaluation of the corresponding Euclidean functional integral in the semiclassical approximation yields a finite life time of the fissioning nucleus.

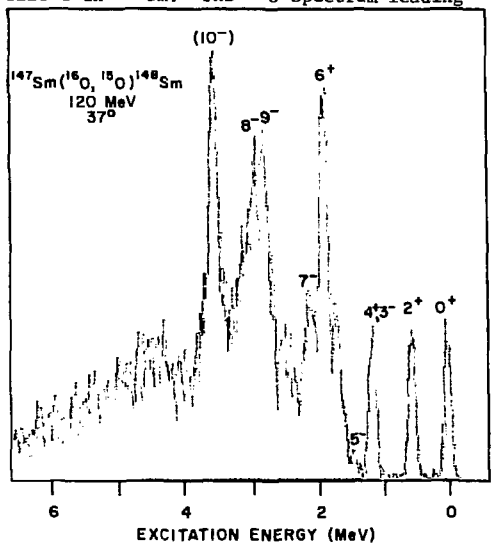
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LOCATION OF HIGH-J ORBITAL TWO-QUASIPARTICLE STATES IN Sm AND Nd ISOTOPES[†]

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Heavy-ion induced single neutron transfer to even Sm and Nd isotopes has been performed in order to determine the two quasiparticle states formed by coupling neutrons in high-j orbitals ($f_{7/2}$, $h_{9/2}$, $i_{13/2}$). Earlier work[1] with the (d,p) reaction was generally unsuccessful in locating the $i_{13/2}$ strength in these even-even nuclei. In contrast to this reaction, heavy-ion induced single neutron stripping reactions with large negative Q values are ideal selectors of high angular momentum transfer, L, because of the large difference between incoming and outgoing grazing angular momenta. The QDDD spectrometer has been used to detect products from two such reactions, (^{16}O,^{15}O) and (^{12}C,^{11}C), on several Sm and Nd isotopes at bombarding energies of 120 MeV, ^{16}O and 90 MeV, ^{12}C. With a ^{148}Sm target the (^{16}O,^{15}O) reaction populates only two states strongly, the $f_{7/2}$ g.s. (L=4 transfer) and the $i_{13/2}$ state at .89 MeV (L=7 transfer). Thus with a ^{147}Sm target one would naively expect only $(f_{7/2})^2$ (positive parity) and ($f_{7/2} \times i_{13/2}$) (negative parity) configurations to be populated in ^{148}Sm. The ^{15}O spectrum leading to states in ^{148}Sm, measured at the peak of the bell-shaped angular distribution, is shown in the figure. The even parity states of $0^+,2^+,4^+,6^+$ are clearly seen, and evidence is also present for previously assigned $5^-,7^-,8^-$ and 9^- states. The previously unobserved 10^- two-quasiparticle state is expected to be the strongest in the spectrum and is likely to be the large, isolated peak at 3.53 MeV. Transfer with the (^{12}C,^{11}C) reaction, which also permits strong $h_{9/2}$ neutron transfer, has firmly established the ($f_{7/2} \times h_{9/2}$) character of the 2.58 MeV, 8^+ state in ^{148}Sm. Similar data has been obtained for ^{150}Sm, ^{141}Nd and ^{146}Nd nuclei and demonstrates that the location of these states moves rapidly with neutron number. Gamma-ray coincidence experiments are being performed in an effort to improve the effective energy resolution, to establish the spin assignments and to locate the missing 4^- and 6^- states.



[†]Work sponsored by the U. S. Department of Energy under Contract No. DE-AC-02-76-CH00016.

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HIGH SPIN RESONANCES IN $^{28}Si + ^{28}Si$ SCATTERING*

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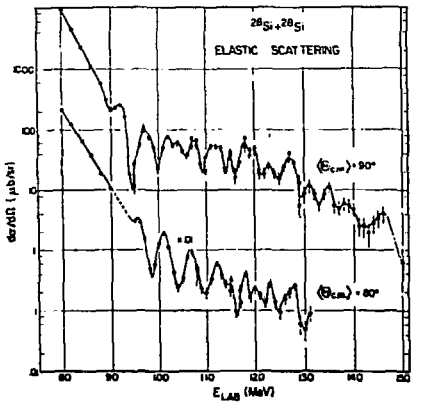
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Recent measurements[1]) of elastic and inelastic scattering of $^{28}Si + ^{28}Si$ have shown the existence of resonance-like behavior, thus indicating a much wider occurrence of this type of behavior than was previously thought likely. Elastic scattering data measured at $\theta_{cm} = 90°$ and $80°$ are shown in the figure, displaying both structure of width $\Gamma_{cm} \approx 2$ MeV and a much narrower structure of width $\Gamma_{cm} \approx 0.5$ MeV. We have recently extended these measurements using a novel technique which allows the collection of high precision angular distribution data for both elastic and inelastic scattering overa wide angular range with high efficiency. The angle integrated cross-sections show almost identical behavior to the previously measured single angle excitation functions-showing structures which appear in a correlated fashion in the elastic and inelastic channels and are also visible in the angle integrated yield of the summed excitation functions for all transitions with $Q \geq -10$ MeV. We therefore conclude that the observed structures arise from a series of entrance channel resonances fragmented by mixing with some presumably molecular degree of freedom. The spins of the resonances determined from the shapes of the elastic scattering angular distributions range from 34 to 42 ħ and closely follow the grazing partial wave. The resonant widths extracted are similar for all the observed resonances. The elastic width is typically a few percent of the total whereas the inelastic widths are much larger. In particular, the width for the poorly match $J^{\pi} = 3^{-}$ inelastic channel is the largest of all, suggesting that the structure of the intermediate width resonances may be quite different from that of the resonances observed in the lighter systems.



*Work supported by the U. S. Department of Energy.

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ROTATIONAL BAND CROSSING IN ^{44}Ti AND CHANNEL COUPLING EFFECTS IN THE ^{28}Si(^{16}O,^{4}He)^{40}Ca REACTION

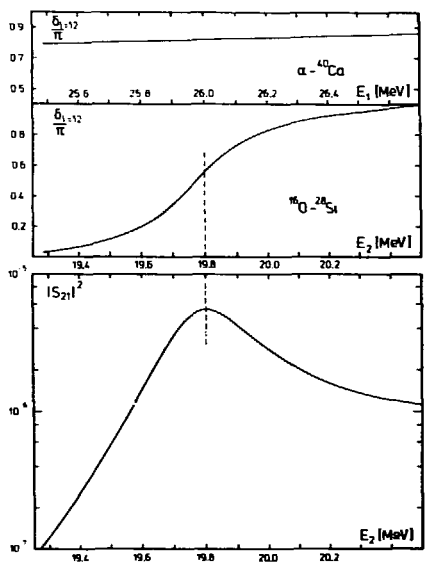
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Rotational band structures deduced from the elastic ^{4}He-^{40}Ca and ^{16}O-^{28}Si scattering, resp., intersect at an excitation energy $E^{*} \approx 33$ MeV in ^{44}Ti, corresponding to a spin value of about $\ell=12$. In the vicinity of this energy one expects an enhancement[1] of the ^{28}Si (^{16}O,^{4}He)^{40}Ca reaction cross section.

The above reaction was studied microscopically on the basis of the coupled-channel generator coordinate method[2]. The internal structures of the fragment nuclei were described by their oscillator shell model ground states. The effective nucleon-nucleon force was approximated by a general central force containing two Gaussian functions. It reproduces the threshold energy (6.2 MeV) of the ^{16}O-^{28}Si channel relative to the ^{4}He-^{40}Ca channel and fits the rotational band structures in the corresponding elastic channels. The Coulomb interaction was treated exactly, including exchange contributions[3].

The results show that the flux $|S_{21}|^2$ from the ^{16}O-^{28}Si channel (2) into the ^{4}He-^{40}Ca channel (1) around the above band crossing energy is in fact dominated by the $\ell=12$ partial wave. Its contribution to $|S_{21}|^2$ exhibits a pronounced maximum (fig.1) at $E_2=19.8$ MeV in the entrance channel, corresponding to $E^{*}=31.2$ MeV. This maximum is clearly related to a resonance structure in the ^{16}O-^{28}Si channel as can be seen by comparing the corresponding phase shifts in the elastic channels (upper part of fig.1). Such maxima become more pronounced with decreasing widths of the underlying resonances and may serve to identify quasimolecular states well below the Coulomb barrier. In the present case the direct coupling is too weak ($|S_{21}|^2 \approx 10^{-5}$) to produce noticeable effects in the reaction cross section, in agreement with ref.1.

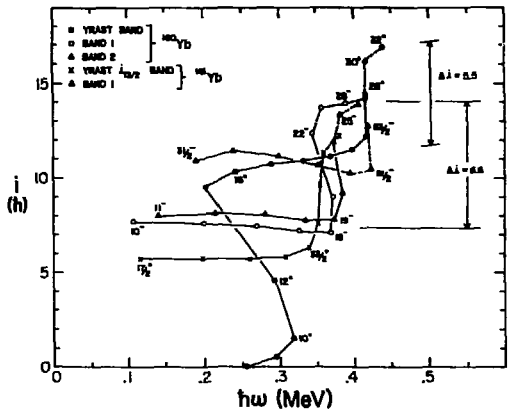


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HIGH-SPIN STATES IN ^{160}Yb

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Extensive spectroscopy experiments were performed recently in Copenhagen on ^{160}Yb with an (^{16}O,3n) reaction,[1] leading to the assignment of the yrast line to spin 28 in addition to 5 side bands. To observe higher spin members of these bands, we have produced ^{160}Yb in a (^{20}Ne,4n) reaction using a 108-MeV Ne beam from the ORIC. An array of 5 Ge(Li) detectors was used to record γ-γ events in coincidence with a total energy signal from a 25-cm x 25-cm NaI counter. The higher ℓ imparted by the Ne beam (compared to ^{16}O) resulted in enhanced population of the high-spin yrast states, e.g., a five-fold increase in $I_\gamma(24^+)/I_\gamma(4^+)$. New transitions of 837 and 878 keV were assigned to the 30^+ and 32^+ yrast levels. The significance of these higher transitions is demonstrated in the figure, a plot of aligned angular momentum, i, relative to the ground configuration versus the rotational frequency (see Ref. 1 for more details). The yrast sequence experiences a second band crossing at $\hbar\omega$=0.43 MeV; our new transitions allow an estimate of the alignment gain in the crossing, Δi=5.5$\hbar$. Both the crossing frequency and the Δi agree well with predicted values[2] from cranking calculations, providing evidence that the alignment of $h_{11/2}$ protons is responsible for this second backbend. Also shown in this figure are two bands in ^{161}Yb from Copenhagen work.[3] The crossing at 0.43 MeV is apparent in one of these bands, demonstrating that $h_{9/2}$ neutrons are not responsible for upbends in ^{160,161}Yb.



Our measurements also led to the assignment of higher transitions in side bands 1 and 2 in ^{160}Yb. These energies suggest $\Delta i \approx 6.6\hbar$ for the crossing which is observed so strikingly in 4 side bands in ^{160}Yb and the yrast band in ^{161}Yb (see Ref. 1). This Δi, along with the crossing $\hbar\omega$ of 0.36 MeV, indicates that the alignment of a secondary pair of $i_{13/2}$ neutrons is responsible for this frequently occurring band crossing.

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**Operated by Union Carbide Corp. for the U.S. Department of Energy under Contract No. W-7405-eng-26.
[a]Part time at Oak Ridge National Laboratory.

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STATISTICAL YRAST LINE EFFECT IN $^{16}O+^{27}Al$ AND $^{19}F+^{24}Mg$ FUSION CROSS SECTIONS

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It is current interest to clarify whether the fusion cross section at high energy is limited by the property of the compound nucleus or the entrance channel effect. One of the crucial way to do this is to compare mass- or Z-distributions of the evaporation residues for two different entrance channels forming the same compound nucleus. The $^{16}O+^{27}Al$ and $^{19}F+^{24}Mg$ systems have been chosen for the present study. The beams of ^{16}O and ^{19}F were obtained from the 12UD Pelletron Tandem at the University of Tsukuba. Self-supporting ^{27}Al targets of 200 $\mu g/cm^2$ were employed for the $^{16}O+^{27}Al$ system, while 100 $\mu g/cm^2$ of ^{24}Mg evaporated on the thin carbon foils were prepared for the $^{19}F+^{24}Mg$ system where the special attention was made to avoid oxydation. Evaporation residues from complete fusion reactions and the elastic scattering were detected in a telescope consisting a gas flow ionization chamber followed by a solid state silicon detector in the angular range $3° \leq \theta_L \leq 30°$.

In Fig.1, shown are the satisfactory agreements of Z-distributions from ^{43}Sc-compound nucleus at E^*=58.2, 63.5 and 69.5 MeV through two entrance channels. This confirms that fusion cross sections are limited by the property of compound nucleus and not by the entrance effect. In Fig.2, The measured fusion cross sections are shown for two entrance channels. These fusion cross sections at high energy are well reproduced by the statistical yrast line prediction with r_0=1.20fm and ΔQ=10 MeV which are common for the systems up to $A \lesssim 80$ [1]. The calculations of the fusion cross sections for whole energy range are made by the use of averaged S-matrix with the same parameters [2] and the agreements with the data are quite satisfactory.

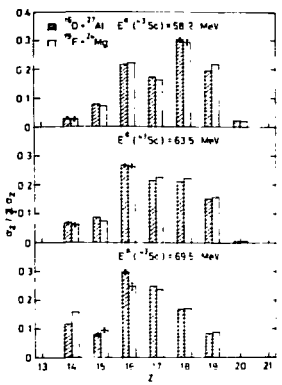


Fig. 1

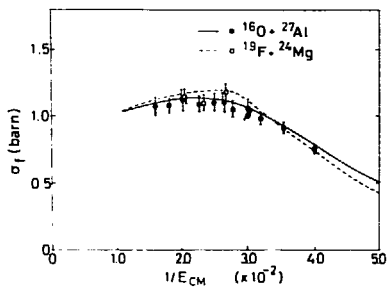


Fig. 2

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BINARY FISSION OF LIGHT AND MEDIUM-HEAVY NUCLEI[†]

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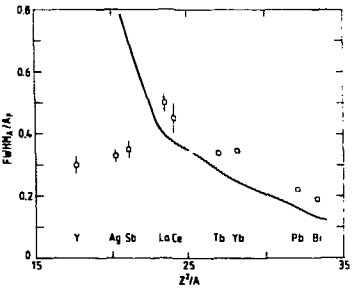
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The binary fission process has been investigated with 600 MeV protons in elements ranging from Y to Bi. This process is of interest in connection with macroscopic models used to desribe fission phenomena. These models predict values of the fission barrier heights, total kinetic energy release ans mass distributions. All models predict the existence of a limit, the Businaro-Gallone point, below which the symmetric saddle becomes unstable towards mass asymmetric distorsions. Below this limit the fission process will be indistinguishable from other reaction channels, e.g. evaporation, due to the highly asymmetric mass distributions expected. Above the limit the models predict symmetric, Gaussian shaped, mass distributions.

In order to provide experimental data for testing model predictions we performed a series of coincidence experiments at the CERN proton synchrocyclotron. The figure shows the relative widths of the mass distributions versus the parameter Z^2/A. Relative widths are obtained from the actual widths (FWHM) in a.m.u. divided with the estimated mass of the fissioning nuclei. The behaviour according to the liquid drop model calculations of Nix[1]) is given by the solid line. From the figure we draw the conclusion that there is no sign of the Businaro-Gallone point in the experimental data although the lightest element investigated (Y) is far below the expected location in any of the macroscopic models.



Of the nuclei displayed in the figure La and Ce are exceptional in that they show non-symmetric mass distributions, in fact their distributions are similar to those observed in the actinide region. Such stable mass asymmetry may be interpreted in terms of shell structure effects. In the present case of La and Ce it turns out in calculations based on Nilsson levels, that the neutron numbers around 80 play the dominant role.

[†]This work was supported by the Swedish National Science Research Council and in part by the Norwegian Research Council for Science and the Humanities

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TARGET DEFORMATION EFFECTS IN HEAVY ION INDUCED FUSION-FISSION REACTIONS†

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A. C. Mignerey

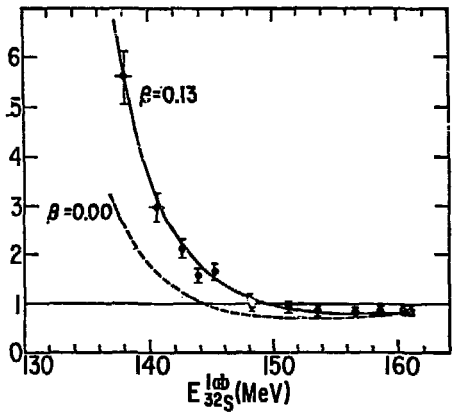
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The static interaction barrier between two heavy ions is determined by the Coulomb repulsion and the attractive nuclear potential at the point of contact between the two nuclei. A significant reduction of the interaction barrier occurs at the poles of a deformed nucleus when compared to that of a spherical nucleus of the same volume, and it is expected, that this reduction of the interaction barrier will lead to a significant increase in the fusion cross section in the sub-threshold region. This effect has recently been demonstrated in a measurement of the fusion of ^{16}O with four different Sm-isotopes[1]).

With the aim of studying these deformation effects at higher angular momenta we have measured detailed excitation functions for fission induced by ^{32}S fusion with $^{144,150,152,154}Sm$. Due to the low fissionability of the Pt compound systems, fission occurs only for large angular momenta, for which the relative height of the fission barrier is reduced sufficiently to render fission decay competitive with neutron emission. Even with this selection of high ℓ-waves ($\ell \gtrsim 40\ \hbar$) introduced by the fission requirement, we observe significant differences in the sub-threshold fission cross section for ^{154}Sm and ^{144}Sm, as illustrated in the figure. Here the solid line represents a statistical model calculation, which includes an integration over the orientations of the deformed ($\beta_2 = 0.13$) ^{154}Sm nucleus. The cross section ratio calculated for $\beta_2 = 0.00$ is shown (dashed curve) for comparison.



†This work was supported by the U. S. Department of Energy.

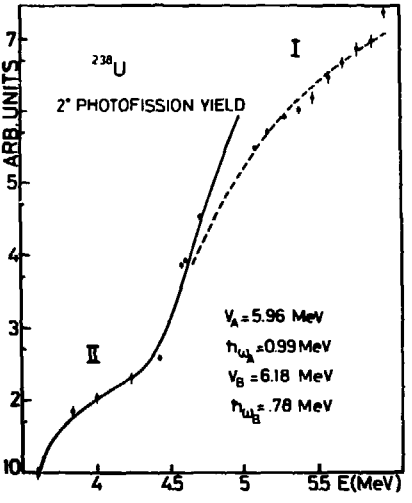
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NON STATISTICAL EFFECTS IN SUBTHRESHOLD PHOTOFISSION OF ^{238}U

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Subthreshold photofission processes are analyzed within the theory of intermediate state reactions, based on a double humped picture of the fission barrier. We show that this widely accepted reaction mechanism[1]) actually leads to two main "regimes" related to different couplings among class I and class II states, depending on the level densities in the two wells. Near the fission threshold we have a strong coupling, with back and forth transitions through the first barrier, where we can introduce statistically averaged quantities. In the very low energy region (weak coupling) in addition to the isomeric transition we can see noticeable non statistical effects due to quasi-degeneraces between single class I and class II states.



We show that this microscopic coupling, which resembles a resonance in the double barrier penetrability, gives the bulk of the observed low energy enhancement of photofission yields usually called "isomeric shelf"[2]). Any attempt to reproduce the data only with the isomeric competition leads to a completely unrealistic choice of the barrier parameters. We finally remark that the forms we get for cross sections and yields are very simple to handle, never requiring a computation of complete double (or triple) barrier penetrabilities.

The results of our analysis for the 2^+ photofission yield of ^{238}U are shown in the figure (curve I: statistical code; curve II: resonant code). The experimental data are from ref.[3]). The same set of deformation parameters along the fission path (heights and curvatures) can reproduce both the low and high energy region. The low energy shelf is due to a resonance at E=3.55 MeV with a total width of 120 keV.

†Supported in part by INFN, Sezione di Catania.

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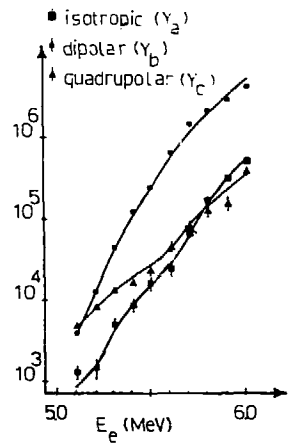
^{238}U SUBTHRESHOLD PHOTOFISSION ANGULAR DISTRIBUTIONS

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Because of its high selectivity in terms of angular momentum, the subthreshold photofission reaction is a very suited tool to investigate the fission barrier of actinides nuclei. In particular it is of interest to study the photofission of the ^{238}U since the obtained informations can be compared with the known values of the partial half-lives of the 2.56 MeV shape isomer and with its fission branching ratio.

We have performed fission fragments angular distribution measurements in the (5.1-6.0) MeV energy range using an intense bremsstrahlung beam obtained with the microtron facility of Catania University. The target was placed at the centre of a cylindrical support bearing a 10 μm thick makrofol foil used as fragment track detector[1]). The experimental data were analysed taking into account finite target effect by Monte Carlo method and the isotropic, dipole and quadrupole contributions were deduced fitting the angular distributions with the expression $W(\theta)=a+b\sin^2\theta+c\sin^2 2\theta$. Theoretical yields are obtained folding cross section, calculated on the basis of a resonant penetrability model[2]), with an empirical linear bremsstrahlung spectrum. The curves resulting from the best fit of the experimental data are shown in figure in fission per coulomb unit. The parameters describing the two-humped barriers obtained from our analysis are summarized in the table. Some interesting conclusions can be drawn. The outer saddle point energy is found to be nearly degenerate in the 1^-0 and 2^+0 channels in agreement with theoretical predictions for a mass asymetric second maximum, and the half-lives for the 2.56 MeV shape isomer together with fission branching ratio are well reproduced.



	E_a	$\hbar\omega_a$	E_{II}	$\hbar\omega_{II}$	E_b	$\hbar\omega_b$
2^+0	5.9	1.2	2.16	0.84	6.0	0.65
1^-0	6.6	1.1	2.98	0.40	6.0	0.56
1^-1	6.6	1.1	3.0	0.50	6.64	0.67

TABLE - E and $\hbar\omega$ are respectively the height and curvatures of the joined parabolas simulating the potential barrier. a,b,II are referred to first and second maximum and to the second minimum respectively.

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Novel Band Crossing Predictions for Rare Earth Nuclei[+]

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Within the framework of a self-consistent HFB theory, giant backbending is predicted to occur in a number of heavy isotopes in the rare earth region. The effect is seen to be the result of the crossing of two bands with very different intrinsic structure (shape β , γ ; gap parameters Δ_p , Δ_n Fig.1 and 2) and thus corresponding effective moments of inertia (Fig.3). These prolate ($\beta > 0$)-oblate ($\beta < 0$) shape transitions (Fig.1) occur at far lower angular momenta and are of an entirely different nature to those anitcipated on the basis of the liquid drop model. Amongst a number of novel features, the new bands may possess superrigid effective moments of inertia (Fig.3) and manifest "Coriolis Enhanced Pairing"effects (Fig.2). A preliminary account of this work has already been published[1]

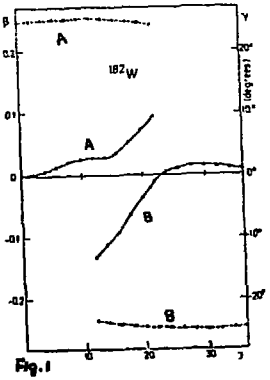


Fig.1

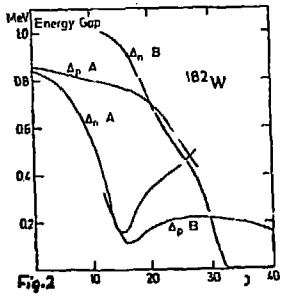


Fig.2

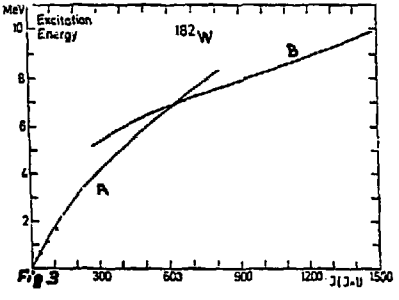


Fig.3

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[+]This work is supported by B.M.F.T. of F.R.G.

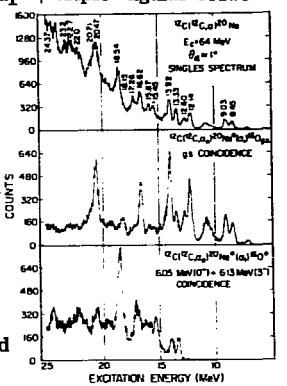
A HIGH SPIN $^{12}C + {}^{8}Be$ CLUSTER STATE IN ^{20}Ne †

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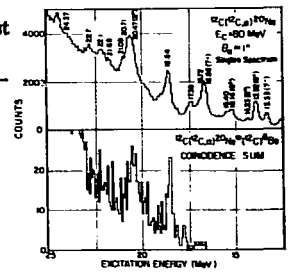
Motivated by the successful application of $\alpha + {}^{16}O$ cluster models in ^{20}Ne and the recent attempts to extend these models to include more complicated cluster configurations, [1] we conducted a series of measurements at the Yale MP Tandem accelerator to study the structure of states in ^{20}Ne populated in the $^{12}C(^{12}C, \alpha)^{20}Ne$ reaction. In this paper we report the direct observation of an 8^+ state at $E_{ex} = 18.538 \pm 0.010$ MeV ($\Gamma_{c.m.} = 125 \pm 25$ keV), which has a large reduced width for decay to $^{12}C + {}^{8}Be$, suggestive of strong $^{12}C + {}^{8}Be$ cluster structure.

The spin of this state was measured from an $\alpha_0 - \alpha_1 - \gamma$ triple angular correlation obtained from the process $^{12}C(^{12}C, \alpha_0)^{20}Ne^*(\alpha_1)\,{}^{16}O^*[6.13,\ 3^-](\gamma)^{16}O_{g.s.}$ at $E(^{12}C) = 64$ MeV. Fig. 1 shows the singles spectrum and the double-coincidence spectra for the decay of $^{20}Ne^*$ to the ground state of ^{16}O and to the doublet at 6 MeV. The branching ratio obtained from this measurement for the α-decay of the $^{20}Ne^*(18.54)$ state to the ground state of ^{16}O is $1.8 \pm 0.9\%$. To obtain the branching ratio for decay to the $^{12}C + {}^{8}Be$ channel, $\alpha + {}^{12}C$ double coincidences from the process $^{12}C(^{12}C, \alpha)^{20}Ne^*(^{12}C_{g.s.})^{8}Be_{g.s.}$ were measured at $E(^{12}C) = 80$ MeV. The singles and $\alpha + {}^{12}C$ double-coincidence spectra are shown in Fig. 2.



1

The measured 12% branching ratio for the $^{12}C + {}^{8}Be$ channel translates into a ^{12}C reduced width (evaluated at R=6 fm) of 1.4 ± 0.3, indicating substantial $^{12}C + {}^{8}Be$ clustering. In contrast, the 2% branching ratio for decay to the $\alpha + {}^{16}O_{g.s.}$ channel translates into an α reduced-width (evaluated at R=5.13 fm) of only 0.003. We suggest that this state belongs to a new 8p-4h band built on the 0^+ state at 12.44 MeV. [2] The 12.44 MeV state has a reduced-width for decay to $\alpha + {}^{16}O_{g.s.}$ of only 0.003, while it has a reduced-width of 0.51 for decay to the $J^\pi = 0^+$ (4p-4h) first excited state of ^{16}O. For the 6^+ member of this new $K^\pi = 0^+_6$ band, we suggest the state [2] at 15.16 MeV, which has a reduced-width for decay to $^{16}O_{g.s.}$ of less than 0.001, but has a reduced-width of 0.91 for decay to the 2^+(4p-4h) state at 6.92 MeV in ^{16}O.



2

This excited 8p-4h band would have a good $^{12}C + {}^{8}Be$ cluster structure, as indicated by the larger moment of inertia relative to the $K^\pi = 0^+_3$ (8p-4h) band and by the large reduced-width for decay to the $^{12}C + {}^{8}Be$ channel of the 8^+ member at 18.54 MeV.

† Work supported by D. O. E. Contract No. DE-AC02-76ER03074

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COMPARISON OF HEAVY ION TRANSFER AND ELECTRON SCATTERING MEASUREMENTS OF NEUTRON DISTRIBUTIONS

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The rms radii of neutron orbits in certain nuclear states can be measured using calibrated sub-Coulomb heavy ion transfer reactions[1,2]. This information can also be obtained, making different interpretational assumptions, using back-angle electron scattering experiments[3]. The results of both techniques show single particle orbits to be somewhat smaller than self-consistent mean field theory predictions. It is possible that the interpretation of the electron scattering results should take into account the effects of core-polarisation and meson exchange contributions, and it is important to compare measurements on the same nucleus made by the two different methods. The reaction $^{86}Sr(^{18}O,^{17}O)^{87}Sr$ has been studied at 45 and 46 MeV ^{18}O bombarding energy using the MP tandem and the split pole magnetic spectrograph of the University of Rochester. The aim was to determine the radial size of the $1g_{9/2}$ neutron distribution in the ground state of ^{87}Sr. This datum has already been determined from electron scattering measurements[3] of the ^{87}Sr magnetisation distribution.

Nuclear distortion of the wave functions of relative motion have some influence on the DWBA predicted reaction cross-sections because of the necessity of performing the experiments at high enough energies to obtain sufficient yield. Preliminary analyses of the ground state transfer cross-sections were made using distortions obtained via fits to detailed elastic scattering experiments for $^{17,18}O$ on $^{87,86}Sr$. These experiments were performed at the Niels Bohr Institute. The rms radius of the $1g_{9/2}$ orbit extracted from the analysis is 4.60±0.08 fm for a spectroscopic factor S of 0.8±0.1 of the full single particle limit, i.e. S = 0.16. The error of 0.08 fm arises from uncertainties in S, uncertainties arising from different choices of distortions and data errors. A bound state potential well with the same geometry parameters as used in the electron experiments was used here to determine the $1g_{9/2}$ single neutron wave function, and so no errors arise from choice of well shape when we compare the present number with the value 4.67 fm previously obtained[3].

There is good agreement between the two techniques for measuring $\langle r^2 \rangle^{\frac{1}{2}}$. The spectroscopic factor used here agrees with the upper limit of 0.17 obtained in the electron experiments. The difference between neutron orbit sizes determined experimentally for several nuclei and Hartree-Fock predictions may be considered as firmly established and necessitates a revision of the input to such theories.

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K-SHELL IONIZATION IN HEAVY-ION COLLISIONS*

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Two proposals to measure reaction times in heavy-ion collisions have recently been put forward. Oscillatory structure either in the energy spectrum of δ-electrons[1] or in the probability for producing K-shell vacancies as a function of impact parameter[2] is related to the reaction time τ. The crucial ingredient in both is the interference between ionization amplitudes for incoming and outgoing trajectories. Both proposals have the deficiency, however, that their treatment of reaction times and the relative motion of the heavy-ions is purely classical.

We present here a fully quantum-mechanical, time-independent description of ionization. Two spin zero nuclei collide and are assumed to produce binary fragments with charges, angular momenta, and energies, Z_1', Z_2', I_1', I_2', E_1', E_2', respectively. We consider only monopole excitation of an electron in the lowest molecular orbital to an ionized state with energy ε. For nuclear separations less than a matching radius R_m, we assume the electron wave functions to be those of a united atom. Keeping only 1st-order contributions to the ionization, using the WKB approximation for the relative radial motion of the separated nuclei, and matching inside and outside solutions at R_m, we derive the following formula for the joint differential cross section for producing the binary fragments and simultaneously ionizing the electron

$$\sum_{I',M'} \left| \sum_{L,L'} \left(a(L) S^{L}_{L'I'}(E-\hbar\omega) + b(L') S^{L}_{L'I'}(E) \right) \frac{\sqrt{\pi}}{K} \sqrt{2L+1}\ (I'L'M' - M' | LO) Y^{M'}_{L'} \right|^2$$

Here $S^{L}_{L'I'}$ is an element of the S-matrix; L and L' are the incident and final orbital angular momenta while the channel spin I' is the vector sum of I_1' and I_2'; E and K are the c. of m. energy and wave number of the incident heavy ions; $\hbar\omega$ is the electronic energy difference for the united atom; a(L) and b(L') are equivalent to the incoming and outgoing ionization amplitudes of the semi-classical theory with impact parameters $\hbar L$ and $\hbar L'$. If we assume that the nuclear partial wave amplitudes are concentrated around $\bar{L}$ and $\bar{L}'$, we may factor out the ionization amplitudes obtaining for the joint cross section

$$\sum_{I',M'} \left| a(\bar{L}) f_{I',M'}(E-\hbar\omega) + b(\bar{L}') f_{I',M'}(E) \right|^2$$

where f is the reaction amplitude. Even when the final kinetic energy E' is sharp, this cross section must be summed over I_1', I_2', E_1'; for any realistic experiment there will be a further summation over the range of E', Z_1' and Z_2' appropriate to the detectors. The probability for producing an electron with energy ε is the joint cross section above, suitably summed, divided by the summed nuclear cross section $\Sigma\sigma$. The phase factor of the semi-classical theory, $\exp(i\omega\tau)$, is replaced by $f^*(E-\hbar\omega)f(E)$, suitably summed, divided by $\Sigma\sigma$. Through first order in ω, the latter equals $(1+i\omega\langle\tau\rangle)$ when one uses the quantum mechanical expression for the (complex) reaction times and weights these by the relevant cross sections. For larger values of ω, an equivalence between $\langle\exp(i\omega\tau)\rangle$ and the quantum mechanical expression places stringent conditions on the correlation function $\Sigma f^*(E-\hbar\omega)f(E)$.

* Work supported in part by United States Department of Energy.

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PION CONDENSATION AND REALISTIC NUCLEON-NUCLEON INTERACTIONS

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During the last few years there has been an increasing interest in the threshold conditions for a possible pion condensation and in the role of "pre-critical" phenomena at normal nuclear densities. A calculation of the pion selfenergy in a nuclear medium, the quantity of which is of central interest in these investigations, strongly depends on the residual nucleon-nucleon particle-hole interaction and the corresponding transition potentials describing the excitation of the $\Delta(3,3)$ resonance. Commonly these interactions are represented by a constant interaction strength[1]), the actual momentum-, energy- and density-dependence being a point of controversial discussion. In the present work the residual interaction is derived from a Brueckner G-matrix and corresponding approximation for the $\Delta(3,3)$ transition potentials. The pion selfenergy is calculated keeping the full complexity of the particle-hole interaction. The resulting selfenergies are analyzed in the model of constant particle-hole interactions. This leads to effective interaction strengths which slightly depend on the pion momentum and the density of nuclear matter being considered.

The pion selfenergy in nuclear matter due to the coupling of the pion to the corresponding excitation modes (S=T=1) also leads to a modification of the pion propagators in the NN interaction. Similar effects also occur in the other (S,T)-channels. This modification of the effective particle-hole interaction in the nuclear medium is called induced interaction[2]). In the present work also isobar excitations are taken into account which yield a significant effect especially for higher momentum transfer in the cross channel. The induced interaction mainly modifies the particle-hole interaction in the S=T=0 particle-hole channel represented by F in the Landau-Migdal nomenclature. The residual interaction in the particle-hole channel carrying the quantum numbers of the pion (g') is made more repulsive. At the saturation density of nuclear matter the Landau parameter g_0' is increased by 25 % using the Reid soft-core potential. At higher densities this effect is enhanced. Therefore the induced interaction should increase the calculated threshold density for pion condensation considerably.

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σ-π^0 CONDENSATION AND THE INSTABILITY OF ABNORMAL NUCLEAR STATE

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In the $\sigma=A\cos(q_\mu x_\mu)$ and $\pi^0=A\sin(q_\mu x_\mu)$ fields, the Dirac equation may be expressed in the form[1]

$$\left[i\gamma_\mu(p_\mu-\frac{1}{2}\tau_3\delta_5 g_B q_\mu)+m\right]\psi=0\ , \tag{1}$$

in which, g_B is the renormalization constant of pseudovector current, $m=gA$, g is the pseudoscalar coupling constant. Under the transformation

$$\psi=\left[\sqrt{\frac{A+p_\mu q_\mu}{2A}}-\frac{m\tau_3\delta_5\gamma_\mu q_\mu}{\sqrt{2A(A+p_\mu q_\mu)}}\right]\frac{1-i\tau_3\delta_5}{\sqrt{2}}u\ , \tag{2}$$

$$A=\sqrt{(p_\mu q_\mu)^2+m^2 q_\mu q_\mu}\ . \tag{3}$$

(1) becomes a Dirac equation of free pseudoparticle with zero mass:

$$i\gamma_\mu Q_\mu=0\ , \tag{4}$$

$$Q_\mu=p_\mu+\left(\frac{m^2}{A+p_\mu q_\mu}-\frac{\tau_3}{2}\right)q_\mu\ . \tag{5}$$

Transformed operator of the third component of isospin is $T_3=\frac{\tau_3\delta_5}{2}$. For the left(right) handed Pseudoparticles $\gamma_5=1(-1)$, therefore $\tau_3=\pm1$ correspond to $T_3=\pm\frac{1}{2}(\mp\frac{1}{2})$. These results are so simple, that made the calculation of the properties of σ-π^0 condensed nuclear matter, in the semiclassical and Van der Waals approximation, a home working one. Using the experimental value $g_B=1.26$ and the σ model parameters determined by the properties of nuclei, it is found that the binding energy per nucleon in σ-π^0 condensed nuclear matter is much larger than that in abnormal nuclear matter, at a density between the normal and abnormal nuclear densities. Therefore, the abnormal nuclear state is unstable against the decay to σ-π^0 condensed nuclear state. For example, if we use the linear dimension per nucleon $r_0=1.2049fm$ and the binding energy per nucleon $b_0=15.677$Mev of normal nuclear state[2] as input, the corresponding quantities of abnormal nuclear state are calculated to be 1.032fm and 18.3Mev, and those of σ-π^0 condensed nuclear state are 1.076fm and 35.8Mev respectively. The condensed wave value and wave number are also calculated to be $A=0.375m_0/g$ and $q=0.59m_0$ respectively, in which m_0 is the mass of nucleon in normal vacuum. Our calculated density and binding energy of abnormal nuclear matter are different from those originally published by T. D. Lee[3]. This is because that, in determining the parameters, we have used the full σ model Lagrangian with sinθ breaking and the relativistic kinematics.

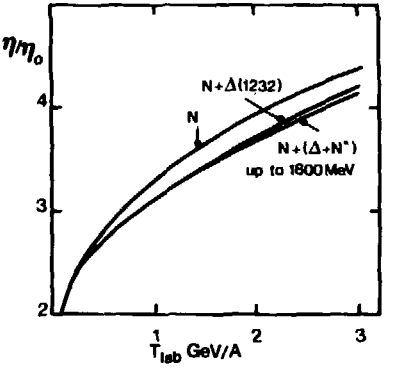
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COMPRESSION IN HEAVY ION HIGH ENERGY REACTIONS

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The relativistic Rankine-Huguoniot equation has been solved as to give simultaneously the maximum compression and the temperature of nuclear matter which can be reached in a high energy heavy ion collision. This equation is built up here for an one-dimension plane shock wave ; we have used an equation of state of a Fermi gas with a Skyrme interaction which gives a reasonable value of the compression modulus of the infinite symmetric nuclear matter (K = 220 MeV for the J. Treiner and H. Krivine SKM Skyrme force used in this calculation). We have also investigated the possibility to have N^* and Δ phases in the compressed zone behind the shock front. The figure shows our results concerning the maximum compression n/n_o (n_o = .17 fm^{-3} equilibrium density) reachable when two equal heavy ions collide versus the laboratory kinetic energy per nucleon. One can see that the $\Delta(1232)$ resonance must be taken into account above 300 MeV/A ; its main effect is a quite strong decrease of the n/n_o rate. On the contrary, the inclusion of the other resonances up to 1 600 MeV gives a very small effect only above 3 GeV/A . We have the same effect with the temperature ; for example, if we have not any effect of the resonances up to the n/n_o = 2 value, at n/n_o = 3 we have a temperature value of 94 MeV without resonances, 70 MeV with Δ (1232) and 66 MeV with the resonances up to 1600 MeV. At n/n_o = 4 we have 184 MeV , 108 MeV and 100 MeV respectively, which exhibits too a strong effect of the $\Delta(1232)$ resonance .



MICROSCOPIC CALCULATION OF FRICTION TENSORS INCLUDING MASS ASYMMETRY

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Using the two-center shell model on the basis of the linear response theory,[1] a realistic calculation of friction tensors $\gamma_{\mu\nu}(\mu,\nu = R,\delta,\eta)$ was performed for the systems $^{63}Cu + ^{197}Au$ and $^{49}Ar + ^{197}Au$, to which the linear response theory seems to be more applicable than to the lighter system $^{20}Ne + ^{28}Si$.[2] The relative distance R, the deformation δ of each nucleus and the mass asymmetry η are taken as the collective variables, where η is defined by $(A_1-A_2)/(A_1+A_2)$ using the masses A_1 and A_2 of both nuclei. The mass tensors $m_{\mu\nu}$ were approximated with hydrodynamical ones obtained by the use of the Werner-Wheeler method and Yukawa-plus-exponential potential was taken as the nuclear potential in the same way as in Ref. 2.

An example of the calculated friction $\gamma_{\eta\eta}(R,\delta,\eta,T)$ and mass $m_{\eta\eta}(R,\delta,\eta)$ is shown in the figure. The value of our microscopically calculated friction $\gamma_{\eta\eta}$ in the surface region is 30,000 to 50,000 MeV·10^{-23} sec. This value seems to support the phenomenological value of 40,000 MeV·10^{-23} sec which is used in Ref. 3. In addition, we obtained the orders of magnitude of 10^{-2} and 10 for the quantities $\sqrt{m_{\eta\eta}T}/\gamma_{\eta\eta}$ and $|(\partial^2V/\partial\eta^2)/(\partial V/\partial\eta)|$, respectively. This seems to verify the validity of the assumption used in this reference that the acceleration term for η-degree can be neglected, i.e., $|\sqrt{m_{\eta\eta}T}/\gamma_{\eta\eta}\,(\partial^2V/\partial\eta)/(\partial V/\partial\eta)| \ll 1$.

We are now solving the equation of motion for reactions $^{63}Cu + ^{197}Au$ and $^{40}Ar + ^{197}Au$ with full coupling terms, in which statistical fluctuations are also included.

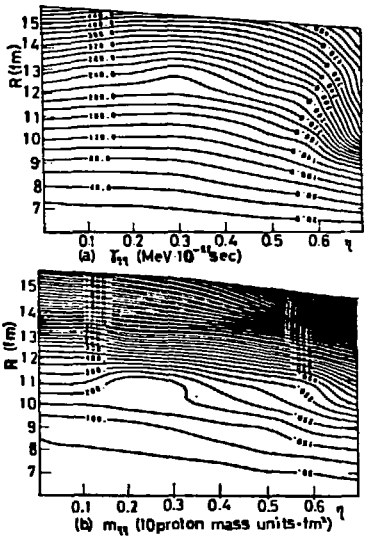


Fig. 1. Contour maps of (a) the friction $\gamma_{\eta\eta}(R,\delta,\eta,T)$ for $\delta = 0.4$ and $T = 1.5$ MeV and (b) the mass $m_{\eta\eta}(R,\delta,\eta)$ for $\delta = 0.4$ as functions of R and η. These quantities are drawn only within the restricted region where two nuclei overlap. The smearing width of $0.2\hbar\omega_0$ ($\hbar\omega_0$ = 6.63 MeV) is fixed for the friction.

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EXACT SOLUTION OF DIRAC EQUATION AND THE π CONDENSATION IN NUCLEAR MATTER

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Dirac equations in the $\pi^{\pm}=\phi e^{\pm i\vec{R}\cdot\vec{r}}/\sqrt{2}$ field may be solved exactly by linear transformations. For example, the pseudoscalar coupling equation

$$[\vec{\alpha}\cdot(-i\nabla)+m\beta-gf_\pi\vec{\tau}\cdot\vec{\pi}]\psi=\epsilon\psi \tag{1}$$

under the transformation

$$\psi=e^{i(\vec{P}-\tau_3\vec{K}/2)\cdot\vec{r}}\left[\left(\frac{A+\vec{P}\cdot\vec{K}}{2A}\right)^{1/2}+i\frac{g\phi\tau_1\beta\vec{\sigma}\cdot\vec{K}}{\sqrt{2A(A+\vec{P}\cdot\vec{K})}}\right]u\ , \tag{2}$$

$$A=\sqrt{(\vec{P}\cdot\vec{K})^2+g^2\phi^2K^2}\ , \tag{3}$$

becomes

$$(\vec{\alpha}\cdot\vec{q}+m\beta)u=\epsilon u\ ,\qquad \vec{q}=\vec{P}+\left(\frac{g^2\phi^2}{A+\vec{P}\cdot\vec{K}}-\frac{\tau_3}{2}\right)\vec{K}. \tag{4}$$

We see, that the nucleons in this field behave as free pseudoparticles with pseudo-momentum $\vec{q}$. The density of states is

$$d\eta=\frac{2}{(2\pi)^3}d\vec{P}=\frac{1}{2\pi^3}\frac{q_0+\tau_3K/2}{\sqrt{(q_0+\tau_3K/2)^2-g^2\phi^2}}d\vec{q}\ . \tag{5}$$

The distortion of distribution of states raises the average energy of nucleon. Therefore, it is impossible to develop the π condensation of this type under the pure pseudoscalar coupling.

π-nucleon p wave interaction may be introduced by pseudovector coupling or chiral symmetry. Dirac equation with this interaction has exact solution similar to (2)-(4). But the effective mass of pseudoparticles now is decreased to

$$m^*=m/\sqrt{1+\frac{4f^2q^2}{m_\pi^2}}\ , \tag{6}$$

in which f is the p wave coupling constant and m_π is the mass of π mesons. It is this effect, which made the π condensation possible. Summing the energy of nucleons exactly, an analytic expression of the coefficient of polarization has been obtained, from which we can discuss the π condensation in isotopically symmetric nuclear matter.

Considering the effect of nucleonic repulsive core by the Van der Waals approximation, a critical radius r_{cc} of repulsive core is found. If the actual radius r_c of repulsive core is larger than r_{cc}, π condensation becomes impossible. Using the empirical value of vacuum p wave coupling constant: $f^2/4\pi=0.081$, r_{cc} is found to be 0.44fm, which is smaller than the r_c of most nuclear forces. It means, if we fix the p wave coupling constant to be it's vacuum value, the π condensation may be completely suppressed by the repulsive core. Another method of consideration on the correlation between nucleons leads to similar result. Parameters determined by current data of nuclei seemed to indicate[1], that the π condensation in nuclear matter is practically impossible for a simple p wave coupling.

But if we consider the σ model seriously, a new aspect appears. As the nuclear density increases, the chiral symmetry restored more completely, the mass of nucleon decreases, and the p wave coupling "constant" increases according to the relation $f=f_0m_0/m$, in which, f_0 and m_0 are the vacuum values of f and m respectively. This effect may overcomes the core suppression, so that made the π condensation realizable. Critical density of π condensation calculated from σ model, parameters of which are determined by the properties of nuclei[2], is about 1.3 times the normal nuclear density.

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PION CONDENSATION IN A THEORY CONSISTENT WITH BULK PROPERTIES OF NUCLEI*

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Pion condensation has not previously been investigated in a theory that accounts for the known bulk properties of nuclear matter, its saturation energy and density and compressibility. We have formulated and solved self-consistently, in the mean field approximation, a relativistic field theory that possesses a condensate solution and reproduces the correct bulk properties of nuclear matter. The theory is solved in its relativistically covariant form for a general class of space-time dependent pion condensates. Self-consistency and compatibility with bulk properties of nuclear matter turn out to be very stringent conditions on the existence and energy of the condensate, but they do allow a weak pion condensate to develop. It is encouraging, as concerns the possible existence of new phases of nuclear matter, that this is so, unlike the Lee-Wick density isomer, that appears to be incompatible with nuclear matter properties.

Pion condensation in neutron stars is an important mechanism affecting strongly their rate of cooling. We also apply this self-consistent theory to study pion condensation in asymmetric nuclear matter, subject to the constraints of the known bulk properties.

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NONLINEAR MESONIC SOLUTIONS IN THE LEE-WICK MODEL

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In order to study effects of highly compressed nuclear matter, Lee and Wick[1] in their original model applied the average field method and the Thomas-Fermi model to solve the coupled equations for the mesonic field ϕ and the nucleonic field ψ.

$$\phi - U'(\phi) = g\,\bar{\psi}\psi \tag{1}$$

$$(\gamma^{\mu}\partial_{\mu} + m_N + g\,\phi(x))\psi = 0 \tag{2}$$

We also average $\langle\bar{\psi}\psi\rangle$ and investigate (i) more detailed time-dependent solutions of the nonlinear eqn (1), and (ii) study the influence on the nucleonic field. For more than one dimension and a positive potential $U(\phi)$, Derrick's theorem[2] denies the existence of nonsingular time-independent finite energy solutions except the ground state. (i) We construct classical time-dependent solutions of finite energy of the mesonic eqn (1). For $U(\phi) = a\phi^2 + b\phi^3 + c\phi^4$, eqn (1) yields in momentum space a nonlinear integral equation, with ϕ having a pole on the energy shell $\omega^2-k^2-2a = 0$. The integral equation for the residual $\chi(\vec{k},\omega) = \phi(\vec{k},\omega)(\omega^2-k^2-2a)$ can be expanded near a given function χ_0, putting $\chi = \chi_0 + \eta$ and introducing an order parameter λ by $b \to \lambda b$, $c \to \lambda c$. Choosing a suitable starting function χ_0 with a finite mesonic Hamiltonian $H_{mes}(\chi_0)$, one can show that the iterative solution gives in each order of λ a finite energy. Then, summing the powers of λ by a Padé series, H_{mes} remains finite. (ii) For sufficiently high densities, the effective potential $V(\phi) = U(\phi) + g\,\langle\bar{\psi}\psi\rangle\phi$ of eqn (1) has a degenerate vacuum. We want to study the effect of a soliton solution ϕ_s of the type $\tgh(u^{\mu}x_{\mu})$, with u_{μ} fixed, using a finite box as a model for heavy-ion collisions to give a finite energy. Inserting this solution, eqn (2) can be Lorentz transformed to

$$(\gamma^{\mu}\partial_{\mu} + M\phi_s(t))\psi = 0. \tag{3}$$

In momentum space eqn (3) has a pole at $k^2 = 0$. For the residue $\chi(\vec{k},\omega) = (\vec{\gamma}\cdot\vec{k}-\gamma_0\omega)\cdot\psi(\vec{k},\omega)$ one finds an effective Lippmann-Schwinger-type equation for the frequencies with $V^{eff}(\omega,\omega') = M\phi_s(\omega-\omega')$ and $G_0^{eff}(\vec{k},\omega) = (\vec{\gamma}\cdot\vec{k}-\gamma_0\omega)^{-1}$. In the Thomas-Fermi model energy densities can be calculated. Such calculations are underway.

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COULOMB CORRECTIONS TO THE "SIMON" MODEL OF HIGH-ENERGY HEAVY-ION REACTIONS*

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Recently Coulomb effects have been shown[1] to be important in heavy-ion reactions even at energies above 250 MeV/A. This restricts the applicability of theoretical models such as microscopic multiple-scattering ("cascade") models, which otherwise give fairly accurate descriptions of most features of such reactions.[2,3,4]

We have now included Coulomb corrections to the "SIMON" multiple-scattering model.[4] Since Coulomb effects are essential only in the final stage of the nucleus-nucleus collision,[1] we have included them as a final-state interaction: at the end of the collision the individual trajectories of the outgoing protons in the combined (moving) Coulomb field of projectile and target residues and all other participant protons are calculated.

The resulting proton distributions are compared to the experimental "summed-charge" distributions, rather than to the proton distribution itself, in order to partially take into account the production of composite particles (d,t, α etc.), which cannot be calculated within the cascade model. There is a marked effect on the calculated ratio of neutron yield to proton yield, as seen in the experimental data.

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MEAN-FIELD CALCULATIONS OF THE MANY-BODY S-MATRIX[†]

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Although the TDHF method can describe inclusive aspects of heavy-ion collisions, it has not been extended to specific reaction cross-sections. We have developed a mean-field approximation to the S-matrix for heavy-ion and atomic collisions. The relative separation is treated semi-classically and evolves through a Newtonian equation in which the force depends upon the intrinsic excitation of the internal degrees of freedom. These, in turn, undergo a nonlinear time-nonlocal one-body evolution which arises from the stationary-phase approximation to a functional-integral representation of the interaction-picture propagator. In practical terms, the method amounts to finding selfconsistent histories of the coupled relative and intrinsic systems, which is accomplished iteratively by performing the equivalent of many TDHF calculations. Our scheme is superior to previous attempts in that it is derived by systematic approximations to an exact expression and results in an S-matrix which is independent of the time at which it is evaluated.

As a test of the one-body approximation to the intrinsic evolution, we have applied our method to the forced Lipkin model. The influence of the relative ion-ion motion is simulated by a time-dependent one-body potential of the form $\exp(-\varepsilon^2 t^2)(J_x + J_y + J_z)$, $\vec{J}$ being the total quasi-spin operator, and ε being the single-particle level spacing. The figure shows the exact and mean-field S-matrix elements, S_{no}, for the excitation of the n'th excited state from the ground state for a system of N = 30 fermions with coupling strength $\chi = (N-1)\,V/\varepsilon = 0.5$.

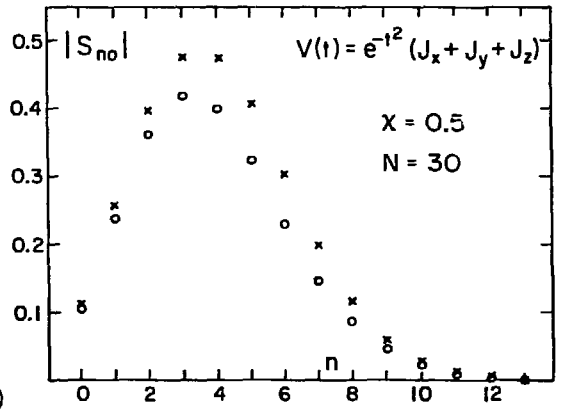


Fig. 1: The moduli of the excitation amplitudes $|S_{no}|$ in the forced Lipkin model: exact (x) and mean field approximation (o).

We are currently applying our scheme to more realistic models of atomic and nuclear reactions. Elastic, inelastic, and transfer cross-sections can all be calculated in a nonperturbative microscopic manner.

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[††]Chaim Weizmann Postdoctoral Fellow.
[†††]Alfred P. Sloan Foundation Fellow.

A NEW METHOD OF EVALUATING THE OSCILLATING AIRY FUNCTION, THE GAMMA FUNCTION AND KLEIN-GORDAN WAVEFUNCTIONS

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Airy functions are required, among many other uses, in the computation of the diffractive and rainbow scattering of heavy ions. Arising out of the methods described for calculating regular and irregular Coulomb functions of real argument and order[1] a program to evaluate Bessel functions $J_\nu(x)$ and $Y_\nu(x)$ has been devised[2], which enjoys the same advantages. The new program can be used to compute the Airy functions Ai(-x) and Bi(-x) and their derivatives in an effective and direct manner for $|x| > 5$. Below this value of $|x|$, because of the presence of the irregular solution $Y_{1/3}$, the procedure becomes inefficient, and so a direct, continued-fraction, solution is used which is extremely rapid. A discussion of the merits of different solution techniques will be given.

The same methods lead to an elegant and rapid method for evaluating $\Gamma(1+\nu)$ for $-1.5 \leq \nu \leq 1.5$ to extreme accuracy (30S on an IBM extended precision compiler), which will also be described. Klein-Gordan wavefunctions are readily available from the original program, RCWFN, and a new version with certain improvements will be described for these calculations.

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COMPOSITE PARTICLE EMISSION AND QUANTUM STATISTICAL THEORIES OF NUCLEAR REACTIONS

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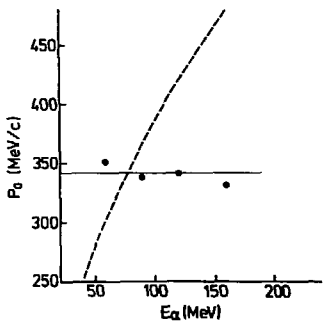
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The emission of composite particles may originate from different reaction modes: projectile fragmentation, preformed particle emission and combination of free nucleons into clusters. Models taking the third mode into account work remarkably well in describing inclusive particle spectra in the energy range from some tens of MeV[1] up to some GeV/A[2-5] projectile energy. There are two theories for the formation of complex particles: Composite particles are formed due to final state interactions[2] and a classical equilibrium thermodynamic approach[4,5]. The first theory assumes coalescence of nucleons into clusters if their relative momenta are less than a certain momentum P_0. This value should be energy independent. The latter theory results in temperature dependent P_0 values.

It is the aim of this work to investigate the energy dependence of cluster emission thus having a tool to discriminate between both theories. There are already data from 400 MeV/A up to 2.1 GeV/A ^{20}Ne induced reactions[6] leading to approximately constant P_0 values. However, these values are derived[6] from folding experimental observed proton spectra but not, if they were corrected for depletion due to complex particle emission. This is inconsistant with the formulation of the coalescence model which is based on the original distribution of nucleons in momentum space. The way of taking the depletion into account might be erroneous due to projectile fragmentation.

We therefore avoid to take experimental proton spectra as original nucleon distributions. In a recent approach it has been shown that for low energies the intermediate nucleon distributions can be calculated (exciton coalescence model)[1]. We have measured ^{54}Fe(α,α'x) reactions with 90, 120 and 160 MeV bombarding energy. Data from ref. 7 are added and analyzed in terms of the exciton coalescence model. It has been found necessary to take multiple particle emission during the non-equilibrium phase into account. The results are indicated as dots in the figure. As already shown P_0 values are similar to the radii of free clusters[8] (solid line in the Fig.). The energy dependence of the thermodynamical model[4] is also shown (dashed line) (normalized to the previous P_0 value at 79 MeV).

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SCALING PHENOMENON IN RELATIVISTIC NUCLEUS-NUCLEUS COLLISIONS*

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Recent experimental and theoretical studies of nucleus-nucleus collisions in the energy range of a few GeV per nucleon indicate that the use of the Feynman scaling variable x_F leads to scaling in some cases but no scaling in some others. It is desirable to look for new scaling variables so that the experimental data can be represented in a simpler manner and the underlying physics of the scaling phenomenon understood.

In the reaction A(target) + B(projectile) → C+X, the two dominant processes of interest are the direct fragmentation and the hard-scattering process. In the direct projectile-fragmentation process, the subsystem c is emitted from the beam particle B without scattering, while the complementary partner interacts with the target nucleus A. The proper scaling variable for projectile fragmentation is

$$x_D = \frac{C_o + C_z}{B_o + B_z} \tag{1}$$

where the letter symbol for a particle also stands for the four-vector of that particle. In the hard-scattering process, the target A and subsystem B emit subsystems a and b which scatter to produce particle C via the basic process ab→Cd. The proper scaling variable is

$$x_H = \frac{\gamma^2 + \sqrt{\gamma^4 - b^2(u'+c_T^2)}}{u' + c_T^2} \left[\left(\frac{m_a}{m_A}\right) \frac{A_o + A_z}{B_o + B_z} - x_D \right] \tag{2}$$

where $\gamma^2 = \frac{1}{2}(d^2 - a^2 - u')$ and $u' = (m_A/m_A - C)^2$. The corresponding scaling variables for target fragmentation can be obtained by interchanging the role of target and projectile.

The introduction of these scaling variables allows a simple representation of the experimental data. We find that there is x_D scaling for proton production and x_H scaling for pion production. As these scaling variables approach Feynman x_F in the limit of very high energies, they can be considered the generalizations of the Feynman scaling variable for the case of weakly bound, but heavy, systems.

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EFFECTIVE SCHRODINGER EQUATION OF THE OPTICAL MODEL FOR COLLISIONS BETWEEN COMPOSITE NUCLEI*

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An effective hamiltonian for elastic collisions between composite nuclei is obtained from the Schrödinger equation of the complete many-body system and its fully antisymmetric wave functions by means of a projection operator technique. This effective hamiltonian, defined in such a way that it has to reproduce the scattering amplitude in full detail, including exchange effects, is explicitly Galilean invariant. The effective interaction operator is a function of the relative distance between the centers of mass of the colliding nuclei and the constants of the motion of the whole system. The interaction operator of the optical model is obtained next, requiring as usual, that it reproduces the average over the energy of the scattering amplitude and keeping the Galilean invariance. The resulting optical potential operator has some terms identical to those obtained in the Resonating Group Method, and others coming from the elimination of all non-elastic channels and the delayed elastic scattering. This result makes the relation existing among the projection operator method a la Feshbach and the cluster model equations of motion for positive energies (RGM) explicit. The additional interaction terms due to the current loss in the elastic channel are non-local, and non-hermitean operators expressed in terms of the transition amplitudes and the density of states of the compound nucleus in such a way that an approximate evaluation in a systematic fashion, seems possible. The angular momentum dependence of the optical potential operator is discussed in some detail.

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AVEREGED S-MATRIX FOR LIGHT HEAVY-ION FUSION REACTIONS

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In the light heavy-ion reactions, the fusion cross section is determined by the measurement of the evaporation residues. Then the following picture can be valid for understanding the fusion process. At first the heavy-ion scattering state interacts with many complicated states of the compound nucleus. After the compound nucleus formation, the compound states decay to many exit channels. To formulate this process, we use the scattering theory by Mahaux and WeidenmÜller [1]) in the case of no channel-channel coupling. After applying the statistical treatment to the original scattering matrix, we get the following averaged scattering amplitude $\langle S^c_{(IL)J} \rangle$ of entrance channel c for a total spin J,

$$\langle S^c_{(IL)J} \rangle = \exp(2i\delta_L)[(1-P_L) + P_L \exp(-\pi\rho_J(E^*)\Gamma^c_J)]$$

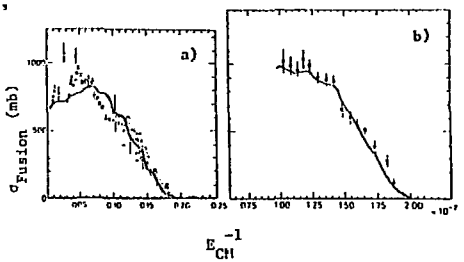
where L and I are the angular momentum and channel spin of entrance channel. The effect of the barrier penetration in contact distance region is explicitly represented by the barrier penetrability P_L.

To evaluate the partial width Γ^c_J, we take the picture that the compound system is disturbed by the incident channel and many exit channels in the range of energy Δ around the incident energy E_{cm}. Then we get the following formula,

$$\Gamma^c_J = 2\pi v^2_c A_1 A_2 / \rho_J(E^*+\Delta)$$

where v^2_c is constant. A_1 and A_2 denote the mass numbers of entrance channel. The excitation energy E^* of the compound nucleus is represented by $E_{cm}+Q$, where Q is the threshold energy.
For the level density formula $\rho_J(E^*)$, we use the one of Ref 2).
By the use of the averaged S-matrix, we can reproduce the general feature of the whole observed fusion cross section in the light heavy-ion reactions ($A \lesssim 80$) as can be seen from the figure.

It should be stressed that the statistical yrast line [3]) can be intertreted as a beginning of the strong absorption due to the formation of the compound nucleus in the process of heavy-ion reaction.



Calculated fusion cross sections for a) ^{12}C-^{12}C and ^{40}Ca-^{40}Ca systems. Data are taken from Ref 4).

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ANGULAR MOMENTUM FRACTIONATION IN HEAVY-ION REACTIONS

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In reactions induced by relatively light heavy ions, such as ^{20}Ne, the gamma-ray multiplicity increases with increasing mass asymmetry, suggesting that the rigid rotation limit is achieved. In contrast, the gamma-ray multiplicity exhibits essentially no dependence on exit channel asymmetry in Kr-induced reactions. It has been suggested[1] that this difference can be explained without abandoning the assumption of rigid rotation by assuming that there is an angular momentum fractionation along the mass asymmetry coordinate.

This fractionation can be traced to two sources: (1) the angular momentum dependence of the potential energy versus mass asymmetry and (2) the angular momentum dependence of the lifetime of the intermediate complex. Both of these mechanisms have been explored using simple models.

The potential energy versus mass asymmetry has been calculated using a quadratic approximation to the liquid drop energy. In the equilibrium limit, simple expressions have been obtained for the average angular momentum as a function of mass asymmetry.[2] The extent to which the angular momentum is fractionated depends strongly on the assumptions made regarding the presence of competing decay modes such as neutron emission. In the absence of such processes, a pronounced fractionation effect is observed. The effect is weakened considerably in the presence of neutron competition.

The fractionation caused by the angular momentum dependence of the lifetime of the complex has been explored using various solutions to the Fokker-Plank equation and estimates of the lifetime obtained from dynamical models. Even on a constant energy surface, angular momentum is strongly fractionated. Second moments calculated in this model are often substantially larger than those of a triangular distribution. Similar calculations have been performed using analytic solutions to the Fokker-Plank equation assuming a parabolic approximation to the liquid potential energy.

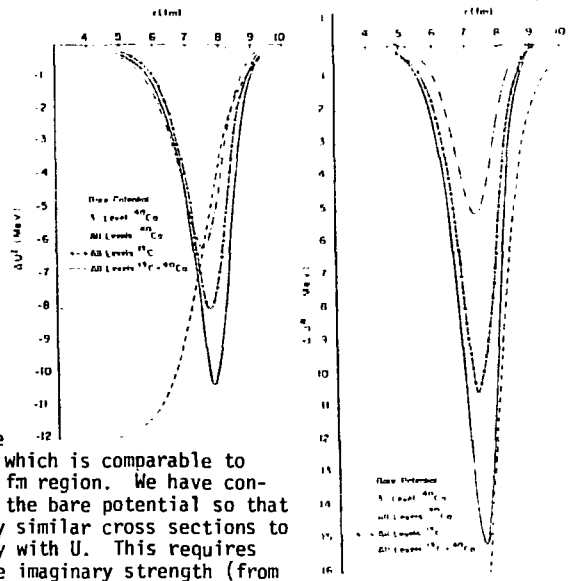
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INELASTIC EXCITATION AND THE OPTICAL POTENTIAL FOR HEAVY IONS[+]

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For 68 MeV ^{13}C scattering from ^{40}Ca we have carried out coupled channel calculations using a "bare" optical potential U from Bond et al[1] and standard derivativ' couplings between the ground state and the various excited states. We have then obtained, numerically, the polarization potential ΔU, such that $(U + \Delta U)$ in a pure elastic scattering calculation gives the same cross section as the coupled channels result. In studies with a single excited level the ΔU are strongly ℓ-dependent, but the coupled channel results can be quite well reproduced by an ℓ-independent ΔU for which the surface partial waves are strongly weighted. We have studied the effect of including in addition to the 3.73 MeV 3^- state of ^{40}Ca, other low levels which are strong in the inelastic excitation of ^{13}C and ^{40}Ca, together with high lying levels in both nuclei chosen to exhaust the energy weighted sum rule. The approximate ℓ-independent ΔU are shown for various sets of levels in the figure, together with the bare potential U. As more levels are included the imaginary component ΔU^I becomes increasingly absorptive and scales approximately according to $\sum_i (\beta_\lambda^{(i)} R_i)^2 / E_x^{(i)}$ where $\beta_\lambda R$ is the deformation length. For the real part, the low levels give a ΔU^R which changes sign in the surface, but the higher states give an attractive surface-peaked potential which is comparable to ΔU^I in the important 8-9 fm region. We have considered modifications of the bare potential so that $(U' + \Delta U')$ gives crudely similar cross sections to those obtained previously with U. This requires a strong reduction in the imaginary strength (from 12 to 2 MeV) or less of a reduction in the strength together with a reduction in the imaginary radius.



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THE TIME-DEPENDENT CLUSTER MODEL

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The Time Dependent Hartree-Fock method has proven itself extremely useful in the description of heavy ion reactions[1,2]. In this method one evolves in time a set of single particle wave-functions. Spin and isospin degeneracy are current assumptions, but apart from this, the wave-functions are not restricted in any way. As a consequence one is led to quite lengthy calculations involving the discretized wave-functions on a three-dimensional mesh. An interesting alternative would be to parametrize the Hartree-Fock wave-function in terms of some simple parameters. The time dependent cluster model (TDCM), suggested from the alpha-cluster model for light nuclei [3], is adequate, as it allows a particularly rich parametrization of the wave-function.

In the TDCM approach the wave-function is written as

$$\phi = \det\{e^{-(\vec{r}_i-\vec{d}_j)^2/2b^2}\}$$

where $\vec{d}_j$ are complex time-dependent quantities describing the positions and momenta of the clusters. The equations of motion for the parameters $\vec{d}$ can be obtained from the variational principle applied on a parameter-dependent family of wave-functions [4].

One obtains the following equations of motion :

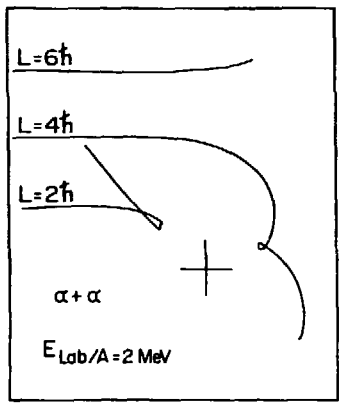
$$\sum_j i\hbar S_{ij}\, \partial d_j/\partial t = \partial E/\partial d_i^* \qquad \text{where} \qquad E = \langle\phi|H|\phi\rangle/\langle\phi|\phi\rangle$$

and

$$S_{ij} = \frac{\langle \partial\phi/\partial d_j^* | \partial\phi/\partial d_i \rangle}{\langle\phi|\phi\rangle} - \frac{\langle \partial\phi/\partial d_j^* | \phi\rangle\langle\phi|\partial\phi/\partial d_i\rangle}{\langle\phi|\phi\rangle^2}$$

H being the nuclear Hamiltonian. The treatment of finite range forces, both in the direct and exchange part, as well as of Coulomb interaction is feasible. So the description of collision involving A nucleons is reduced to a set of classical-looking equations of motion for 3A/4 complex parameters d_i.

As an application of the TDCM, we present some selected trajectories for α-α scattering at a laboratory energy of 2 MeV per particle, at various angular momenta, obtained with the Brink-Boeker B1 interaction. In the figure we represent the trajectory of the center of one of the clusters. The results ressemble clearly to the TDHF ones. We obtain scattering for nearly central collisions, orbiting at higher impact parameters and Coulomb scattering at still larger ones. Reactions between heavier systems are currently being investigated.

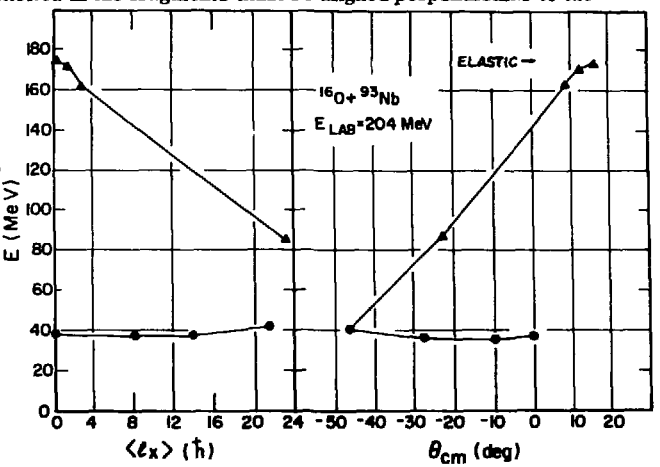


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TDHF STUDIES OF THE $^{16}O + ^{93}Nb$ REACTION AT E_{Lab} = 204 MeV†

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TDHF calculations are presented[1] for $^{16}O + ^{93}Nb$ collisions at a laboratory bombarding energy of 204 MeV. We employ an approximation in which the degrees of freedom perpendicular to the reaction plane are frozen in time. Our calculations exhibit several interesting properties. In fig. 1 the outgoing kinetic energy of the deep inelastic fragments, as a function of the CM scattering angle, shows that the reaction yield is strongly peaked in the forward direction. Also in fig. 1 the mean angular momentum excited in the deep inelastic fragments is given as a function of the outgoing kinetic energy. The triangles represent those trajectories near grazing while the circles represent those trajectories which are near head-on. The approximation that the perpendicular degrees of freedom are frozen in time requires that the mean angular momentum excited in the fragments must be aligned perpendicular to the reaction plane.



In our calculations we observe a large region of intermediate angular momenta which lead to fusion. The lower ($\ell_<$) and upper ($\ell_>$) limits to the fusion region are $\ell_< = 33$ and $\ell_> = 75$. Thus there is a large region of angular momentum below the fusion limit which corresponds to strongly damped inelastic scattering. The angular momentum transfer shown in fig. 1 has a completely different dependence on the outgoing kinetic energy for the two different inelastic branches, corresponding to the partial and complete dampening in the two different regions. We conclude that a measurement of the angular momentum excited in the deep inelastic fragments might provide experimental evidence for the existence of the inelastic branch below fusion.

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1) K. R. Sandhya Devi, M. R. Strayer, K. T. R. Davies, and J. M. Irvine, to be published

HOW DOES THE NUCLEUS-NUCLEUS POTENTIAL BEHAVE IN THE INNER REGION ?

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The relative motion between complex nuclei is successfully treated by the resonating group method (RGM) which takes full account of the Pauli principle. The solution of the relative wave function, in general, oscillates in the inner region due to the orthgonality to the forbidden states. Its qualitative feature can be well reproduced by the orthgonality condition model (OCM)[1]:

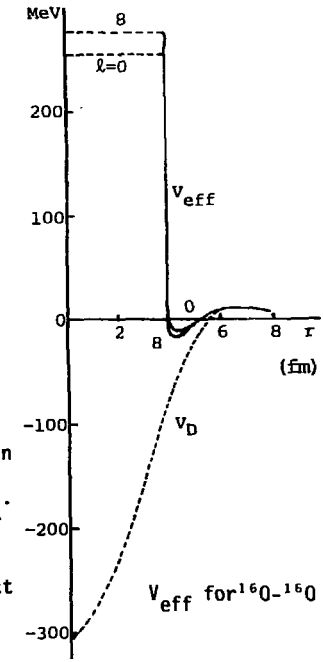
$$\sqrt{1-K_\ell}\,(T_{rel}+V_{eff}-E_{cm})\,\sqrt{1-K_\ell}\,\tilde{u}_\ell = 0 \quad , \qquad (1)$$

where K_ℓ is the normalization kernel and V_{eff} means an effective local potential. The wave function free from redundancy is also described by $\tilde{u}_\ell$. On the other hand, the RGM equation can be written by

$$\sqrt{1-K_\ell}\,(T_{rel}+V_D+G_\ell-E_{cm})\,\sqrt{1-K_\ell}\,\tilde{u}_\ell = 0, \qquad (2)$$

where V_D is the direct (folding) potential and G_ℓ stands for non-local kernel due to nucleon-exchanges between two colliding nuclei.

In the case with α-α system, the result of Eq.(2) is reproduced fairly well even if G_ℓ is neglected. The V_{eff} in Eq.(1) can be, therefore, substituted by V_D. On contrary, the ^{16}O-^{16}O potential V_{eff} for the lowest band shows a striking core of 250 MeV height in the inner region (fig.). In this case, the Volkov No.2 force[2]) with the Majorana exchange mixture m= 0.65 is adopted for two-nucleon force, which reproduces the separation energy of ^{16}O from ^{32}S. The repulsion disappears around the outermost nodal point of inner oscillation from where V_{eff} shows a shallow attraction. The V_{eff} with strong repulsion in the region where the forbidden states exist thus allows us to take a local potential picture without the orthgonal condition. The reduction of the strength of the repulsion or the increase of the depth of the attractive part is necessary in order to simulate the RGM phase shifts. This repulsion may be related to the fact that the ^{16}O-^{16}O configuration belongs to the continuum state of ^{32}S.



The property of ^{20}Ne as a fused compact nucleus strongly influences the α-^{16}O interaction for the lowest band. The α-^{16}O configuration describes fairly well the ground state of ^{20}Ne. This guarantee has been made in the repulsive effect around the surface region[3]). This role pulls α-cluster inside the contact distance, giving a large overlapping between α and ^{16}O. The inner repulsion does not exist.

In conclusion, the heavy nucleus-nucleus potential behaves like a repulsion with energy-dependency. On contrary, the potential between light nuclei is related to the structure of low-lying state of a fused compact nucleus.

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TDHF CALCULATIONS FOR THE ^{136}Xe + ^{209}Bi REACTION

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Axially-symmetric time-dependent Hartree-Fock calculations with non-degenerate proton and neutron states, have been performed for the study of ^{136}Xe + ^{209}Bi reactions at E_{lab} = 1130 MeV. The effective interaction used in the calculations consists of the direct and exchange contributions of the Coulomb interaction and a non local finite range Skyrme force. A dynamical generalization of the filling approximation has been considered to obtain spherical HF ground states of the reacting ions. The calculations have been performed for a series of relative orbital angular momenta corresponding to L = 0, 50 ħ, 100 ħ, 150 ħ, 200 ħ, 300 ħ, 350 ħ, 400 ħ, 450 ħ, 500 ħ and 550 ħ. In cc oaring with the Wilczynski Plot (fig. 1) we note that the experimental ridge develops near θ_{cm} = 50° and extends down in energy almost parallel to TKE axis with the distribution broadening with energy loss and tending to forward angles. Although the TDHF results reproduce fairly the energy and angle in the grazing region, the ridge is reproduced within about 5-10° and is indicative of sideways peaking and finally turning to more backward angles for small impact parameters. Some of these differences may in part be due to the imposed axial symmetry constraint which restricts equilibration into transverse degrees of freedom and inhibits totally angular momentum transfer between the reacting partners. For L = 100 h, we observe a three-body break up with an alpha-like emission from the neck at scission, while for L = 0, 50 h and 150 h a pronounced three-body behaviour is manifested but the system finally separates into only two distinct fragments. Fig. 2 exhibits the calculated deflection function in comparison to the Coulomb and the "experimental" deflection functions. At E_{lab} = 900 MeV, 1000 MeV and 1300 MeV, we do not see any fusion for the head-on collision between the reacting ions.

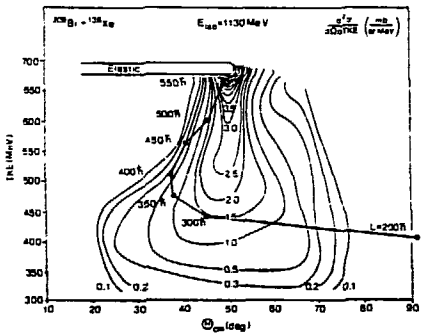


Fig. 1

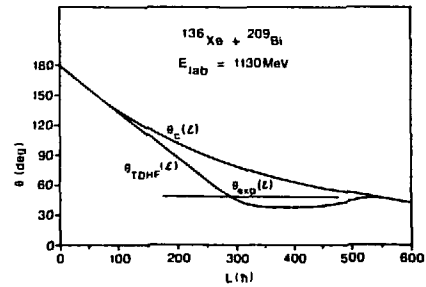


Fig. 2

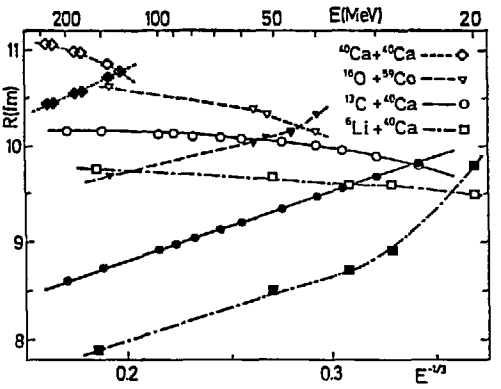
DIFFRACTION OR RAINBOW IN HEAVY-ION ELASTIC SCATTERING ?

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The angular dependence of the differential cross section for heavy ion elastic scattering shows the typical pattern of a Fresnel diffraction in many cases. The steep boundary of the absorptive region accounts for this. Alternatively the pattern can be explained as a Coulomb rainbow effect. We suggest that a comparison between the strong absorption radius, R_{sa} (distance of closet approach for the Rutherford trajectory corresponding to the orbital momentum with 50% absorption) and the Coulomb rainbow radius, R_r (same for orbital momentum leading to the rainbow angle under the real potential) can inform about the relative influence of absorption and refraction.

Videbaek et al [1]) noted that for $^{16}O+^{208}Pb$ the "sensitive radius" (where different "best fit" potentials cross each other) increases and R_{sa} decreases with increasing energy, the former being larger for laboratory energies above 90 MeV. For the same pair Vaz et al [2]) find $R_r > R_{sa}$ for incident energies greater than 90 MeV.



We have investigated the energy dependence of R_r and R_{sa} for several pairs. The figure displais only some of our results. Open symbols refer to R_r and black symbols to R_{sa}. We note that:

- R_{sa} decreases with increasing energy. This is a well known feature;
- R_r increases with increasing energy;
- These effects are comparable with, or even smaller than, the degree of inaccuracy with which the R_r and R_{sa} are determined due to the ambiguity of the optical potential or to the insufficienty of the data;
- Eventually the lines $R_{sa}(E)$ and $R_r(E)$ will cross at a given energy which probably has a systematic monotonous dependence on $Z_1 Z_2$.

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GENERATOR-COORDINATE DESCRIPTION OF HEAVY-ION COLLISIONS WITH A SPIN-ORBIT FORCE

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The generator-coordinate method (GCM) or the equivalent resonating-group method provide a description of heavy-ion collisions where the antisymmetrization and the conservation of parity and angular momentum are exactly taken into account. Although computational reasons restrict the number of channels included in the model, useful informations about molecular resonances have been obtained for several collisions. However, the calculated energy location of resonances disagree with experiment for some systems involving open-shell nuclei. Moreover, in multichannel collisions, the GCM provides in general incorrect values for the different reaction thresholds, which may lead to unsatisfactory results [1]. This weakness of the model is due to the lack of free parameters.

We are investigating the influence of the introduction in the GCM of the *two-body spin-orbit force*

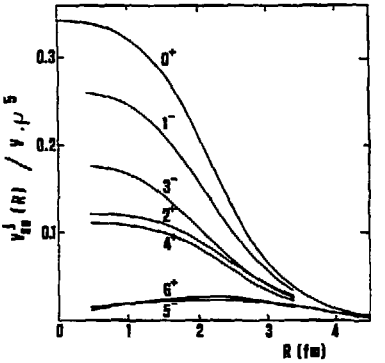
$$v_{so} = -V \sum_{ij} (\vec{r}_i - \vec{r}_j) \times (\vec{p}_i - \vec{p}_j) \cdot (\vec{s}_i + \vec{s}_j) \exp(-(\vec{r}_i - \vec{r}_j)^2/\mu^2)$$

The use of a more elaborate nucleon-nucleon force should improve the physical content of the nucleus-nucleus interaction. Furthermore, the strength V and range μ of the spin-orbit force can be considered as adjustable parameters. Instead of the usual LS coupling scheme, which is well adapted for central forces, the jj-coupling is used to define new GCM wave functions. Both bases are identical for collisions between closed-shell nuclei. In the jj-coupling, the number of selection rules between the non-orthogonal individual wave functions is reduced. The computation time severely increases.

As an illustration, we briefly discuss the spin-orbit effects for $\alpha + {}^{12}C$ elastic scattering. For this system, the quantitative agreement with experiment is rather poor in the usual GCM description [1]. The expectation values of the spin-orbit operator v_{so}

$$V_{so}^{J}(R) = \langle \Phi^{J}(R) | v_{so} | \Phi^{J}(R) \rangle / \langle \Phi^{J}(R) | \Phi^{J}(R) \rangle - E_{so}(^{12}C)$$

are presented in the figure as a function of the generator coordinate R. The Φ^{J} are GCM wave functions defined in the two-centre harmonic oscillator model projected on the total angular momentum J; E_{so} is the ^{12}C internal spin-orbit energy. The ratio $V_{so}^{J} / V.\mu^5$ does not depend on V and is nearly independent on μ [2]. The different V_{so}^{J} can be interpreted as nucleus-nucleus spin-orbit interactions. The J-dependent $\alpha + {}^{12}C$ interaction appears to be essentially repulsive. The strongest repulsion is obtained for J = 0. The spin-orbit repulsion is weaker for higher partial waves and all the curves become very similar beyond J = 4. Qualitatively, these effects seem to correct the defects observed in the GCM calculation of ref. [1]. We thus believe that non-central forces can improve the microscopic description of heavy-ion scattering.

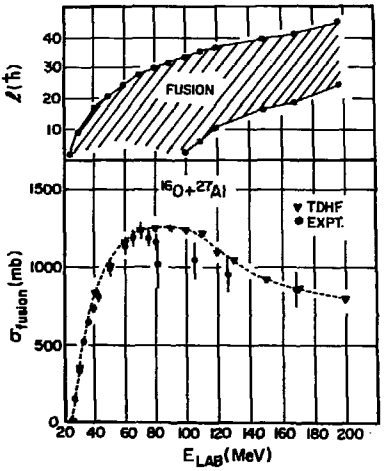


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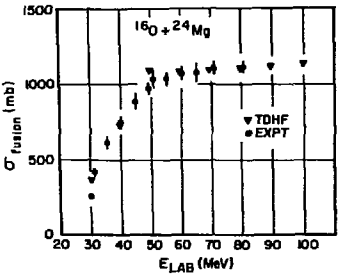
TDHF FUSION EXCITATION FUNCTIONS FOR $^{16}O + ^{27}Al$ AND $^{16}O + ^{24}Mg$†

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TDHF calculations[1] of fusion excitation functions have been carried out for the $^{16}O + ^{27}Al$ and $^{16}O + ^{24}Mg$ systems. We have employed the 2-dimensional frozen approximation using the full Skryme force with finite-range extensions and separate neutron and proton orbitals. The comparison with experimental data is shown in fig. 1 together with a plot of the angular momenta contributing to the fusion cross section in the shape cut-off approximation. One should note the onset of a sharply increasing angular momentum window beginning at about $E_{lab} \geq 100$ MeV and a subsequent decreasing fusion cross section for energies between 100 and 200 MeV. Similar agreement between theory and experiment is obtained for the $^{16}O + ^{24}Mg$ reaction shown in fig. 2.



1



2

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APPLICATION OF GENERALIZED FRESNEL MODEL TO THE ELASTIC SCATTERING OF ^{32}S ON ^{50}Ti AT E_{lab}=130 MeV

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Recently a simple generalization of the widely used Fresnel model to the collision of heavy ions has been proposed [1]. The ratio $\sigma(\theta)/\sigma_R(\theta)$ of the differential elastic scattering cross section to the Rutherford cross section is given by

$$\frac{\sigma(\theta)}{\sigma_R(\theta)} = \begin{cases} 1+1/2[(1/2-C)^2+(1/2-S)^2]F^2+(C+S-1)F, & \theta \leqslant \theta_R \\ 1/2[(1/2-C)^2+(1/2-S)^2]F^2, & \theta \geqslant \theta_R \end{cases}$$

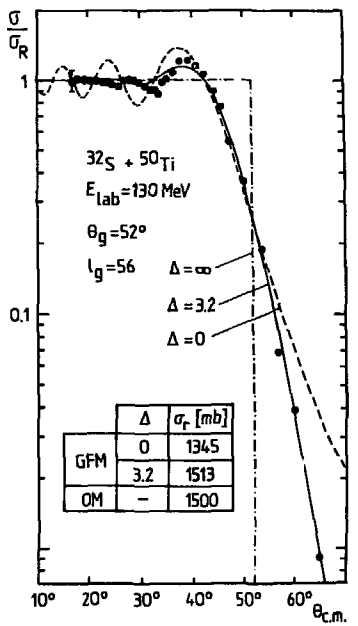
where θ_R corresponds to the angle at which $\sigma(\theta)/\sigma_R(\theta)=1/4$, C and S are the Fresnel integrals. The F function is defined as

$$F(\alpha) = \alpha/\sinh\alpha; \quad \alpha = \pi\Delta(\theta_R-\theta).$$

The Λ parameter describes the l - space diffuseness of the reflection function taken in the form

$$n(l) = [1+\exp((l-\Lambda)/\Delta)]^{-1},$$

where $\Lambda = l_g + 1/2$ and l_g is the grazing angular momentum. The only one free parameter of this model it is Δ and it should be determined from the best fit to the experimental elastic scattering angular distribution.



	Δ	σ_r [mb]
GFM	0	1345
	3.2	1513
OM	–	1500

Fig. 1.

The generalized Fresnel model (GFM) gives a better description of heavy ion elastic scattering data and provides a simple method of total reaction cross section determination.

We have applied GFM to the case of elastic scattering of ^{32}S ions on ^{50}Ti nuclei at E_{lab}=130 MeV [2]. Fig.1 shows a comparison of the experimental angular distribution with predictions of GFM for different values of Δ parameter. The best fit corresponds to Δ = 3.2 . One can see that strong oscillations of calculated cross section presented in the simple Fresnel model (Δ = 0 in our case) are damped giving much better agreement with the experimental data. Also the value of total reaction cross section σ_r calculated with GFM is practically the same as those given by the optical model best fit (see table in Fig. 1).

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POSSIBLE FORMATION OF MOLECULAR ORBITS IN THE SCATTERING OF ^{12}C ON ^{13}C

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H. Voit and W. Treu
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The molecular-orbits formation of a neutron around the two centres of two ^{12}C nuclei has been investigated in the scatterings of ^{12}C on ^{13}C. The molecular-orbits are assumed to be constructed at each point of r, the distance between two ^{12}C, from the shell model orbits of the valence neutron around each ^{12}C nucleus, that is, 1p1/2, 2s1/2 and 1d5/2 orbits.

The characteristic molecular orbits $\varphi^{JM\pi}_{pk}(r;R)$ (k;z-component of the total angular momentum projected on the z-axis of the intrinsic rotating frame) are obtained in the plus parity (π=+) of the total system. For example, one of these (p=1,K=1/2) takes at the grazing region the density distribution of the type of linear chain, ^{12}C-n-^{12}C (see fig. 1). The remarkably localized density-distributions are due to the mixing of the shell-model orbits of different parities, i.e., p- and sd shell orbits[1].

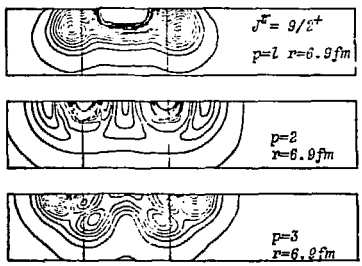


Fig 1.

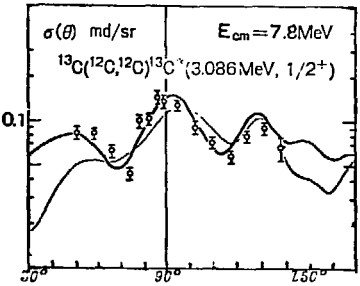


Fig 2.

The states $\varphi^{JM\pi}_{pk}$ mentioned above hardly suffer from the Colioris mixing interaction. This shows that the molecular orbits are not affected by the rotation of the intrinsic frame. Furthermore, it is shown that at low incident energies just above Coulomb barrier the neutron has the time enough to move the molecular orbits although they change their forms with the distance r during the collision.

Numerical calculation shows that the inelastic cross section $^{13}C(^{12}C,^{12}C)^{13}C^*(3.086MeV,1/2^+)$ is contributed mainly from the π=+ scattering, which is caused through the formation of the molecular orbits mentioned above. The angular distribution with the calculation (Fig. 2) agrees with the experiments fairly well and takes nearly symmectic form with respect to 90° reflecting the π=+ contribution to the cross section. This is the evidence of the existence of the molecular orbits studied here.

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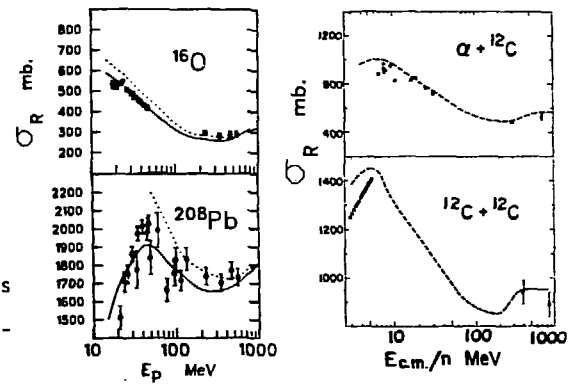
DO NUCLEON-NUCLEON COLLISIONS DOMINATE PROTON-NUCLEUS AND NUCLEUS-NUCLEUS INTERACTIONS?

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Perhaps the most interesting question in medium and high energy heavy-ion physics centers on whether or not so called "exotic" effects are in fact observable. One way to address this question is to compare the experimental parameters of heavy-ion collisions with microscopic calculations which are based on the assumption that only nucleon-nucleon collisions are involved. Deviations from such calculations could be taken as evidence for collective or coherent effects.

We are following this philosophy in a series of experiments and theoretical calculations. We start with measurements of the total reaction cross section, σ_R, and calculations based on the optical limit of Glauber theory. On the left side of the figure we display $\sigma_R(E)$ for proton collisions with ^{16}O and ^{208}Pb. The dotted curves represent the simple Glauber calculations and involve only electron scattering densities and the nucleon-nucleon total cross sections. This first-order theory has been improved on by including (with no free parameters) the effects of the Coulomb and real nuclear potentials, Fermi motion and Pauli blocking. The results, shown as solid lines, are in excellent agreement with the data from 15 to 1000 MeV. Thus proton-nucleus collisions appear to be dominated by nucleon-nucleon collisions.



The right side of the figure displays existing $\sigma_R(E)$ data for two nucleus-nucleus cases (data points shown without error bars were derived from elastic scattering data). The fact that $\sigma_R(E)$ is still strongly energy dependent and resembles the proton-nucleus data suggests that the nucleon-nucleon effects also dominate. This is supported by the simple Glauber calculations (with Coulomb corrections) which reproduce the data quite well. However, the need for more data is clear. To this end, we are in the process of measuring $\sigma_R(E)$ for nucleus-nucleus systems using the attenuation method. We are also pursuing more realistic calculations.

Should further data also agree with these nucleon-nucleon based calculations, we will be able to conclude that collective processes certainly do not constitute a large part of the reaction cross section for heavy-ion collisions and the search for such effects will have to center on more exclusive measurements with correspondingly smaller cross sections.

†Produced by the U.S. Department of Energy - O.M.A.

PRODUCTION OF PROTONS AND PIONS AT 180° IN HIGH ENERGY NUCLEUS-NUCLEUS COLLISIONS†

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Early investigations[1] of the production of high momentum particles at large backward angles in collisions involving nuclear targets have shown the predominance of the production of protons over pions. This is consistent with the suggestion[2] that these protons were present in the nucleus before the scattering and were ejected by the projectile. Theoretical models have recently been developed [2-4] which indicate the importance of direct fragmentation processes in the production of protons at 180°. The production of pions at 180° is usually treated in a hard scattering mechanism. It is found that both mechanisms involve the presence of high momentum components in nuclei. As such, these differing physical mechanisms should give consistent pictures of high momentum distributions in nuclei.

We are currently in the process of extracting structure functions of various nuclei using data of pion and proton spectra at 180°. The data is from an experiment we have performed using the full range of beams and energies available from the Bevalac facility. Early analysis of the pion data[5] showed results which are consistent with the hypothesis that the pions are produced in collisions involving high momentum tails in the nucleus or in collisions with clusters within the nucleus. Analysis of the proton data[6] has revealed behaviour indicative of limiting target fragmentation. The limiting shapes of the proton data also indicate the presence of nuclear correlations. These protons at 180°, in a direct fragmentation picture, potentially carry direct information of the nuclear wavefunction. The results of these analyses and extraction of structure functions will be presented. Comparison with results of other hard scattering mechanisms will also be presented.

†This work was supported in part by the Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S.Dept. of Energy.

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REACTION DEPENDENCE OF NUCLEAR DECAY LINEWIDTHS[+]

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The presence of a reaction product in the vicinity of a decaying nucleus may introduce interactions which can affect the apparent lifetime (width) of a nuclear level, giant resonance, etc. An apparent effect was found by Berkowitz[1] who proposed that $(\Gamma^{-1} - \Gamma_o^{-1})$ should be proportional to the reaction time ($\propto v_{rel}^{-1}$). Such an effect should have increased importance with heavy ions. The previous systematic investigations [1,2] have been limited to study of $^8Be^*$ (2^+) employing mostly light-ion reactions E $\lesssim$ 20 MeV.

We have studied $^8Be^*$ and $^{16}O^*$ at BNL and elsewhere using LI and HI reactions, E >20 MeV. The differences $(\Gamma^{-1} - \Gamma_o^{-1})$ for $^{16}O^*$ versus v_{rel} are shown in fig. 1. Similar results were obtained for $^8Be^*$. Although the Γ differ slightly (± 20 %) between certain reactions there is no obvious dependence on v_{rel} in agreement with ref. [2]. The data were subsequently analyzed with spectral functions of the form [3]: $N(E) = \rho(E)[A+B(E)]$ where $\rho(E)$ is a 3-body phase space term, A is background, and B(E) is a resonance line shape with $\Gamma(E) = 2\gamma^2 P(E)$.

Such a fit is shown in fig. 2. The differences in Γ noted in fig. 1 are now reduced owing to the more realistic spectral shape employed. As noted previously [3,4] the 3-body phase space alone and/or coherent interference can produce distortions (ghost states) near decay thresholds. Here, only $^9Be(p,d)$ and $^9Be(d,t)$ clearly exhibit this effect (fig. 2). Such "bumps" may be expected near any decay threshold, however.

[+]Supported in part by the NSF (Grant PHY78-07754). BNL is operated by the DOE.

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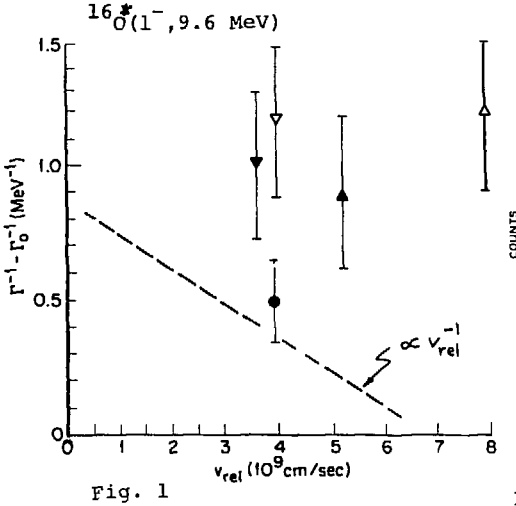


Fig. 1

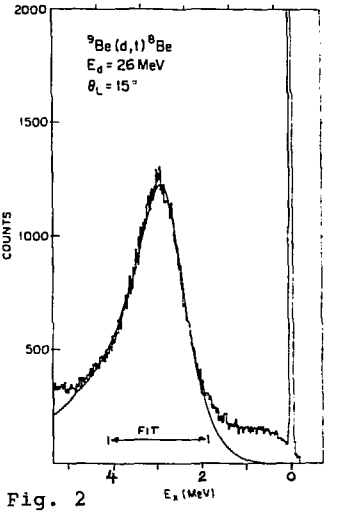


Fig. 2

SOLUTION OF THE TIME-DEPENDENT SCHRÖDINGER EQUATION IN A LIMITED SUBSPACE†

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The effort spent on the time-dependent Hartree-Fock description of heavy-ion reactions has motivated us to study different approximate solutions to the ordinary time-dependent Schrödinger equation. Numerical methods to solve the time-dependent Schrödinger equation are necessarily restricted to highly truncated subspaces of the total Hilbert space. The straightforward method of truncating the exact Hamiltonian to the selected subspace and then solving the truncated problem is nonphysical. It leads to a time evolution that is unitary within the selected subspace whereas the true time evolution generally allows for a flux of probability out of a subspace.

An alternative approximate solution in a limited subspace is based on a reformulation of the time-dependent Schrödinger equation as a second-order equation in time and projections, P and Q, onto the selected subspace and its orthogonal complement. This leads to the second-order subspace time-evolution equation[1] for

$$\psi_P(t)=P\psi(t) \qquad -\hbar^2(\partial/\partial t)^2\psi_P(t) = PH^2P\psi_P(t) \tag{1a}$$

with the initial conditions

$$\psi_P = \psi_O \text{ and } i\hbar(\partial/\partial t)\psi_P = PHP\psi_P \qquad (t=0) \tag{1b}$$

The approximation consists here in neglecting the coupling terms with the Q space part of the wave function. This should be a reasonable approximation if the P space is chosen such that it contains the initial state. Although the subspace time-evolution in general allows for a flux of probability into the excluded space, it is completely defined and solvable within the selected subspace once the subspace matrix elements of H and H^2 are known.

The degree of approximation achieved by solving eq.(1) has been studied in a number of examples including the Lipkin model, schematic Hamiltonians with parametrized matrix elements and a simple heavy ion model. It turns out[1] that the second-order subspace time-evolution is in many cases much closer to the exact solution than the result of only truncating the Schrödinger equation to the subspace.

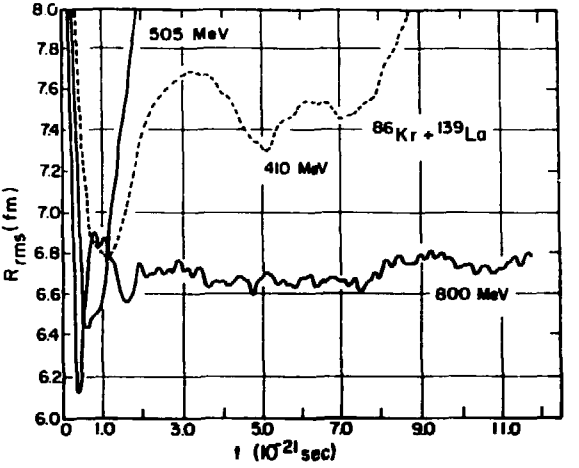
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TDHF FUSION IN $^{86}Kr + ^{139}La$ †

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In the TDHF studies[1] of the $^{86}Kr + ^{139}La$ system we have observed new dynamical features, foremost among which is the existence of a fusion energy threshold. For heavy nuclear systems such thresholds are seen in macroscopic fluid dynamic calculations. There are two distinct regimes where fusion like behavior is observed: a narrow energy region just above the Coulomb barrier at about E_{Lab} = 410 MeV, and also for a broad band of energies from E_{Lab} = 650 MeV to 850 MeV. The fusion behavior exhibited near the Coulomb barrier is significantly different from that seen at the higher energies. At E_{Lab} = 410 MeV the coalesced shape resembles an asymmetric dumbbell, while in the higher energy regime we observe much more compact shapes. In the figure the rms radius of the system is given as a function of time for three laboratory bombarding energies. The energy E_{Lab} = 505 MeV is intermediate between the two fusion regimes. In our calculations, the system is assumed to fuse if the rms radius undergoes several complete oscillations. Strictly speaking the 410 MeV configuration satisfies our definition of fusion since the radius undergoes several oscillations before separating at about 10^{-20} sec. We have followed the 800 MeV configuration for longer than 12×10^{-21} sec with no indication of separation. We conclude from our studies that the fusion behavior as a function of laboratory bombarding energy is more complicated than previously realized and that it would be interesting to investigate experimentally this system at 400 and 800 MeV.



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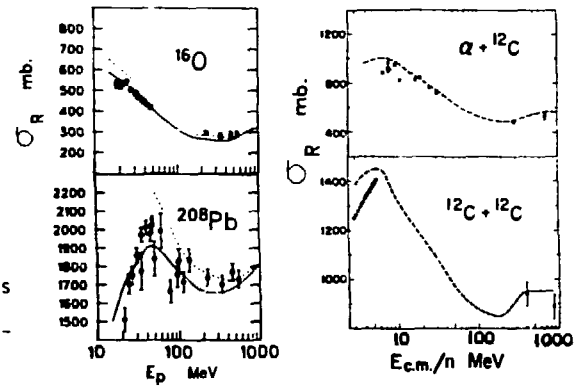
DO NUCLEON-NUCLEON COLLISIONS DOMINATE PROTON-NUCLEUS AND NUCLEUS-NUCLEUS INTERACTIONS?

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Perhaps the most interesting question in medium and high energy heavy-ion physics centers on whether or not so called "exotic" effects are in fact observable. One way to address this question is to compare the experimental parameters of heavy-ion collisions with microscopic calculations which are based on the assumption that only nucleon-nucleon collisions are involved. Deviations from such calculations could be taken as evidence for collective or coherent effects.

We are following this philosophy in a series of experiments and theoretical calculations. We start with measurements of the total reaction cross section, σ_R, and calculations based on the optical limit of Glauber theory. On the left side of the figure we display $\sigma_R(E)$ for proton collisions with ^{16}O and ^{208}Pb. The dotted curves represent the simple Glauber calculations and involve only electron scattering densities and the nucleon-nucleon total cross sections. This first-order theory has been improved on by including (with no free parameters) the effects of the Coulomb and real nuclear potentials, Fermi motion and Pauli blocking. The results, shown as solid lines, are in excellent agreement with the data from 15 to 1000 MeV. Thus proton-nucleus collisions appear to be dominated by nucleon-nucleon collisions.



The right side of the figure displays existing $\sigma_R(E)$ data for two nucleus-nucleus cases (data points shown without error bars were derived from elastic scattering data). The fact that $\sigma_R(E)$ is still strongly energy dependent and resembles the proton-nucleus data suggests that the nucleon-nucleon effects also dominate. This is supported by the simple Glauber calculations (with Coulomb corrections) which reproduce the data quite well. However, the need for more data is clear. To this end, we are in the process of measuring $\sigma_R(E)$ for nucleus-nucleus systems using the attenuation method. We are also pursuing more realistic calculations.

Should further data also agree with these nucleon-nucleon based calculations, we will be able to conclude that collective processes certainly do not constitute a large part of the reaction cross section for heavy-ion collisions and the search for such effects will have to center on more exclusive measurements with correspondingly smaller cross sections.

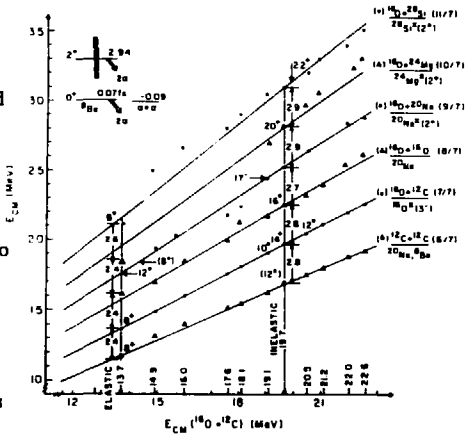
†Produced by the U.S. Department of Energy - O.M.A.

ON THE SYSTEMATICS OF HEAVY ION RESONANCES*

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The previously reported[1] correlation between resonance structures in the systems $^{16}O + ^{20}Ne$ [2] and $^{16}O + ^{12}C$ [3] appears to be a general property of heavy ion scattering resonances observed in the systems $^{12}C + ^{12}C$ and $^{16}O + ^{12}C$, ^{16}O, ^{20}Ne, ^{24}Mg and ^{28}Si. The correlation between the intermediate width resonances observed in the inelastic scattering of $^{16}O + ^{12}C$ [3] and in the indicated inelastic or reaction channels of the other systems have been found to reflect a linear scaling of the center of mass energy in the entrance channel.[1] The scaling factor is indicated in parenthesis. In each system two structures in the excitation functions of different exit channels are pronounced (e.g. $E_{c.m.}$ ($^{16}O + ^{12}C$) = 19.7 and 13.7 MeV and $E_{c.m.}$ ($^{16}O + ^{24}Mg$) = 27.8 and 18.5 MeV). These pronounced structures in the different systems are approximately correlated by the linear scaling of $E_{c.m.}$. The first structure is strongly observed in the elastic channel. If we apply the aforementioned scaling to the $E_{c.m.}$ ($^{16}O + ^{12}C$) = 19.7 resonance we find resonances in the different systems with $E_{c.m.} = 2.8\ N_\alpha$ and $L = 2N_\alpha$, where N_α, the scaling factor, appears to be equal to A/4. Extending this observation we would predict a series of resonances with $\Delta J^\pi = 2^+$ and $\Delta E_{c.m.} \approx 2.8$ MeV. The corresponding "2^+ quantum" is reminiscent of the 2^+ state at 2.9 MeV in ^8Be. The breadth of this state ($\Gamma = 1.5$ MeV) is also very similar to the width of these heavy ion resonances. For the resonances which we suggest may be correlated with the $E_{c.m.}$ ($^{16}O + ^{12}C$) = 13.7 MeV resonance we find $J^\pi = 8^+$ in four systems or a series of resonances with $\Delta J^\pi = 0^+$ and $\Delta E_{c.m.} \approx 2.4$ MeV. This "0^+ quantum" is very similar to the one observed in the binding energies of A = 4n nuclei.[4] It should be emphasized that this study is concentrated on selected well studied systems and on two pronounced resonances in each system. Many resonances were left out in this first attempt to obtain a general view of this resonance phenomena.



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EMPIRICAL FORMULA FOR THE BINDING ENERGIES OF A = 4n NUCLEI*

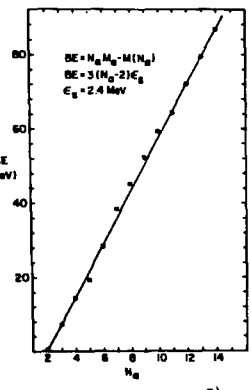
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The regular behavior of the binding energies (B. E.) of 4n nuclei led Gamow (1930) to the assumption of an independent α-particle motion within light nuclei. The relationship between the number of α-particles in the nucleus (N_α) and the α-particles B. E. s led Hafstad and Teller (1938) to the assumption of a saturated α-α interaction with hard repulsive core, such as the Van der Waals force (or Morse potential) between atoms in a molecule. Hence in this model the nucleus is viewed as "polyatomic" nuclear molecule, namely the α-particles are "arranged" in a geometry that maximizes the number of α-α bonds. Thus, the B. E. of 4n nuclei is shown[1] to arise from an assumed B. E. per bond times the total number of bonds. However, the nucleus ^{8}Be is in contradiction to this empirical rule.[1] This contradiction can be easily resolved by empirically writing the B. E. as:

$$BE(N_\alpha) = N_\alpha M(\alpha) - M(N_\alpha) = 3(N_\alpha - 2) \times 2.4 \text{ MeV}$$

This linear relationship is shown in the attached figure for all measured B. E. of 4n nuclei up to ^{56}Ni; of course this empirical formula includes ^{8}Be in a trivial fashion as well as the factor of three which is inherent to the geometrical α-bond theory.[1] The deviation of ^{20}Ne can be explained in this geometrical model, too.



With the advent of heavy ion accelerators and the study of the scattering of 4n nuclei, it has been suggested[2] that nuclear molecular configurations are realized at high excitations. It is of value to check whether there is a connection between these old alpha particle molecular models[1] and the new molecular models,[2] thus providing a bridge between the structure of light nuclei and the heavy ion resonance phenomena. This search may require a larger amount of consistent data than is actually available today. However, the systematics study[3] of available partial data may provide a hint of this possible connection. This empirical study[3] suggests the occurrence of a "0^+ quantum" at 2.4 MeV -- precisely as in the formula for the binding energies of 4n nuclei. It is well known[4] that B. E. s of even-even nuclei are given in terms of 0^+ fermion pairs. It will be interesting to examine the fundamental aspects of this apparent connection between the B. E. s of 4n nuclei and the systematics of heavy ion resonances, especially since the α-α interaction is given by a Morse potential which yields a strong S-wave interaction.

* Supported by the U. S. Department of Energy and the National Science Foundation

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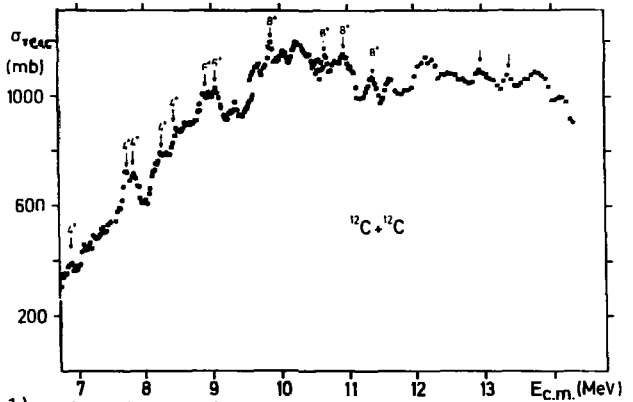
$^{12}C+^{12}C$ REACTION CROSS SECTION IN THE ENERGY RANGE OF THE QUASIMOLECULAR RESONANCES +

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One major problem for the determination of quasimolecular resonances is connected with the lack of criteria which allow to distinguish unambiguously between true resonances and nonresonant structures. This problem is in particular serious if data are analyzed which (i) exhibit fluctuations or (ii) belong to an exit channel carrying only small fractions of the resonant flux. It is obvious that the total reaction cross section represents data without these shortcomings and thus should be in particular suited for a resonance analysis.

We have determined the $^{12}C+^{12}C$ reaction cross section for energies between 7 and 15MeV(c.m.) in order to find all $^{12}C+^{12}C$ resonances which exist in this particular energy range with a high degree of confidence. The reaction cross section was deduced from carefully measured elastic angular distributions (30 angles between $\Theta_{c.m.}$ =6 and 90° simultaneously measured) by applying the sum of difference method [1]. The figure shows σ_{reac}. Many narrow structures are obviously superimposed on a smooth background. It turns out that all resonances found in the α-particle and ^{8}Be exit channels [2,3] show up in σ_{reac} as well. This demonstrates that σ_{reac} is well suited for a resonance analysis. In addition several new resonances have been found for the first time in σ_{reac}.



Since σ_{reac} has been measured in small energy steps (ΔE=25keV) it was possible to extract reliable values for the total width Γ and the entrance channel width Γ_c. It turns out that quite a few resonances carry a large fraction of the single particle width. This can be interpreted as an indication of the quasimolecular nature of the corresponding nuclear states.

+ This work was supported by the Deutsche Forschungsgemeinschaft, Bonn, W.-Germany

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"Far" and "Near" Decomposition of the scattering Amplitude for Resonance Scattering between Light Heavy Ions

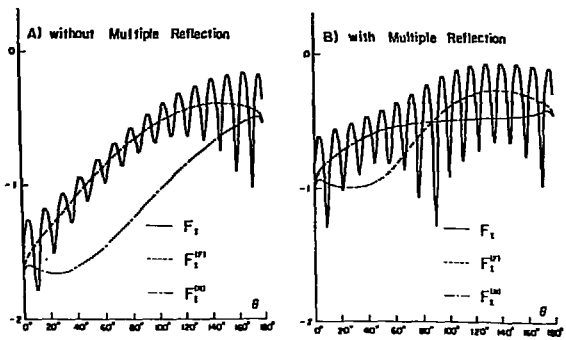
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The angular distribution and the excitation function of the elastic scattering between α particle and nucleus and between light heavy ions sometimes exhibit characteristic resonance structures. The semiclassical theory of multi-turning point scattering problem[1]) clearly relates those resonance structures to the scattering mechanism and to the optical potential parameters. On the other hand,Fuller[2]) has shown that in some cases the diffraction pattern observed in the angular distribution is due to the interference between the so called far and near components of the scattering amplitude.

In this work,we combine the semiclassical theory and Fuller's "far" and "near" decomposition of the scattering amplitude. As an example,we take the scattering between ^{16}O and ^{12}C at E_L = 43 MeV from an ℓ-dependent absorptive potential. This system is known[3]) to have resonances with long life times. The figures represent $\log_{10}(d\sigma/d\theta)$ (solid line) for the so called internal wave cross section as well as the corresponding far (dashed line) and near (dott-dashed line) components. Fig.A ignores the effect of multiple reflection of internal waves inside the potential well,while Fig.B takes this effect into account.

We thus draw following conclusions:(1)each of the far and the near components causes a fairly smooth angular distribution, (2)the diffraction pattern in the internal wave angular distribution can be attributed to the interference between the near and the far components of the scattering amplitude,(3)the multiple reflection of the internal waves enhances both of the far and the near components over the whole angular region,(4) the enhancement of the "near" component is large, especially at forward angles,(5) due to this effect, the magnitudes of two components become equal at an intermediate angle, (6)this then gives rise to a deep interference minimum around that angle.



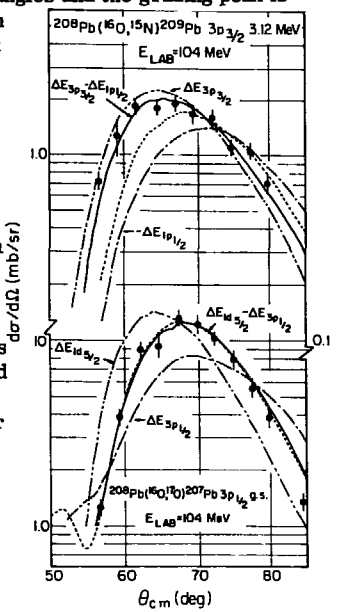
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HEAVY-ION INDUCED TRANSFER REACTIONS ON CLOSED SHELL NUCLEI*

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A large number of heavy-ion induced transfer reactions have been measured which have not been successfully described by existing distorted-wave treatments. Even for such classic situations as stripping onto a closed shell nucleus, calculated angular distributions are often too small at forward angles and the grazing peak is consistently overestimated. Calculations for neutron pickup reactions, however, are usually in agreement with data. It has been suggested that an explanation of these results may lie in the existence of shifts in valence nucleon energy levels which occur when the collision partners are in proximity.[1] The model involved calculates first-order, R-dependent energy shifts (ΔE) for both the initial (i) and final (f) states of the transferred nucleon. These shifts are incorporated into a distorted-wave Born approximation (DWBA) calculations through a state-dependent correction ($\Delta E_f - \Delta E_i$) to the exit-channel distorting potential. The figure shows results for typical reactions involving a ^{208}Pb target;[2] the solid curves include both energy shifts ($\Delta E_f - \Delta E_i$) while the dotted curves are the conventional DWBA. Also shown are the effects of including individual energy shifts. Our calculations demonstrate that for the (^{16}O, ^{15}N) reaction, a particle-state centered around lead has a larger energy shift than that of the tightly bound $1p_{1/2}$ hole in oxygen. This implies a more attractive exit-channel distorting potential ($|\Delta E_f| > |\Delta E_i|$) and an enhanced forward angle scattering. Conversely, the (^{16}O, ^{17}C) reaction has equally important shifts for both the hole-state in lead and the weakly bound $1d_{5/2}$ particle around oxygen. It is the near complete cancellation between these shifts that explains the conventional DWBA's satisfactory fit to the neutron pickup data. Similar improvements have been obtained for other transitions in this system and for analogous reactions induced by ^{12}C on ^{208}Pb.



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COUPLED CHANNEL CALCULATIONS OF HEAVY ION INELASTIC SCATTERING WITH DWBA APPROXIMATION FOR COULOMB INTERACTION

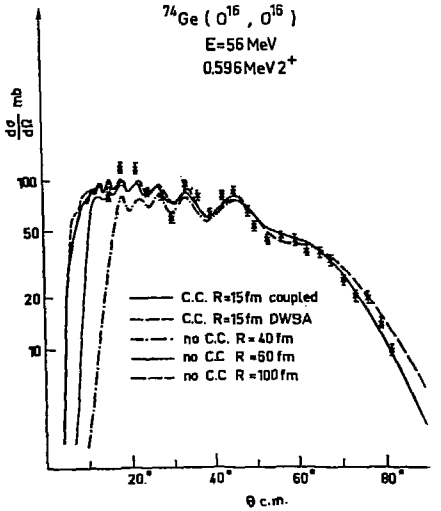
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In coupled channel calculations of heavy ion inelastic scattering, the long range behaviour of the Coulomb interaction implies the use of very large matching radii and many partial waves. To lessen these difficulties, a recurrence computation of $M(H,K,R)^{-2}_{\ell\ell} = \int_R^\infty r^{-2} H_\ell(r) K_\ell(r) dr$, where H and K are regular or irregular Coulomb functions, has been set up in the codes ECIS78/ECIS79. Any integral $M(H,K,R)^{-\lambda-1}_{\ell_i\ell_f}$ can be expressed with four of these special integrals and the Coulomb functions at the point R. With these integrals, coupled channel equations can be solved in the DWBA approximation between R and infinity[1], for every J value for which there can be interference between Coulomb and nuclear scattering. For larger J-values, integrals from the origin to infinity with regular Coulomb functions[2] are used to set up a reactance matrix.

There must be some matching radius R from which coupled channel effects matter no more. In cases where a matching radius larger than 50fm proved to be necessary, we found that the nuclear matching radius in enough in this approach.

We take as an example the inelastic scattering of ^{16}O on ^{74}Ge at 56MeV for which results with R=30, 50, 60fm were published[3]. The second-order vibrational model is used. The optical potential parameters are V=24.4, r=1.36, a=0.43 for the real part, W=36.6, r=1.27, a=0.42 for the volume imaginary part, r=1.36 for the charge distribution ; the deformations are .234 for the nuclear potentials and .208 for the Coulomb one. The plain curve is the result obtained with the Coulomb corrections at R=15fms ; the dashed curve is the DWBA result, which shows that coupled channel effects are mostly the nuclear ones. The other curves are conventional calculations with a matching radius at 40, 60 and 100fm respectively. Note the convergence of the conventional result to the plain curve except between 5° and 10° where the curve is sensitive to very high partial waves (400 to 600).



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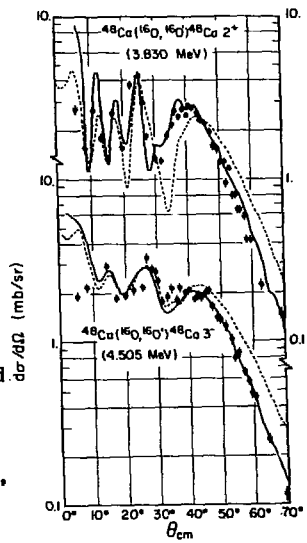
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ENERGY SHIFTS AND HEAVY-ION INELASTIC SCATTERING*

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The conventional distorted-wave Born approximation (DWBA) treatment of heavy-ion induced inelastic scattering often fails to describe basic features of the experimental data. In particular, the Coulomb-nuclear interference minimum is improperly positioned and the cross section falls too slowly at large angles. Even an arbitrary variation of the nuclear deformation length (an ad-hoc procedure) cannot consistently improve fits to data. We have proposed a model which successfully explains both inelastic and transfer reactions by accounting for shifts in valence nucleon energy levels which result from the force introduced by the proximity of the colliding ions.[1] In lowest order, only the energy of a state is altered by the pertubation; there is no readjustment of the wavefunction (or the formfactor).[2] Thus for inelastic excitations, this diabatic approximation yields an energy correction (non-diagonal in ℓ) for the target nuclei's excited state which depends on the separation and relative orientation of the ions.



The solid curves in the figure demonstrate the success of this approach for two inelastic excitations.[3] In these calculations the nuclear deformation length was chosen to be equal to the Coulomb value determined by measured electromagnetic transition rates. The conventional DWBA calculations are shown as dashed curves. The present model is not meant to represent an exhaustive treatment of the energy shift phenomenon, but its evident success clearly demonstrates that this effect (long familiar for atomic scattering) must also be considered for heavy-ion nuclear reactions.

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ERICSON FLUCTUATIONS IN PRE-EQUILIBRIUM REACTIONS†

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Both the Hauser-Feshbach expression for the cross section, and the Ericson expression for the auto-correlation function, must be generalized from their compound-nucleus forms in order to describe pre-compound reactions. We have found[1] that the generalizations needed to describe the multi-step compound part of pre-equilibrium reactions can be obtained very simply provided that the pre-equilibrium flux arises from a sequence of "nested doorway" states (as in the exciton model); i.e., from groups or classes of doorway states whose widths are arranged in the sequence

$$\Gamma_1 >> \Gamma_2 >> \ldots >> \Gamma_N \ , \tag{1}$$

where the states in the Nth class are defined to be the actual fine-structure resonant eigenstates of the compound system.

If a nested sequence, I_n, of energy-averaging intervals is interpolated between the Γ_n's,

$$\Gamma_{n-1} >> I_n >> \Gamma_n \ , \tag{2}$$

it can be used to define a sequence of optical S-matrices, $\bar{S}_n \equiv \langle S \rangle_{I_N}$, in terms of which we can write $S = \bar{S}_1 + \sum_n^N S_n^{f\ell} \equiv \bar{S}_1 + (\bar{S}_2 - \bar{S}_1) + \ldots + (S - \bar{S}_N)$. Then defining $(\sigma_n^{f\ell})_{cc'} \equiv \langle |(\bar{S}_n^{f\ell})_{cc'}|^2 \rangle_{I_1}$, we are able to obtain the desired generalization of the auto-correlation function

$$\begin{aligned} C_{cc'}(\varepsilon) &\equiv \langle \sigma_{cc'}(E)\sigma_{cc'}(E+\varepsilon) - \bar{\sigma}_{cc'}(E)\bar{\sigma}_{cc'}(E+\varepsilon) \rangle_{I_1} \\ &= \left| \sum_{n=1}^{N} (\sigma_n^{f\ell})_{cc'} \frac{\Gamma_n}{\Gamma_n + i\varepsilon} \right|^2 + 2\sigma_{cc'}^{dir} \sum_{n=1}^{N} (\sigma_n^{f\ell})_{cc'} \frac{\Gamma_n^2}{\Gamma_n^2 + \varepsilon^2} \ . \end{aligned} \tag{3}$$

It is a direct extension of Ericson's expression for a single class (N=1), and is found to provide a convincing fit to recent data of Bonetti et al.[2]

In like manner we find the fluctuation cross section to be

$$\langle \sigma_{cc'}^{f\ell} \rangle_{I_1} = \sum_{n=1}^{N} X_{n,cc} \, X_{n,c'c'} + X_{n,cc'} \, X_{n,c'c} \ , \tag{4}$$

with $X_{n,cc'} \equiv (2\pi/\Gamma_n D_n)^{\frac{1}{2}} \langle g_{qc}^{(n)} g_{qc'}^{(n)*} \rangle_{I_n}$, where $g_{gc}^{(n)}$ is the partial-width amplitude for doorway q to decay into channel c. Since the X_n's can be written explicitly in terms of the transmission matrices P_n and P_{n+1}, Eq. (5) is a direct generalization of the 1-class Hauser-Feshbach formula.

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EXCITATION FUNCTIONS OF THE $^{197}Au(\alpha,2n)^{199}Tl$ AND $^{197}Au(\alpha,2p)^{199}Au$ REACTIONS

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It is well known that, in an α induced reaction, a high energy tail of the excitation function can be explained in terms of pre-equilibrium emission of particles. Although it is possible that more than two particles be emitted with high energies, it is very difficult to exclusively observe these processes because of small cross sections. Aiming to obtain informations to what extent two-fast-particle emission plays a role in α induced reactions, we have measured the excitation functions of two reactions; $^{197}Au(\alpha,2n)^{199}Tl$ and $^{197}Au(\alpha,2p)^{199}Au$. The Coulomb barrier ($\sim$10 MeV for p) suppresses the proton emission in the evaporation stage and thus it will be possible to select out the process that two fast protons are emitted.

A stack of Au foils was bombarded by the 67 MeV α beam from the SF cyclotron at Institute for Nuclear Study. The higher energies of 109 MeV and 118.5 MeV were also dilivered from the RCNP cyclotron, Osaka Univ.. The γ rays following the decay of ^{199}Tl ($t_{1/2}$= 7.42 hr) and ^{199}Au ($t_{1/2}$=3.13 d) were measured with use of a Low Energy Photon Spectrometer(LEPS). Since both isotopes decay to ^{199}Hg, we identified the mother isotopes by taking into account their half-lives and decay schemes. In contrast to the $(\alpha,2n)$ reaction which peaks corresponding to the compound reaction, the excitation function of the $(\alpha,2p)$ reaction increases monotonically and becomes almost flat at higher energy than 70 MeV as shown in Fig. 1. The two excitation functions become close to each other at higher energy, but the $(\alpha,2n)$ reaction is still $\sim$4 times larger than the $(\alpha,2p)$ reaction at 120 MeV. The difference can be understood by considering the Q values and the Coulomb barrier for a proton.

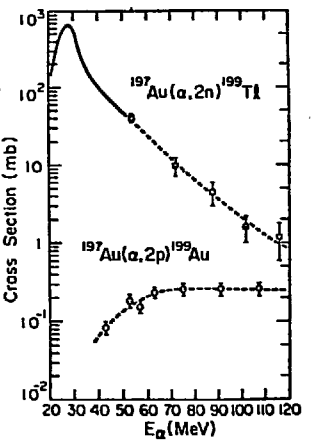


Fig. 1
Excitation functions of the $^{197}Au(\alpha,2n)^{199}Tl$ and $^{197}Au(\alpha,2p)^{199}Au$ reactions. The solid line is the measured excitation function given in ref [1].

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STATISTICAL APPROACH TO TDHF-EXTENSIONS

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The time-dependent Hartree-Fock approximation[1]) provides a one-body theory for the nuclear dynamics as long as the residual nucleon-nucleon interaction is negligible. In contrast to microscopic transport theories, TDHF may be used to identify the relevant collective variables from microscopic input. With rising bombarding energy, however, the approximation breaks down because two-body collisions become increasingly important. This has been recognized in several analytical[2]) and numerical[3]) investigations of collision terms.

We propose to use statistical assumptions on the matrix elements of the residual interaction $V(t) = H - H_{MF}(t)$ to go beyond the TDHF approximation. An investigation of the weak-coupling model

$$\overline{V_{ij}(t)} = 0 \quad , \quad \overline{V_{ij}(t)V_{kl}(s)} = Q_{ijkl}\,\delta(t-s)$$

with many-body states i, j, k, l yields for the average A-body density matrix $\overline{\rho_A}(\vec{x}_1 \ldots \vec{x}_A\,;\, \vec{x}_1' \ldots \vec{x}_A'\,;\, t)$ the equation

$$i\dot{\overline{\rho}}_A = \left[H_{HF}(t), \overline{\rho}_A\right] + i\left[\overline{V\overline{\rho}_A V} - \tfrac{1}{2}\overline{\rho}_A\overline{VV} - \tfrac{1}{2}\overline{VV}\overline{\rho}_A\right] .$$

Due to the statistical averaging which causes a loss of phase memory this equation is no longer time-reversal invariant. The reduction to a one-body problem by tracing over (A-1) variables and using the statistical properties of the matrix elements of V between two-body states leads to a natural termination of the hierarchy for $\overline{\rho}$ at the level of $\overline{\rho_3}$. The resulting equation for $\overline{\rho_1}$ is in its mean-field part comparable to the TDHF result whereas the incoherent contributions from the nucleon-nucleon residual interaction lead to the collision term. In the weak-coupling limit memory effects are absent and a numerical solution may be feasible. The limit is expected to be realistic for a suitable choice of the basis (e.g., the adiabatic basis) which is used to formulate the statistical assumptions.

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A Time Dependent Formulation of Statistical Heavy Ion Collisions

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We have extended[1]) a semiclassical theory of heavy ion collisions[2]) to fully take account of the fluctuations of the relative motion around the classical trajectory and to explicitly treat both of the excitations of compound states of each fragment and of the prompt emission of light particles,i.e. the emission of light particles from a nucleus due to their collision with the moving wall created by the other nucleus.

We start from the many body von Neumann equation. The principal features of the present theory are as follows:1)the intrinsic state is not approximated by the canonical distribution function,but is determined based on a von Neumann equation,2)the coupling hamiltonian is not necessarily assumed to be weak,3)the effect of Green functions which describe the multiple scattering of particles with the moving wall are taken into account. We have applied the theory to Deep Inelastic Collisions where the matrix elements of the coupling hamiltonian form a statistical ensemble. The present theory is thus intimately related to a work of Brink et.al.[3]).

Based on the random coupling assumption, the time evolution of the intrinsic state is described by the coupled master equations,

$$\frac{\partial}{\partial t}\hat{\rho}^{(B)}_{mm}(t) = \sum_n \int_{t_0}^{t} d\tau\ (\hat{K}(t,\tau))_{mmnn}\{\hat{\rho}^{(B)}_{nn}(t)-\hat{\rho}^{(B)}_{mm}(t)\}$$
$$-\frac{1}{\hbar}\Gamma^{\uparrow}_{m}(t)\ \hat{\rho}^{(B)}_{mm}(t) + \frac{1}{\hbar^2}\int_{t_0}^{t} d\tau\ \Sigma_\alpha\ W_{m\alpha}(t,\tau)\hat{\rho}^{(B)}_{\alpha\alpha}(t), \qquad (1)$$

and the corresponding equation for $\hat{\rho}^{(B)}_{\alpha\alpha}(t)$.In eq.(1),$\hat{\rho}^{(B)}(t)$ and $\hat{K}$ are the density operator of the intrinsic motion and the memory kernel,while {m} and {α} are the discrete compound states and the scattering states of a nucleus respectively. The first, the second and the third terms on the rhs of eq.(1) describe the heat up of the intrinsic state of nucleus by the energy supply from the relative motion,the emission of light particles and the feed back from the open channels respectively. The relative motion is described in terms of the Newton equation and a diffusion equation. Their structure is the same as the corresponding equations in the linear response theory(LRT)[4]). They are,however,modified in the sense 1)-3) mentioned before.

We derive following conclusions:(a)taking finite decay time of Green functions into account is vital to correctly estimate the time scales of the memory kernel,the response and the correlation functions,(b)the form factor of the Green functions differs in the limits of weak and strong coupling,and thus leads to different expressions of the friction tensor and to different fluctuation dissipation theorems in the two limits,(c)the Green function naturally gives rise to the cut-off time,which has been phenomenologically introduced in calculating the friction tensor based on LRT,(d)various Green functions can be related to each other,especially when the spreading width far dominates the escape width.

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ANGULAR MOMENTUM DYNAMICS PROBED BY EVAPORATED LIGHT PARTICLES

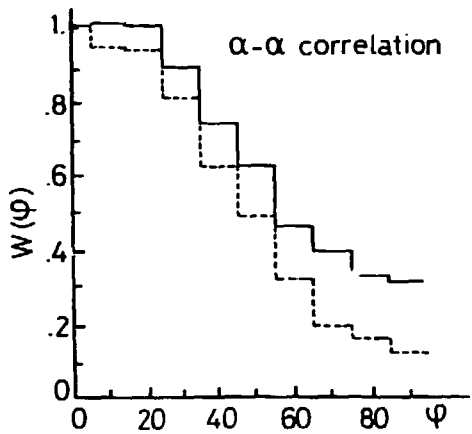
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The evaporation of light particles from heavy ion collision products can be a source of informations not only on the nuclear states at high excitation energies and high angular momenta, but also on the nuclear collision dynamics itself.

We present some theoretical calculations, obtained using a recently deviced Monte-Carlo code [1], which show such a possibility. In particular we present calculations of i) Angular distributions of light particles in fusion reactions, ii) Angular distributions of fusion residues, iii) Angular correlations between light particles, iv) Light particle angular distributions from partially polarized nuclei (with reference to deep inelastic collisions).

In the figure we report the results of the calculation for the alpha-alpha angular correlation following the $^{28}Si + ^{28}Si$ fusion reaction. The figure shows the sensitivity of the correlation on the assumed spin population of the fused nucleus. Two detectors are supposed to be placed in a plane perpendicular to the beam direction. The correlation, as a function of the angle φ between the two detectors, is calculated for 60 MeV in the C.M. and for the 2alphas-1proton decay, which is the only channel involving two alphas (it feeds the residue ^{47}V). The full line is the result one gets assuming a "triangular distribution", while the dashed one corresponds to an initial spin population with a low angular momentum window. The conclusion one can draw from the figure is that it could be possible to test experimentally the low angular momentum window, present in e.g. TDHF calculations, by alpha-alpha correlation measurements.



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MEAN FIELD THEORY AND STATISTICAL TREATMENT OF RESIDUAL INTERACTIONS

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The time-dependent Hartree-Fock theory is generalized in order to include two-body collisions. The density matrix $\rho^{(A)}(t)$ of an interacting many-particle system (A particles) can be considered as the sum of an uncorrelated part and a correlated part $\rho^{(A)}(t) = \rho_0^{(A)}(t) + \rho^{(A)}_{cor}(t)$. The uncorrelated part $\rho_0^{(A)} = \mathcal{A}\rho^{(1)}(1,t)\ldots\rho^{(1)}(A,t)$ is defined by the anti-symmetrized product of the one-particle density matrices $\rho^{(1)}(t)$. The restriction of many-particle density matrix to the uncorrelated part is equivalent to the single-determinantal description and eliminates the residual interactions. In order to include the residual interactions in the equation of motion we use the Nakajima-Zwanzig projection formalism. This leads to a generalized equation for the one-particle density matrix

$$i\frac{\partial}{\partial t}\rho^{(1)}(t) = \mathcal{L}\rho^{(1)}(t) - i\int_{t_0}^{t} dt' \mathrm{Tr}\,\{L_1 G(t,t') L_1 \rho_0^{(A)}(t')\}_{A-1} \quad (1)$$

where $\mathcal{L}$ and L_1 denote the Liouville operators corresponding to the mean field and the residual interactions, respectively and $G(t,t')$ is a propagator expressed in terms of the total Liouville operator L. The first term on the r.h.s of (1) describes the changes in the one-particle density matrix due to the mean field. The second term (collision term) describes the changes due to the residual interactions. The exact equation for $\rho^{(1)}(t)$ provides a natural extension of the mean field theory and forms a basis for further approximations. We simplify this equation by introducing statistical properties of the residual interactions. In the limit where the mean free path λ of the particles is larger than the correlation length σ of the residual interactions, $\lambda >> \sigma$, the collision term in (1) can be approximately evaluated. We consider the expansion of $\rho^{(1)}(t)$ with respect to the eigenstates of the mean field Hamiltonian. As a result of the statistical approximation, the diagonal elements of the density matrix satisfy a master equation[1,2].

The expectation value of a many-body operator contains contributions due to the correlations which can not be described by the one-particle density matrix alone. In the present formalism an equation is obtained for the rate of change of the expectation value of an operator O.

$$\frac{d}{dt}\langle O\rangle = \langle -iO\mathcal{L}\rangle - \int_{t_0}^{t} dt' \langle O L_1 G(t,t') L_1\rangle_0 \quad (2)$$

which takes both the mean field and the correlations into account. Here, in the second term $\langle\ldots\rangle_0$ denotes the average over the uncorrelated density matrix. The structure of (2) is similar to the Langevin equation of statistical mechanics. The first term on the r.h.s. can be regarded as the generalized force arising from the mean field. The second term can be considered as the contributions to the rate of change of the expectation value arising from a fluctuating force due to the residual interactions. The equation (2) can be used to calculate the mean value and the variances of the collective variables and the associated currents. It turns out that the correlations introduce fluctuations primarily into the current distributions, which eventually broaden the distributions of the corresponding collective variables like a diffusion process.

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INITIAL CORRELATIONS IN DISSIPATIVE COLLISIONS AND COMPOUND-NUCLEUS FORMATION

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During the fast approach of the nuclei the individual nucleons cannot follow the lowest possible (adiabatic) levels. The nucleonic wave functions stay essentially unchanged (conservation of number of nodes). Such a 'diabatic' behaviour is encountered also for electrons in atom-atom collisions. The motion of nucleons on diabatic levels gives rise to a large potential energy in addition to the adiabatic potential. The doorway configuration which is formed during the fast approach of the two nuclei can be considered as a highly correlated state of (n particle, n hole)-excitations with respect to the adiabatic configuration. This correlation is effectively lost by the decay via residual interactions. The time which is necessary to obtain local statistical equilibrium between all excited states at a given shape, is denoted by τ_{loc} and expected to be of the order 10^{-21}s. To take account of these initial correlations we have introduced a new concept in transport theories[1], the explicitly time-dependent dynamical potential which decays with time constant τ_{loc} from the initial diabatic value to the final adiabatic value.

A Fokker-Planck equation including the dynamical potential has been applied[1] to the compound nucleus ^{248}Fm. In general, the total cross-section consists of three components. For $0<\ell<\ell_{crit}$ or ℓ_{cap} there is compound-nucleus formation, for $\ell_{crit}<\ell<\ell_{cap}$ a slow component and for $\ell_{cap}<\ell<\ell_{gr}$ the familiar fast component of dissipative collision exist. For Ar + Pb excitation functions for the capture cross-section σ_{cap} have been calculated. For $\sigma_{cap}\leq\sigma(\ell_{crit})$ the capture is expected to lead to compound-nucleus formation. For small bombarding energies the compound-nucleus formation is strongly suppressed. At higher bombarding energies a long-living component of dissipative collision occurs. The threshold for this component is well above the interaction barrier V_C. A significant dependence of the capture cross-section is roughly determined by an energy-independent upper limit ℓ_{cap} of relative angular momentum which depends on τ_{loc}. As a result of this, the capture cross-section exhibits a rather pronounced maximum as function of the bombarding energy. For more symmetric projectile-target combinations the depth of the pocket in the (adiabatic) potential is reduced and hence, the capture cross-section goes down correspondingly. Experimental evidence for the existence of the long-living dissipative component has been reported earlier[2].

We hope that the further study of excitation functions for various projectile-target combinations will reveal more about the role of the dynamical potential and hence, about the peculiar interplay between single-particle and collective degrees of freedom in nuclei. Calculations including the dynamical treatment of deformations are in progress[3].

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NUCLEAR SPIN ALIGNMENT OF $^{12}B_{gs}$ PRODUCED IN HEAVY ION REACTIONS[+]

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From measurement of beta ray asymmetry, spin alignment as well as polarization was determined for $^{12}B_{gs}$ ($I^{\pi}=1^{+}$, $T_{1/2}=20.3$ ms, $E_{\beta max}=13.37$MeV), produced in heavy ion reactions (^{14}N, ^{12}B) on ^{100}Mo and ^{232}Th. Products ^{12}B were implanted in a magnesium single crystal, the c axis of which was parallel to the static magnetic field $\vec{B}_0$ applied in the direction of the reaction normal. Splitting of magnetic substates in $^{12}B_{gs}$ was induced by the magnetic dipole and the electric quadrupole interactions. Rf transitions were induced between the selected magnetic substates and the populations were interchanged. A set of resultant nuclear polarization was obtained from the ratio of beta ray counts in a pair of counter telescopes at 0° and 180° to $\vec{B}_0$. Thus, the original alignment A $=1-3a_0$ and polarization $P=a_1-a_{-1}$ were determined. Here, a_m denote the original m state populations.

Observed alignment is shown, together with polarization[1] as functions of ratio of energy loss $Q_{gg}-Q$ to Coulomb energy V_C, in Fig.1 . The experimental values are approximately 1/10 of predictions of classical models; A=1, P=±1. This suggests that there are depolarization mechanisms, which populate m=0 state in the collision process.

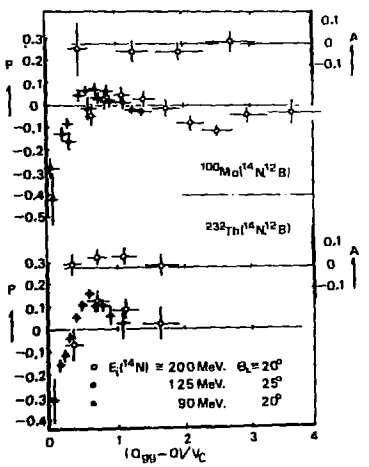


Fig.1 Alignment A and polarization P of ^{12}B. Sign of the polarization is positive, when parallel to the reaction normal to $\vec{k}_f \times \vec{k}_i$.

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EJECTILE POLARIZATION IN HEAVY-ION REACTIONS*

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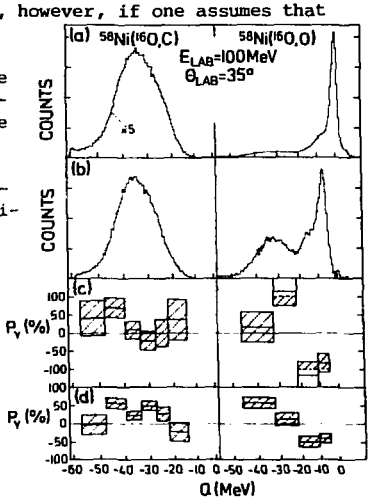
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The polarization of ^{12}B (g.s.) ejectiles from $(X, ^{12}B)$ transfer reactions shows mainly features characteristic of one-step processes[1] whereas, for similar reactions, the amount and orientation of the spin transferred to the heavy fragment supports a multi-step reaction mechanism which can be described by a friction model[2,3]. Here we report on a measurement of the spin polarization of excited projectile-like fragments from the reaction $^{16}O + ^{58}Ni$ at 100 MeV. For this case the heavy-fragment polarization is already known[2] and serves as basis for a study of polarization correlations between the reaction partners.

We have used a double-symmetric detector setup consisting of two heavy-ion telescopes at ±35° in the reaction plane and two γ-ray polarimeters of the transmission type perpendicular to the reaction plane. We have determined the circular polarization of discrete γ-ray lines from the ejectile deexcitation and of the underlying statistical continuum (E_γ>3 MeV) due to the heavy-fragment decay as a function of Q.

The results are shown in the figure together with free (a) and γ-ray coincident (b) particle spectra. For the $^{16}O, 3^- \rightarrow O$, transition (right hand side of c) we find a large polarization with values $|P_\gamma|$ up to 100% and the same sign as for the heavy fragments. This can be seen from the polarization of the continuum (d). The situation is different in the transfer channel. Here the $^{12}C(2^+)$ polarization decreases from $P_\gamma \equiv 40\%$ at Q≡-15 MeV to small negative values at Q≡-30 MeV (c, l.h.s.). This P_γQ dependence, familiar from $(X, ^{12}B)$ reactions[1] and qualitatively understood in terms of Brink's kinematic conditions[4], seems to be a general phenomenon associated with the quasi-elastic transfer. The increase of P_γ towards positive values with further increasing energy loss is not connected with a transition from positive to negative scattering angles (c,d). It can be understood, however, if one assumes that the correlation between polarization and Q-value established in the quasi-elastic region also holds in the deep-inelastic region. Since the same kinematic considerations[4] are sufficient to also explain sign and magnitude of the $^{16}O(3^-)$ polarization it seems that the ejectile excitation in these asymmetric systems can be treated as a one-step process irrespective of the multi-step character of the associated heavy fragment excitation.



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BOUNCE-OFF EFFECTS IN RELATIVISTIC NUCLEAR COLLISIONS

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Highly inelastic fragments have been observed at a laboratory scattering angle of 90^{o} in coincidence with a spray of light fast particles centered at an azimuthal angle of 180^{o} from the slow heavier fragment. This type of events have been observed in relativistic heavy ion reactions where Au was bombarded with a beam of 400 MeV/n ^{20}Ne. For the lighter slow fragments, Z=6, the azimuthal distribution of coincident fast particles appears nearly isotropic, but for slow fragments with Z>26 the 180^{o} enhancement is clearly visible. A typical event in this later category might involve 12 fast particles 80% of which are emitted on the side of the beam opposite of the slow Z>26 fragment. This observed asymmetry in the coincident fast particles suggests conservation of momentum with the asymmetry being more pronounced for the heavier slow fragments which carry more momentum perpendicular to the beam ($p_{\perp}$) by virture of their mass.

It is particularly interesting to understand the mechanism responsible for these reactions since $p_{\perp}$ can be quite large. Perpendicular momenta of 2 GeV/c have been measured for Z=26 fragments- this is greater than can be transfered via a single nucleon-nucleus collision. Such high momentum transfer events, therefore, indicate a cooperative nuclear interaction mechanism between many nucleons of the projectile and the target. Furthermore, calculations using a nuclear fluid dynamics model[1] appear to reproduce this sort of phenomena. According to this model, at intermediate impact parameters the projectile is deflected due to high thermal and compressional pressures in the reaction zone. Following deflection the projectile explodes, giving rise to the observed spray of fast light particles. The target residue is than detected as the heavier fragment with a large $p_{\perp}$.

Measurements now in progress to explore this bounce-off effect further may test additional implications of the model (e.g. deflection function). In particular the current measurements extend the region of light fast fragment detection forward to smaller angles than our previous measurements. In the spirit of this model one expects less violent events with larger impact parameters to generate more forward peaked light particle distributions and, likewise, heavier, slower, target residues.

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MICROSCOPIC CALCULATION OF VISCOSITY COEFFICIENT IN HEAVY NUCLEI

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We present a realistic calculation of the viscosity coefficients for ^{236}U from the ground equilibrium shape to the saddle point based on the linear response theory in which the single particle spectra and wave functions are provided by generalized Nilsson model. The dependence of viscosity coefficients $\gamma_{\delta_2\delta_2}$, $\gamma_{\delta_3\delta_3}$, $\gamma_{\delta_4\delta_4}$, $\gamma_{\delta_2\delta_3}$, $\gamma_{\delta_3\delta_4}$, $\gamma_{\delta_2\delta_4}$ on the collective variables δ_2, δ_3, δ_4 is studied at various values of the nuclear temperature with the smearing width $\Gamma = 0.1\hbar\omega_0$. It is found that our results coincide with those of Nix's empirical parameters in their dynamic calculations of nuclear fission.

Fig.1. shows the dependence of the viscosity coefficient $\gamma_{\delta_2\delta_2}$ on δ_2.

Fig.2. shows the dependence of the viscosity coefficients on δ_4.

Fig.3. shows the dependence of the viscosity coefficients on δ_3.

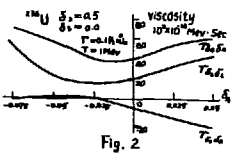


Fig. 2

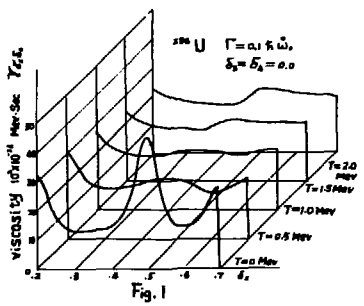


Fig. 1

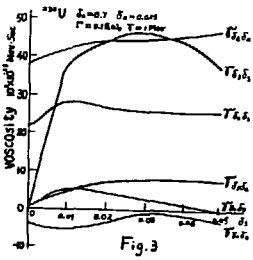


Fig.3

HIGH-MULTIPOLE ISOVECTOR MODES AND CHARGE FLUCTUATIONS IN HEAVY ION REACTIONS

L.G. Moretto, C. R. Albiston and G. Mantzouranis

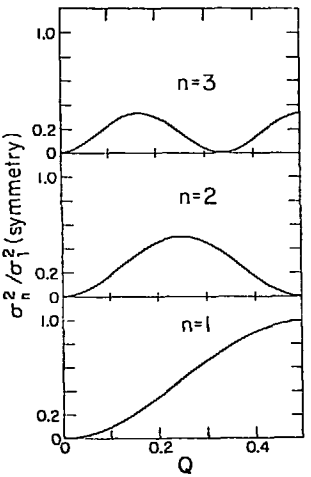
Nuclear Science Division
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Berkeley, Calif. 94720

The isobaric charge distribution of fragments in deep-inelastic scattering provides information regarding the thermal and quantal fluctuations of the axial component of the E1 mode associated with the intermediate complex.(1) There have been allegedly contradictory findings of small and large charge fluctuations at large and small asymmetries, respectively.

In order to elucidate the role played by asymmetry and the higher-order isovector modes, we propose a simple model in which the intermediate complex is approximated by a cylinder split into two parts, and study its axial isovector modes.

Using the Steinwedel-Jensen model, we obtain the mode frequencies $\omega_n = k_n u$, where u is the isospin sound velocity and $k_n = (\pi/2a)n$, the wavenumber of the nth mode, is given by the boundary conditions of the mode wave functions on the cylinder. The potential energy as a function of the charge excess of one of the fragments yields the stiffness constant

$$c_n = \pi^2 X\left(\frac{A}{Z^2}\right) \frac{n^2}{\sin^2[n\pi Q]}$$



where X is the liquid drop symmetry energy coefficient and Q is the degree of symmetry. The stiffness constant for the lowest mode is compared to that obtained for two touching spheres using the liquid drop mass formula.

In the limit of low temperature, the partial charge widths are given by $\sigma_n^2 = \hbar\omega_n/2c_n = \sigma_1^2(\text{symmetry})\sin^2[n\pi Q]/n$ and are plotted in the figure as a function of Q for the first few values of n. The contribution of the higher modes is comparable to that of the lowest one, and the partial widths of all the modes depend strongly on Q. At complete asymmetry (Q=0), all partial widths vanish.

The total charge width

$$\sigma^2 = \sigma_1^2 \ (\text{symmetry}) \sum_n \frac{\sin^2[n\pi Q]}{n}$$

diverges logarithmically; however, the finite size of the nucleon sets on upper limit on n.

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SYSTEMATICS IN ^{3}He OPTICAL POTENTIAL VOLUME INTEGRALS†)

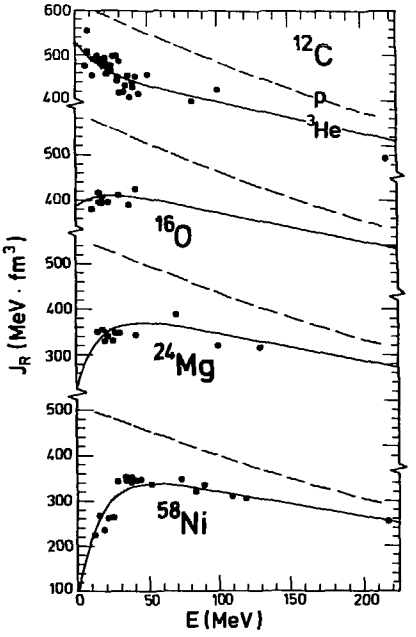
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The volume integral per interacting nucleon pair $J_R = (A_p \cdot A_t)^{-1} \cdot \int V(r) 4\pi r^2 dr$ provides a tool for removing the discrete ambiguity in optical model analyses of composite projectile elastic scattering data. In the Watanabe model its value is determined via uniquely known nucleon-nucleus potentials.

Recent analyses[1] of ^{3}He elastic scattering, however, indicate significantly lower magnitudes of $J_R(^3\text{He})$ as compared to $J_R(p)$. For comparison, the figure displays as dashed curves the corresponding results for proton scattering[2] (at $E_p = 1/3 E_{^3\text{He}}$).

We want to stress in particular the drastic change in the trend of $J_R(E)$ at $E < 40$ MeV for ^{58}Ni. This behavior - though qualitatively interpreted in terms of Pauli blocking, ^{3}He-intrinsic motion and breakup[3] - is far from being understood quantitatively. The solid curves represent cuts through the 3-dimensional surface which approximates the values of $J_R(E,A)$ obtained from an extended analysis of own and literature data. They show how the behavior of $J_R(E)$ at small energies gradually changes to the opposite trend from ^{58}Ni towards the lighter nuclei.



†) Supported by the "Bundesministerium für Forschung und Technologie"

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A PARITY DEPENDENT POTENTIAL MODEL APPLIED TO BACKWARD ANGLE ANOMALY IN INELASTIC α SCATTERING

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Backward angle anomaly appears in inelastic α scattering from calcium isotopes as well as in elastic one and has not been understood by the standdard optical potential model[1,2]. We apply the parity dependent potential model[3] to the inelastic scattering. The experimental data of $\alpha+^{40}Ca$, ^{42}Ca, ^{44}Ca and ^{48}Ca at E_α=24 and 29 MeV are systematically analyzed with the coupled channel method. The vibrational form factor with a complex coupling is used.

Fig.1 and Fig.2 show the calculated results for $\alpha+^{40}Ca$ and $\alpha+^{48}Ca$ respectively. While the standard optical model calculation(dotted lines) deviates from the experiment in the order of magnitude one or two,the parity dependent potential model caculation(solid lines) reproduces the data satisfactorily at backward angles,except for $^{40}Ca(2^+;3.90$ MeV) for which the vibrational form factor is not appropriate. Good agreements are also obtained for inelastic α scattering from ^{42}Ca and ^{44}Ca. It is found that the parity dependent potential model is useful for backward angle anomaly in inelastic scattering as well as in elastic one. Details will be reported elsewhere[4].

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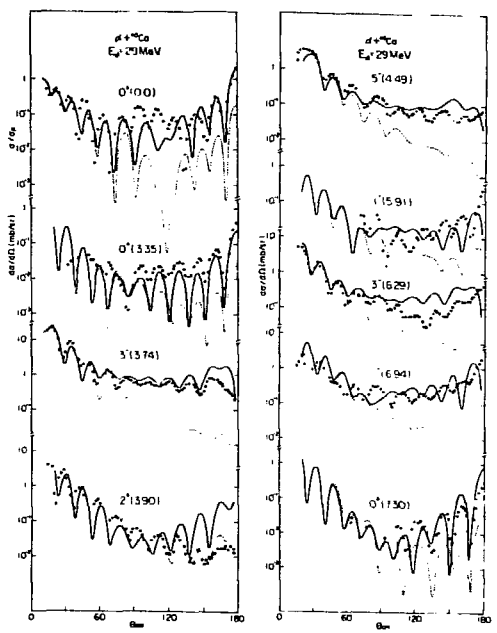


Fig.1

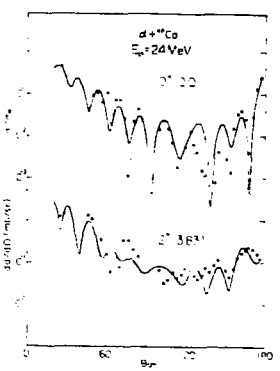


Fig.2

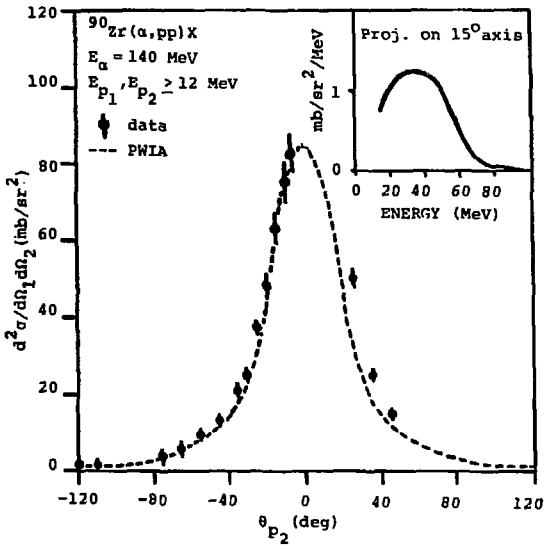
CORRELATIONS BETWEEN BEAM-VELOCITY PROTONS FROM α BREAKUP[†]

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Earlier coincidence studies[1]) have demonstrated that target absorption with escape of a single beam-velocity fragment (absorptive breakup) is the dominant process contributing to the singles spectra in α particle fragmentation.[2]) We have recently observed the emission of two beam-velocity protons in coincidence. Using a ^{90}Zr target with $E_\alpha = 140$ MeV we have measured coincidences between protons at 15° and protons at other angles. The 2-dimensional E1 vs. E2 spectra show a broad continuum structure which peaks at $E_{p_1} \sim E_{p_2} \sim 1/4\ E_\alpha$. Projections on either energy axis show peaks at $\sim 1/4\ E_\alpha$ with shapes consistent with energy distributions of the singles spectra. This effect is most pronounced at small angular separations but persists even at separation as large as 50°.

The figure shows the angular correlation for one proton at 15° as a function of the angle of the second proton. The inset of the figure shows a typical energy distribution for coincident protons at 15°. Assuming symmetry about the beam axis, we have estimated the 2-proton relative contribution to the proton singles yield at 15° to be at most ~10% by integrating the angular correlation of the figure. Our estimate is an upper bound on the relative contribution to the 15° proton singles based on the assumption that the p-n angular correlation is the same as the p-p angular correlation and assuming that the two unobserved neutrons fused with the target nucleus, i.e., the projectile-fragment multiplicity is 2. The observed angular correlation function between two beam-velocity protons suggest that the exit-channel p-p momentum distributions are not correlated.



[†]This work was supported in part by the National Science Foundation.
[††]Permanent address: ORNL, Oak Ridge, Tennessee.

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α-α ELEMENTARY AMPLITUDE AND HIGH-ENERGY NUCLEUS-NUCLEUS COLLISION

Liu Yuan, Li Yang-guo and Wang Ru-ling

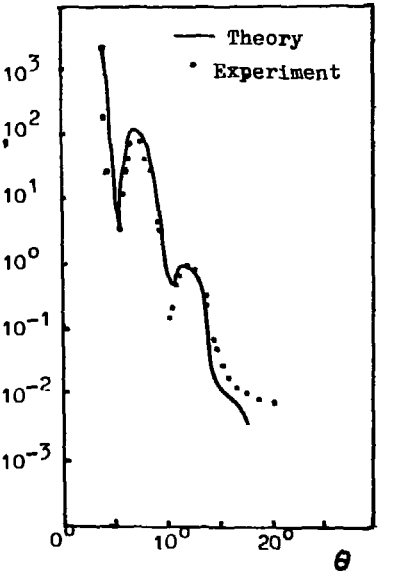
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Many experiments[1] on high energy nucleus-nucleus collision show that in small angles, there are clear diffractive patterns and multiple scattering features of collision.

It is know that in nuclei, in particular light nuclei, there exists cluster structure, therefore, it is interesting to describe the high-energy nucleus-nucleus collision by using the cluster model in the frame of Glauber's theory.

In this paper, the α-α elastic scattering amplitude $f_{\alpha\alpha}$ in the eikonal approximation is taken as the elementary amplitude, using the same approximation as in ref.(2), the angular distribution of 1.37 Gev.α particle elastic scattering on C^{12} has been calculated. The parameters adopted are as following:

σ (total cross section of N-N scattering) = 2.84fm^2.
R (radius of α particle) = 1.3fm.
ρ (the ratio of real to imaginary) = 0.2
d (the length of equilateral triangle) = 2.75fm.
a (harmonic parameter) = .045fm^2.



Theoretical results are given in the figure and favour the cluster model. The agreement between theory and experiment is in satisfactory.

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THE MULTIPLE SCATTERING MECHANISM AND SHORT RANGE CORRELATION EFFECT OF HIGH ENERGY NUCLEUS-NUCLEUS COLLISIONS.

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Nucleon-nucleon multiple scattering mechanism of high energy elastic nucleus-nucleus scattering is investigated in this paper.

By means of the " rigid projectile" approximation within the Glauber multiple scattering framework, and using the "determinant method", the differential cross section of $\alpha - C^{12}$ elastic scattering at 1.37 Gev incident energy has been calculated. All contributions of high orders of multiple scattering are involved.

In our calculation, here is no any adjustable parameter in the differential cross section. All parameters are taken from experimental data. A good agreement between theoritical calculation and experimental data at small angles ($q^2 \lesssim 5$ fm^{-2}) is obtained.

In order to improve the agreement with experimental results we also have considered the effect of short-range dynamical correlation for C^{12} . Than, the calculated differential cross section do indeed follow the behavior of the measured differential cross section quite well.

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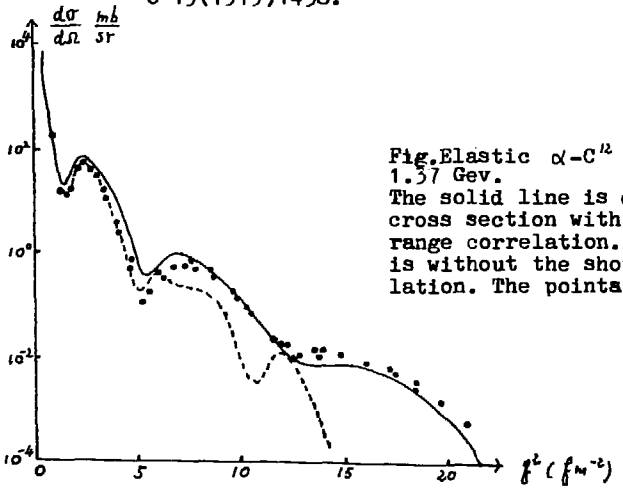


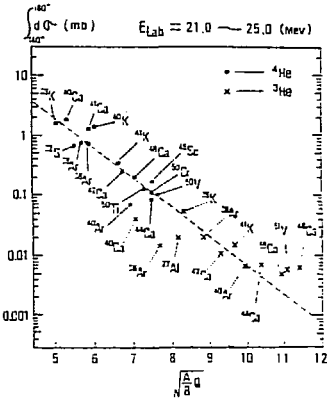
Fig. Elastic α-C^{12} scattering at 1.37 Gev.
The solid line is differential cross section with the short range correlation. The dash one is without the short-range correlation. The points are Scalay data.

Q-VALUE EFFECT ON ELASTIC α-SCATTERING IN Ca-REGION

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[†]Institute of Physics, University of Tsukuba, Ibaraki 305, Japan.

Fig. 1



It is pointed out that the target dependence of elastic α-scattering at backward angles in Ca-region is interpreted systematically by the effect of Q-value. Here the Q-value means so-called threshold energy of two-body breakup from compound nucleus. To show the systematics clearly, the observed values of the angle integrated cross section at backward angle region are shown as the function of $\sqrt{A/8 \cdot Q}$ in Fig.1. [1]. The whole data are well reproduced by a function $\exp[-a\sqrt{A/8 \cdot Q}]$. This Q-value dependence is also seen in all other observed cross sections in Ca-region, e.g., the fusion cross sections of $^{40}Ca+\alpha$ and $^{44}Ca+\alpha$ [2] and the excitation functions of backward elastic α-scattering from Ca-isotopes in low incident energy region [3].

From this Q-value systematics, we can take a picture that the imaginary part of optical potential should be determined by the coupling between the entrance channel and the many complicated compound states. Based on the study of averaged S-matrix for light heavy-ion fusion reactions [4], we can introduce the following imaginary potential which depends on the level density $\rho_L(E^*)$ of the compound nucleus,

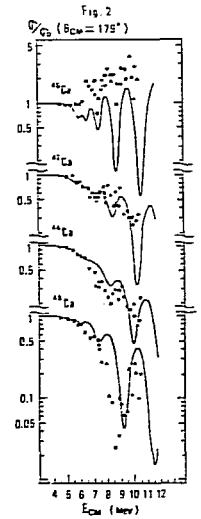
$$W_L(r) \propto \rho_L(E^*)/\rho_L(E^*+\Delta) \cdot f(r)$$

where $E^*=E_{cm}+Q$. Δ means the energy range in which the copmound states around the incident energy are disturbed by the entrance and many exit channels. In this case, we use the vale $\Delta=2\hbar\omega$, where $\hbar\omega$ is a harmonic oscillator energy of the compound nucleus. The real part of the optical potential is determined to reproduce the calculated phase shift by resonating group method [5].

By the use of the present potential, we obtained the reasonably good result for reproducing the backward elastic α-scattering in Ca-region, (see Fig. 2).

Therefore the so-called ALAS is understood by the coupling between the entrance channel and the many complicated compound nucleus.

Fig. 2



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INDICATION OF FAST α-CASCADES IN THE ^{232}Th(α,xnypzα) REACTION AT 160 MeV[§]

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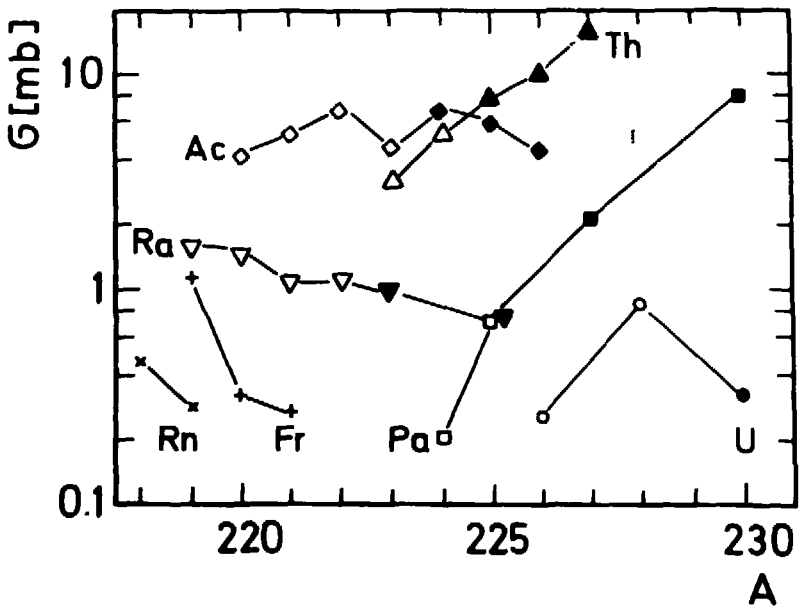
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The reaction ^{232}Th + α was studied at 160 MeV measuring the yields of α-emitters from U to Rn isotopes (see figure). Here, the full symbols give the results of catcher foil spectroscopy ($T_{1/2} > 8$ m), the others represent the yields for short-lived activities ($T_{1/2} > 10$ ms) as obtained by the apparatus BANDIT[1]) where a mylar tape at different velocities is used as a movable catcher. Within a factor of two similar results were found at 130 MeV.

Calculations with the code OVERLAID ALICE[2]) roughly reproduce the measured U and Pa cross sections but underestimate the Th and Ac yields by a factor > 100 (input options: PE nucleon emission in the GDH model with $n_0 = 4$, subsequent W.E. evaporation and fission competition with shell corrected LDM fission barriers, $a_\nu = a_f = A/8$, fixed J - removal by emitted particles). Similar calculations, yet starting from ^{232}Th* with excitation energies and strengths being derived from experimental ^{232}Th(α, α'X) spectra at 130 MeV do remove this discrepancy. Thus simulating PE α-emission lacking in the code the Ra yields are still predicted too low by factors of ~10 (^{220}Ra) up to 100 (^{225}Ra). We conclude that the considerable yields for Ra as well as for Fr and Rn isotopes (see figure) indicate a prompt emission of two to three pre-equilibrium (PE) α-particles from the composite system ^{236}U .

[§]This work was supported by the Bundesminister für Forschung und Technologie.

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THE $^{238}U(\alpha,^{3}He\ f)$ REACTION AT E_α = 152 MeV

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E. E. Gross, D. J. Horen

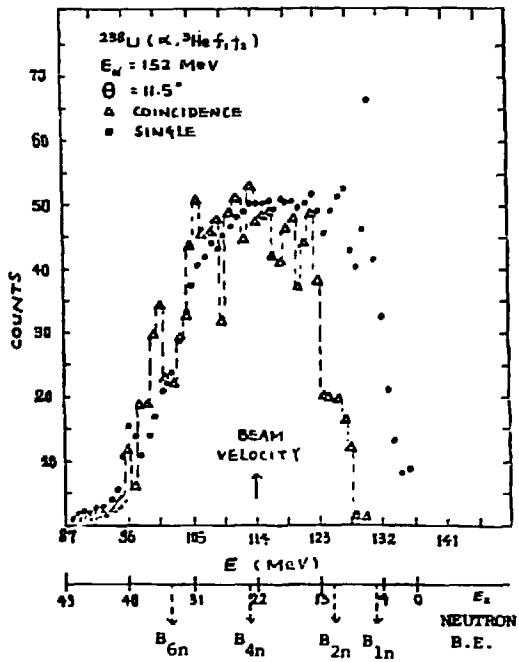
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We have measured the ^{3}He spectrum in coincidence with fission fragments from ^{238}U bombarded by 152 MeV α particles in order to investigate the projectile-target reaction mechanism. High energy ^{3}He particles were detected at 11.5° in coincidence with two fission fragments detected with position sensitive gas proportional counters covering an angular range from 63° to 85° (opposite to ^{3}He) and -95° to -117° (same side as ^{3}He). The ^{3}He spectrum in coincidence with fission exhibits a broad peak at the beam velocity. The same spectral shape was observed in the "singles" ^{3}He spectrum (see figure). The results suggest that the neutron fuses with the target forming a compound nucleus while the ^{3}He, acting as a spectator, escapes with the incoming beam velocity. The compound nucleus, ^{239}U, then decays by neutron emissions and fissions. This incomplete fusion-fission mechanism constitutes a substantial fraction of the total reaction cross section leading to fission. The fission probability as a function of excitation energy and angular momentum transfer will be discussed.



*Operated by Union Carbide Corporation under contract W-7405-eng-26 with the U.S. Department of Energy.
+Work supported in part by NSF.

HADRON-NUCLEUS INELASTIC TO ELASTIC SCATTERING RELATIONS APPLIED TO COMPOSITE PROJECTILES.†

R. D. Amado, J. A. McNeil and D. A. Sparrow

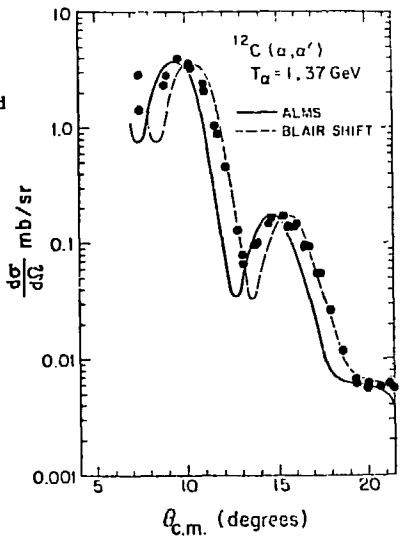
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Recently we have obtained simple relationships between elastic and inelastic scattering in hadron nucleus scattering that are both well grounded in theory and agree well with the data.[1] In this work we examine the extension of those relations to reactions induced by composite projectiles. Our relations are based on using a collective model for the excitation, a Fermi density for the nuclear ground state, and embedding these in a large momentum transfer (q) treatment of the eikonal description for the reaction. The relation is between the elastic cross section σ_E and the inelastic cross section for excitations of a state of angular momentum L, σ_L

$$\sigma_L(\theta) = C_L q^2 \sigma_E(\theta + \phi_L/pc) \qquad (1)$$
$$\phi_L = (L-1)\arctan(\pi\beta/c) + \eta_L \quad \eta_L = 0, (\pi/2) \quad L = \text{odd, even}$$

where θ is the scattering angle, p the incident momentum, and c and β are the diffusivity and half density radius respectively of the Fermi distribution. C_L is a constant that expresses the excitation strength. In the limit of a sharp edge nucleus (β=0) this form recovers the Blair phase rule but it is far more general since it relates the shapes of the cross sections and not just the positions of the diffraction minima.

In the Figure we show Eq. (1) applied to the excitation of the 4.44 MeV 2^+ state in ^{12}C by 1.37 GeV α's.[2] The solid line is $q^2\sigma_E$ shifted by the appropriate amount and vertically normalized, while the points are the 2^+ data. We show both angle shifts based on Eq. 1 with β and c taken from the elastic scattering and the Blair phase rule shift. They bracket the data and certainly agree as to general shape. The agreement compares favorably with the analysis of reference 2. We are encouraged to proceed to the investigation of heavier and lower energy projectiles.



†Supported in part by the U. S. National Science Foundation.

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MEASUREMENT OF PARTICLE SPECTRA OF α INDUCED NON-EQUILIBRIUM REACTIONS FOR $^{206-212}$Po

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In order to study the reaction mechanism of the ^{209}Bi(α,charged particle xnγ) reactions at incident energies of 45 MeV and 75 MeV spectra of p, d, and t have been investigated. The charged particles were measured in coincidence with γ rays characteristic of the resultant Po nuclei. The α beams were provided by JULIC. The coincidences were measured by placing the particle detector telescope at angles of 45°, 90° and 135°.

As result of the 45-MeV experiment at 45° three spectra of protons coincident with γ rays in ^{210}Po(#1), ^{211}Po(#2) and ^{212}Po(#3) are shown in fig. 1. The maxima of the spectra are at 15.0 MeV, 22.5 MeV and 26.5 MeV for the (α,p2n), (α,pn) and (α,p) channels, respectively. The width of the respective peaks are 7.5 MeV, 6.7 MeV and 3.9 MeV. The low energy tails seen in the spectra # 2 and # 3 are most probably not real but due to incomplete background subtraction. This notion results from an analysis in which gates have been set on 2.5-MeV portions of the proton spectrum in order to produce the corresponding γ spectra. The γ lines resulting from the (α,p) and (α,pn) reactions are in the γ spectra corresponding to the maxima of the respective p peaks at least a factor of 10 more intense than in the γ spectra corresponding to proton energies outside the peak region. Similar spectra as in fig. 1 have been obtained for d and t. The angular distributions for all channels in the 45-MeV experiment are shown in fig. 2. It can be seen that the (α,p), (α,d) and (α,t) reactions are strongly forward peaked. The angular distributions are less pronounced for reactions in which one or two additional neutrons are emitted. For 75 MeV incident energy a similar decomposition of the inclusive p spectra as in case of 45 MeV has been obtained. The maxima (widths) of the proton peaks are 20.5 MeV (13.0 MeV), 28.8 MeV (12.0 MeV), 38.9 MeV (10.0 MeV), 48.2 MeV (6.0 MeV) and 55.0 MeV (4.0 MeV) for the (α,p4n), (α,p3n), (α,p2n), (α,pn) and (α,p) reactions, respectively.

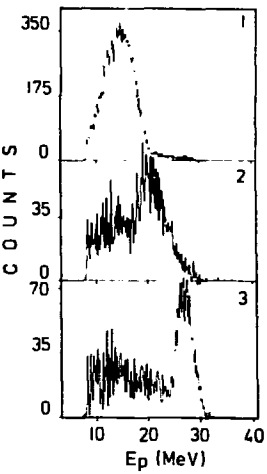


Fig. 1

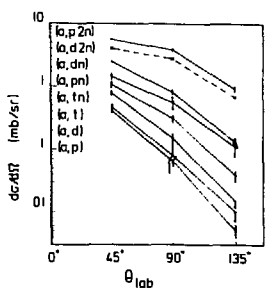


Fig. 2

The energies of the proton peaks for the various (α,pxn) channels can be understood assuming that the protons populate directly the entry lines of the respective final nuclei. This implies that the neutrons carry along only a small kinetic energy. It may be concluded, therefore, that the protons are emitted at first after the formation of the fused system and that the neutrons are emitted subsequently.

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GAMMA RAYS FROM 720-MeV α AND 200-MeV $\pi^{\pm}$ ON CHROMIUM*

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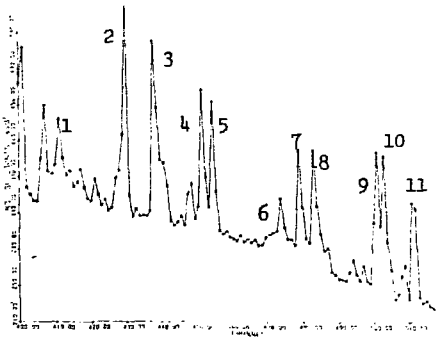
The states of daughter nuclei produced by bombardment of natural chromium by 720-MeV α particles and 200-MeV $\pi^{\pm}$ have been studied through analyses of spectra of de-excitation γ rays taken in prompt coincidence with incident beam particles at the SREL synchrocyclotron.[1])

Transitions were observed which correspond to inelastic scattering and removal of from one to sixteen nucleons. For removal of more than four nucleons the cross sections decrease gradually with increasing ΔA. 720-MeV alphas tend to be more effective in removing one or two neutrons relative to single and double proton removal than are 200-MeV pions.

The γ spectrum arising from α bombardment shows a moderately strong transition for equivalent single α removal (^{48}Ti I → 0), but there is no unambiguous evidence for removal of more than one equivalent α particle, as has been seen with lighter target nuclei.[2]) Instead, the multiparticle removal pattern follows the valley of stability for the daughter nuclei.

Comparisons will be made with results of similar π and α experiments performed on lighter nuclei at these and other energies.

A portion of the spectrum resulting from α bombardment: representative peaks include (1) the ^{49}V V→I and/or ^{46}Ti V→II at 1048 keV, (2) ^{50}Cr II→I at 1098 keV, (3) ^{50}Ti II→I and/or ^{46}Ti II→I at 1119 keV, (4) ^{49}V VI→0 and/or ^{44}Ca I→0 at 1156 keV, (5) ^{51}Cr III→0 at 1163 keV, (6) ^{52}Cr III→I at 1213 keV, (7) ^{42}Ca IV→I at 1226 keV, (8) ^{45}Sc VIII→0 at 1236 keV, (9) ^{50}Cr V→II at 1283 keV, (10) ^{53}Cr III→0 at 1289 keV, and (11) ^{48}Ti II→I at 1310 keV.



*Supported by the NSF, NASA, and the Commonwealth of Virginia.

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PREEQUILIBRIUM α-EMISSION IN THE QUASI-FREE SCATTERING MODEL

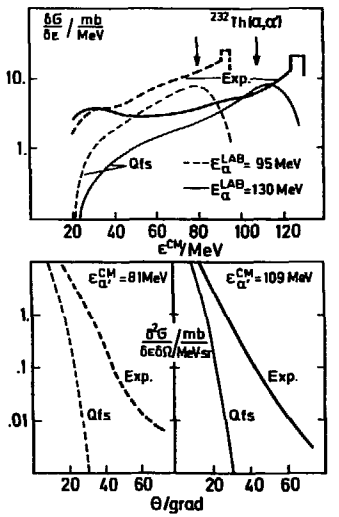
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The quasi-free scattering model 1) has been successful in reproducing angle integrated preequilibrium spectra measured in reactions such as (α,α'), (n,α), (p,p') and (α,p). The model assumes (α,N) or (N,N') scattering in the nuclear environment to constitute the equilibration process and treats the two body collisions on the basis of experimentally measured free scattering data taking proper account of Pauli priciple restrictions.

Since the model evaluates the two body kinematics explicitely, it can also be used to calculate the angular distributions of particles emitted from the preequilibrium reaction phase. We have extended the existing computer codes to that purpose. As a test of the procedure, calculations for (p,p') reactions were performed first. The results are in close agreement with those obtained from intranuclear cascade calculations 2).

Subsequently, the approach was extended to reactions involving clusters. The figure shows a typical result for an (α,α') reaction. While the calculation fits the angle integrated data reasonably well, the agreement is very poor for the angular distributions. No reasonable choice of model parameters was found to do any better than the calculation shown in the figure.



We conclude that the angular distributions observed in preequilibrium cluster emission cannot be understood in terms of (cluster,nucleon) quasi-free scattering. It is not clear, however, if and to what extent this result invalidates the underlying model.

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The authors wish to thank M. Blann for valuable discussions and for making his computer codes available.

INCIDENT ANGULAR MOMENTUM WINDOW IN LIGHT-ION INDUCED COMPOUND NUCLEAR REACTIONS†

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The angular momentum distribution of the final-nucleus entry states populated in a compound-nuclear reaction is determined by the angular momentum distribution of the initial compound nucleus and the angular momentum removed by particle decay. Conversely, the J distribution of the compound nucleus can be deduced from the measured J distribution of the entry states and assumptions about the angular momentum removed by outgoing particles.

Measurements of relative intensity for yrast γ-rays from ^{151,152}Sm in coincidence with 2-20 MeV neutrons from the 35 MeV ^{150}Nd(α,x$n\gamma$) reactions showed that the population of high-spin entry states decreases rapidly with increasing neutron energy. Moreover, n-γ-γ coincidence measurements showed that the relative intensities of yrast γ-rays coincident with the lowest yrast transitions and 5-20 MeV neutrons were constant for $J_i < 10\hbar$ and decreased sharply for $J_i > 10\hbar$. These measurements show that only entry states with $J > 10\hbar$ are populated by the 35 MeV ^{150}Nd(α,x$n\gamma$) reactions with x = 2 or 3. Only initial compound-nuclear states with $J > 10\hbar$ thus decay by the x = 2 and x = 3 channels, implying an incident impact-parameter dependence in these reactions.

Other measurements support these conclusions. From the measured neutron spectra, the excitation energy for maximum entry-state population in the ^{150}Nd(^{3}He,5nγ)^{148}Sm reaction was found to be 4.9 MeV at E(^{3}He) = 34 MeV, and 13.3 MeV at E(^{3}He) = 43 MeV. Both of these spectra are well-described by pure evaporation calculations at different temperatures. Entry states are populated in these reactions along lines roughly parallel to the yrast line[1]; entry states at higher energy therefore have higher J. The median J value in the (^{3}He,5nγ) reaction thus increases dramatically with beam energy, even at the evaporation stage.

The angular distributions of neutrons from compound reactions are forward peaked for E(n) $\gtrsim$ 5 MeV, and increase in steepness with increasing E_n. This implies that the incoming and outgoing impact parameters are highly correlated for large E_n. It has been shown that the incident impact parameter for a given multiplicity increases with increasing beam energy; the angular distributions show that the outgoing b must also increase. Fast neutrons (with $E_n > E_{(Beam)}/A_{(Beam)}$) thus remove significant angular momentum from the compound nucleus. When this angular momentum removal is included, the incident angular momentum window for extreme pre-equilibrium reactions, such as the 35 MeV ^{150}Nd(α,2nγ) reaction, is found to be only $\sim 2\hbar$ around the classical maximum.

†Supported in part by USDOE

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A STUDY OF THE $^{28}Si(^{3}He,\alpha)^{27}Si$ REACTION

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The analysing power and differential cross section of the $(^{3}He,\alpha)$ reaction on ^{28}Si leading to the ground state, the 0.78, 2.65 and 4.14 MeV excited states of ^{27}Si have been measured using a 33.4 MeV polarized ^{3}He beam. The angular momentum transfers involved were $5/2^{+}$, $\frac{1}{2}^{+}$, $5/2^{+}$ and $(\frac{1}{2}, 3/2)^{-}$ respectively. The striking feature of the obtained results is the very large negative analysing power observed throughout the angular range for the ground state transition. This is consistent with a semiclassical model of the reaction[1]), where the sign of the analysing power is predicted to be negative for $j = \ell + \frac{1}{2}$, as in the case of the $5/2^{+}$ transfer, and positive for $j = \ell - \frac{1}{2}$, assuming the attractive nuclear force to be dominant and the effect of the Coulomb force negligible. The analysing power for the other transitions showed the usual oscillatory pattern.

It has been known for some time[2]) that the approximations of the DWBA theory may be braking down when applied to describing the $(^{3}He,\alpha)$ reactions. In the present work the role of the distorting potentials, the Q-value effects and the finite-range corrections are investigated within the framework of the conventional DWBA. An attempt is also made to interpret the present results taking into account multi-step processes. The $(^{3}He,\alpha)$ reaction cross sections and analysing powers, together with the elastic and inelastic ^{3}He scattering data obtained simultaneously, are analysed in terms of the coupled channels and coupled reaction channels formalisms.

[+] Now at the Kings College, London

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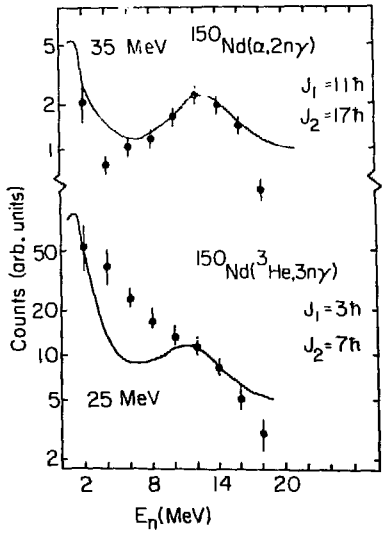
One-Step Approach to Equilibrium Model for Pre-equilibrium Neutron Emission†

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A simple model has been found to reproduce reasonably well the spectra of neutrons from light-ion induced low-multiplicity reactions in which pre-equilibrium neutron emission occurs.

The density of states at excitation U and angular momentum J in medium-heavy nuclei can be approximated by[1] $\rho(U,J) \propto (2J+1)(U+\delta)^{-2}\exp 2(a(U-U_J+\delta))^{\frac{1}{2}}$ where U_J is the excitation of the yrast state of spin J, $\delta \sim 1$ MeV is a pairing energy, and an A/8 MeV is a density-of-states factor. Above the neutron separation energy, such states have a probability P_n of neutron decay. If other forms of particle decay are ignored, the density of particle-stable states is: $\rho_s(U,J)=\rho(U,J)(1-P_n)$. The decay probability P_n is proportional to density of states $\rho'(U',J')$ in the nucleus with one less neutron, and thus increases exponentially with excitation U above a critical excitation $U_c=S_n+U'(J)$.



The one-step approach to equilibrium model is defined by two assumptions. One is that the nucleus reaches equilibrium after the emission of one neutron, and thereafter decays by evaporation characterized by a temperature kT which depends only on the final nucleus entry state excitation. The other is that the density of populated entry states is given by $\rho_e(U,J)=F(J)\rho_s(U,J)$, where F(J) is assumed to have the form F(J)=1 for $J_1<J<J_2$ and F(J)=0 otherwise. The free parameters were J_1,J_2, and an overall normalization.

Two examples of measured and calculated neutron spectra are shown in the figure. The high-energy part of the neutron spectra are reproduced reasonably well, and the resulting values of J_2 are consistant with the classical maximum angular momentum of the projectile. The calculation fails to reproduce the extreme high-energy tail, due to the failure of the statistical level density formula at low residual excitation. The calculation also does poorly in the region between the "equilibrium" and "pre-equilibrium" parts of the spectrum, probably due to the failure of the simple evaporation model which is discussed in the preceding contribution to this conference.

†Supported in part by USDOE
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HIGH-TEMPERATURE MAXWELLIAN EVAPORATION OF NEUTRONS BY COMPOUND NUCLEI[†]

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In the equilibrium statistical model for the evaporation of neutrons from an excited compound nucleus, the spectrum of decay neutrons is given by[1]) $Y(E_n) \propto E_n \exp(-E_n/kT)$, where $(kT)^{-1} = (a/u)^{\frac{1}{2}} - 2/u$. In these expressions kT is the temperature, u the excitation of the final nucleus, and $a \simeq A/8$ MeV is a density-of-states parameter.[2]

The neutron spectra from $(\alpha, xn\gamma)$ and $(^3He, xn\gamma)$ reactions on a variety of targets have been measured using n-γ coincidence and neutron time-of-flight techniques. Neutron spectra from reactions induced by 35 MeV α particles are shown in the figure; the curves are evaporation fits with kT a free parameter.

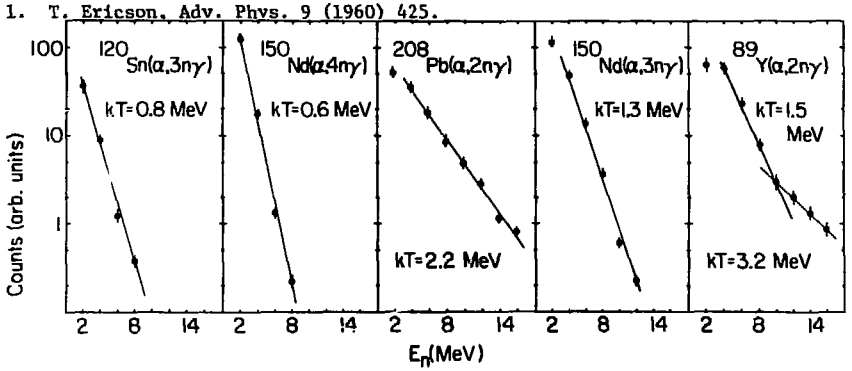
The striking feature of the observed spectra is that almost all can be described by a single temperature kT, that is, that they indeed represent Maxwellian evaporation. While for $^{120}Sn(\alpha, 3n\gamma)$ and $^{150}Nd(\alpha, 4n\gamma)$ the temperatures obtained (0.8 and 0.6 MeV) by the evaporation model are consistant with the predictions of the evaporation model, the excitation associated by the evaporation model with the temperature obtained for $^{208}Pb(\alpha, 2n\gamma)$ is 130 MeV, five times the excitation of the initial ^{210}Po compound nucleus.

A possible explanation of the very high temperatures obtained for certain of the spectra, such as $^{208}Pb(\alpha, 2n\gamma)$ and $^{150}Nd(\alpha, 3n\gamma)$, is that these temperatures correspond to the excitation of only a small fraction of the nuclear volume. If this were true, however, the neutron spectrum would not be expected to have a pure Maxwellian shape, but rather to have both a high-temperature and a low-temperature part. These parts would correspond to the initial decay of a small excited region followed by equilibrium decay from the entire nuclear volume. Only one spectrum, that of $^{89}Y(\alpha, 2n\gamma)$, shows such features. From these data it is evident that the equilibrium model relation between kT and final-nucleus excitation is often invalid. However, a two-temperature model is also not supported by the bulk of the present data.

[†]Supported in part by U. S. Department of Energy.

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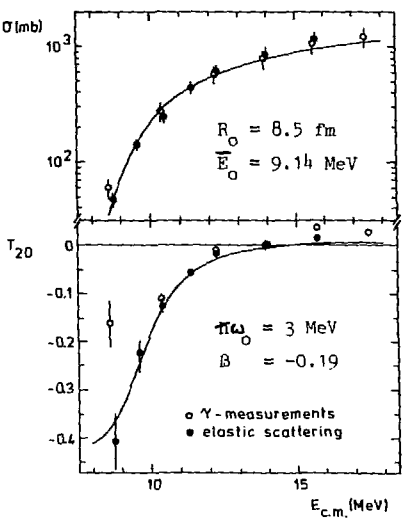


MEASUREMENT OF THE REACTION CROSS SECTION FOR THE SYSTEM $^{7}Li + ^{51}V$ WITH ALIGNED ^{7}Li IONS

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A dependence of the reaction cross section on the projectile alignment was observed for the interaction of aligned ^{7}Li with ^{51}V. The reaction cross section was investigated measuring the characteristic γ rays of the reaction residues and independently measuring the elastic scattering (including inelastic scattering to the first excited state of ^{7}Li, 0.487 MeV). From the latter data the reaction cross section was obtained by applying the "sum-of-differences" method[1]) to the results obtained with the aligned and unpolarized beams. The excitation functions of the reaction cross section and of the analyzing power T_{20} (normalized difference of cross sections for aligned and unpolarized beams) from both experimental methods agree well with each other (figure). Moreover, the trend in T_{20} is the same for all observed reaction residues $^{55,56}Fe$, $^{52,53}Cr$ and $^{54,55}Mn$. It can be interpreted as an entrance channel effect in terms of the oblate deformation of ^{7}Li. Its negative spectroscopic quadrupole moment is aligned along with the spin. The experimental data were analyzed in terms of the barrier penetration model of Wong[2]) which was generalized for aligned projectiles. Assuming that the interaction is localized at the distance of closest approach, the l-wave reaction barriers can be calculated for aligned ^{7}Li ions. The model which fits the data quite well (solid lines) needs four parameters: an interaction radius R_0, an s-wave barrier $\overline{E}_0$, the curvature $\hbar\omega_0$ of the interaction potential at the barrier and the parameter β describing the ^{7}Li deformation. R_0 and $\overline{E}_0$ are well determined by the excitation function of the reaction cross section. However, T_{20} is very sensitive to both β and $\hbar\omega_0$. Especially in the energy range 11–14 MeV T_{20} is sensitive to β alone. It is believed that the parameter β extracted from this experiment describes the matter deformation of ^{7}Li. Up to now it is not clear whether its much smaller value as compared to the one obtained from the electric quadrupole moment ($\beta \approx -0.3$) reflects a lack in the theoretical description or is really due to a different deformation of the matter and charge distribution of ^{7}Li.



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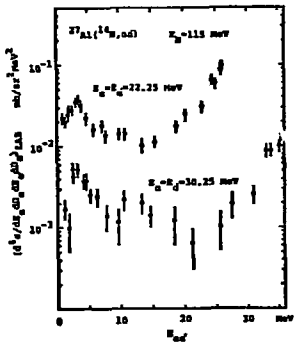
LIFETIME MEASUREMENT OF A HEAVY-ION PREEQUILIBRIUM SYSTEM VIA α-α CORRELATION

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The forward-peaked fast alpha particles, which strongly appear in heavy ion collisions, have often been argued in relation to the preequilibrium nature of the composite system of two colliding ions. The present report is concerned with an experimental attempt to directly determine the lifetime of such a preequilibrium system by measuring the correlation between two fast alpha particles in the $^{27}Al + ^{14}N$ reaction at 115 MeV incident energy. The α-α correlation was recorded using four sets of SSD telescopes placed at a fixed polar angle $\theta = 50°$. As to the azimuthal angle difference $\Delta\phi$ between a pair of telescopes, we have altogether taken 24 angles from 21° to 180°.

The observed correlation is depicted for two typical cases in the figure, where the coincidence cross sections for given lab energies E_α and $E_{\alpha'}$ of the coincident alpha particles are plotted as a function of the relative kinetic energy $E_{\alpha\alpha'}$ between the two particles. A characteristic aspect of the correlation is that enhanced cross sections over the continuum distribution appear around $E_{\alpha\alpha'} \approx 3.0$ MeV, which corresponds to the resonance energy of the 2^+ excited state of ^8Be.



The origin of such resonance-like cross sections, $(d^4\sigma/dE_\alpha d\Omega_\alpha dE_{\alpha'} d\Omega_{\alpha'})_{res.}$, may be attributed either to the breakup of excited ^8Be produced in the primary reaction process or to the final state interaction between two alpha particles inuependently emitted from the composite system. One may estimate the production cross section of excited ^8Be in terms of the Q_{gg} rule and the singles cross sections for the other Be isotopes. The cross section thus deduced was hardly sufficient to account for the observed coincidence yield.

Provided that the final state interaction is dominant, the magnitude of the resonance-like cross section may be related to the lifetime τ of the alpha-particle emitting system; using the approximation[1]) for the proximity scattering we may write

$$(d^4\sigma/dE_\alpha d\Omega_\alpha dE_{\alpha'} d\Omega_{\alpha'})_{res.}/(d^4\sigma/dE^0_\alpha d\Omega^0_\alpha dE^0_{\alpha'} d\Omega^0_{\alpha'}) = \langle 1/D^2\rangle (d\sigma/d\Omega_{\alpha\alpha'})J.$$

In this approximation, the resonance-like cross sections are assumed to be due to the scattering between two alpha particles successively emitted in the same direction in the c.m. system. D represents the distance from the center of the emitting system to the point at which the chasing particle with larger energy $E^0_{\alpha'}$ catches up the preceding particle with smaller energy E^0_α. Thus D is related to the time interval between the successive emissions and hence to τ. $d\sigma/d\Omega_{\alpha\alpha'}$ is the α-α scattering cross section, J the Jacobian relevant to the coordinate transformation involved. Applying this relation to the 2^+ resonance we obtained $\tau = 4\sim6 \times 10^{-22}$ sec, which is shorter than typical lifetimes of some 10^{-21}sec for equilibrated compound systems.

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^{16}O-^{12}C ELASTIC SCATTERING BETWEEN 140 AND 315 MeV

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Angular distributions have been measured for the elastic scattering of ^{16}O from ^{12}C at laboratory energies of 140,218 and 315 MeV for angles up to 46° c.m. No nuclear rainbow was observed, as reported before[1] for the scattering of oxygen nuclei from ^{28}Si.

The data was analyzed in terms of a six-parameters optical potential with real and imaginary nuclear parts of the Woods-Saxon form. The determination of the optical parameters at each energy shows the ambiguities already known for heavy-ions. The real part of the potential is well determined only between ∿ 6.6 and 7.4 fm, being this sensitive radial region the same for the three energies. Good fits can be obtained for real depths ranging between 10 and 70 MeV at all three energies.

The three sets of data were also analyzed simultaneously, assuming an energy-independent optical potential. The quality of the joint fit is poorer than the individual fits at each energy, χ^2/N increasing roughly in a factor of two. Some of the ambiguities still remain, and the various sets of potential parameters which give an equally good fit to all sets of data are characterized by: i) both V(r) and W(r) are well determined in the region close to 6.9 fm, ii) V(r)/W(r)∿1.4 in the sensitive region iii) the depth of the imaginary part is always less than 20 MeV, and iv) the real parameters satisfy the relation $V\exp(r_o/a) = 175 \pm 10$ MeV, provided V is shallower than 25 MeV and the diffuseness ranges between 0.49 and 0.66 fm.

† Supported by Consejo Nacional de Ciencia y Tecnología, México.

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ELASTIC AND INELASTIC SCATTERING OF ^{12}C BY ^{19}F

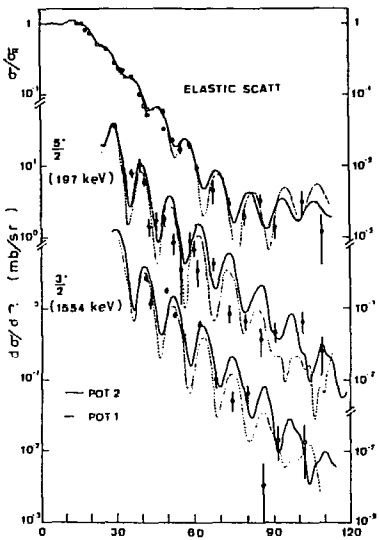
N.Kato, K.Kimura, K.Kobayashi, H.Fujita, Y.Ishikawa, T.Tachikawa, K.Morita and Y.Nakajima

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The present paper describes the measurement and preliminaly analysis of angular distributions of ^{12}C elastic scattering and of inelastic scattering to the 5/2+(197 keV) and 3/2+(1554 keV) states in ^{19}F at bombarding energy of 40.6 MeV. The experiment was performed with the ^{12}C beam from the Kyushu University tandem accelerator and the outgoing particles were detected by Si detectors cooled to Liq. N_2 temperature. In order to separate the peaks due to the inelastic scattering to the 5/2+ level from the elastic ones, paticular considerations were made on the energy resolusion of the system. The energy resolusion finally obtained was 130 keV in FWHM.

So far the elastic scattering of ^{12}C by ^{19}F has been studied by Voos et al.[1] and they have stated that the contributions from the inelastic scattering for the 197 keV level to the elastic one were less than 10% at angles smaller than 100° c.m. In the present study, however, the yields due to the inelastic scattering to the 5/2+ level could be separated from the elastic ones and the differential cross sections of the inelastic scattering were found to be comparable with those of the elastic scattering at angles larger than 60°. In the figure the angular distribution of the elastic scattering is shown with the curves obtained by the optical model fitting to the data. Several sets of the potential parameters are possible to reproduce the experimental angular distribution. (see Table) It should be noted that all these sets have almost the same value (~2 MeV) of the real well depth at the radius around 7.7 fm.

Inelastic scattering calculations using the code DWUCK with a macroscopic collective form factor are also shown in the figure with the data. Experimental differential cross sections for the 5/2+ and the 3/2+ states are fairly well fitted using the amplitudes of the K=1/2+ band, $\alpha_{\frac{1}{2}}(5/2+)=0.90$ and $\alpha_{\frac{1}{2}}(3/2+)=0.73$ [2], and the same quadrupole deformation parameter $\beta_2=0.32$. It is interesting that the experimental inelastic cross sections are similarly well reproduced with the different optical potential sets, which can fit the elastic angular distribution. However there exists a slight phase difference in the oscilation of the inelastic angular distributions between the data and calculations. This phase difference can not be removed simply in the lst order DWBA calculation, if the optical potential parameters are constrained to those obtained in the optical model analysis of the elastic scattering.



Pot.#	V_R	r_{OR}	a_R	W_I	r_{OI}	a_I
1	57.22	1.25	0.48	72.34	1.26	0.26
2	15.34	1.37	0.52	51.52	1.25	0.37
3	7.46	1.45	0.53	29.22	1.26	0.45

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2)E.B.Paul Phil.Mag. 2(1957)311

FUSION CROSS SECTION OF LIGHT HEAVY-IONS AT SUB-COULOMB ENERGIES

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It is useful to have an analytic formula for the fusion cross section σ_F . From fitting experimental data one can get a first order value of the barrier parameters and their systematic trend with masses of fusing nuclei. At energies around and not too high above the Coulomb barrier E_o an important role was played by the Glass and Mosel model [1]) and the more elaborate formula of Wong [2]). Although the latter includes penetrability effects it cannot be applied at energies well below E_o because the Coulomb tail is not properly taken into account.

The idea of the present work is to derive a formula valid at energies well below the Coulomb barrier and is based on a model previously proposed by Avishai [3]). This model consists in replacing the half parabola at the right of the barrier position R_o by a Coulomb potential between two point charges Z_1 and Z_2 . We propose a modification of Avishai's model in order to include the centrifugal barrier on both sides of R_o . We make a series expansion with respect to the centrifugal term in the penetrability integral. This is a good approximation for low ℓ or $E \ll E_o$. On the other hand high partial waves contribute less and less to the fusion section with decreasing E/E_o . Based on this approximation we derive an analytic expression for the transmission coefficient and hence we obtain the following expression for σ_F

$$\sigma_F = \frac{\pi}{2(D_P + D_C)k^2} \ell n \ (1 + e^{-2K_o})$$

where k is the incident wave number and D_P, D_C and K_o are functions of the relative energy E , of the parameters E_o, R_o and $\hbar\omega_o$ describing the parabola and of the Sommerfeld parameter $\eta = Z_1 Z_2 e^2 \mu / \hbar^2 k$, with μ-reduced mass

$$K_o = \frac{\pi(E_o - E)}{2\hbar\omega_o} + \pi\eta - 2\eta \arcsin\left(\frac{kR_o}{2\eta}\right)^{\frac{1}{2}} - [kR_o(2\eta - kR_o)]^{\frac{1}{2}}$$

$$D_P = \left(\frac{\hbar^2}{8\mu R_o^2}\right)^{\frac{1}{2}} \left\{ \frac{(E_o - E)^{\frac{1}{2}}}{E - E_o + \mu\frac{\omega_o^2}{2} R_o^2} + \frac{\mu\,\omega_o^2\, R_o^2}{2(E - E_o + \mu\frac{\omega_o^2}{2} R_o^2)^{\frac{3}{2}}} \left[\arcsin\left(\frac{2(E_o - E)}{\mu\omega_o^2 R_o^2}\right)^{\frac{1}{2}} + \frac{\pi}{2}\right] \right\}$$

$$D_C = \frac{1}{2\eta} \left(\frac{2\eta}{kR_o} - 1\right)^{\frac{1}{2}} .$$

This formula was applied to the fusion of light heavy ions of astrophysical interest and found that the results are sensitive to the inner side of the barrier.

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3. Y. Avishai, Z. Physik A286 (1978) 285.

MICROSCOPIC THEORY OF COLLECTIVE MOTION WITH FRICTION [+]

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Current theories of collective frictional motion start with the assumption of a given collective coordinate and a given Hamiltonian which is split into a collective part, a single-particle part and a coupling term. No attempt is made to derive this form from an underlying microscopic theory. In the present paper, we try to overcome this short coming.

For definiteness, we consider deep-inelastic scattering of heavy ions. The collective coordinate in this case is the relative distance of the two nuclei. Our approach is based on a multi-channel generalization of the well-known resonating-group ansatz for the wave-function [1]. The inclusion of excited states allows for an energy loss from the relative (collective) motion of the nuclei. The resulting set of coupled integrodifferential equaitons can be transformed approximately into a set of Schroedinger-like equations by a symmetrized moment expansion of the integral kernels. This approximation is justified for a sharply peaked form of the nonlocal integral kernel. The width of the kernel decreases with increasing particle number. Test calculations have, however, demonstrated the reliability of this approximation already for relatively small nuclei.

The Schroedinger equations exhibit the required splitting into collective, single-particle and coupling term. The collective potential is given by the usual double-folding potential plus a correction due to the Pauli principle. Similarly, the reduced mass is modified for short distances to an effective one.

In the limit of large particle numbers, the Schroedinger equation can be reduced to a classical equation of motion. If interactions between excited states are neglected, we find a Newtonian equation of motion with a friction term proportional to the velocity. The friction coefficient is proportional to the transition probability to excited states and can be calculated on a microscopic basis.

The formalism can easily be generalized to other examples of collective motion, e.g. fission. As an application, the damping of giant resonances in heavy nuclei is considered. The calculated widths are in reasonable agreement with experiment.

[+]This work was supported by the DFG

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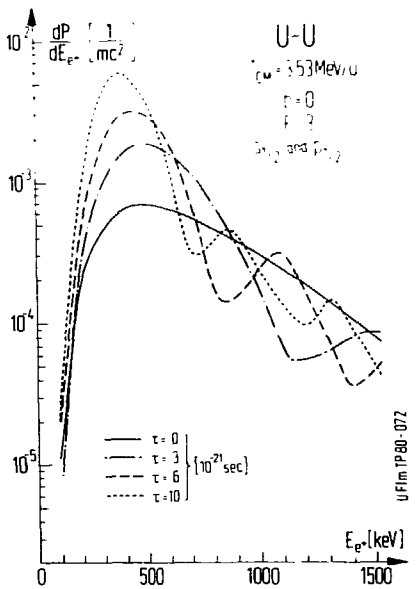
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POSITRON EMISSION IN SUPERCRITICAL DEEP INELASTIC COLLISIONS

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The observation of positron emission of very heavy ions is a main tool to study QED in the presence of strong external fields.[1] The predicted enhancement of production rates with increasing nuclear charge as well as a steep variation with impact parameter and collision energy was confirmed by recent experiments.[2] In supercritical collisions ($Z_1+Z_2 \geq 173$) the quasimolecular 1sσ-level joins the lower continuum of the Dirac equation and becomes a resonance. Due to the small decay width the resulting spontaneous emission of positrons will be best observable in collisions with prolonged nuclear times.[3] Using a projection operator technique for the resonance wavefunction we have performed coupled channel calculations[4] assuming classical trajectories with varying delay times τ. For U-U collisions the Figure shows an increasing contribution of spontaneous positron emission which is characteristic for supercritical systems. The observation of enhanced positron production at the energy of the 1s-resonance would demonstrate the change of the vacuum in the presence of a strong electric field.



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NUCLEAR MOMENTUM DISTRIBUTION AND RELATIVISTIC HEAVY-ION REACTIONS*

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In a relativistic heavy-ion reaction there are many processes which contribute to the fragmentation phenomenon. We examine the direct fragmentation process in which the detected proton is emitted from a parent nucleus without additional scattering and the hard-scattering process in which a nucleon from one nucleus makes a collision with a nucleon from the other nucleus. In terms of a combination of these two processes, the proton-inclusive data of Anderson, et al. for the reaction $\alpha + {}^{12}C \rightarrow p+X$ at different bombarding energies can be successfully analyzed. We find that the direct fragmentation process dominates the cross section at 0° and 180°. On the other hand, the hard-scattering process dominates the cross section at the quasielastic peak when the transverse momentum far exceeds 0.1 GeV/c. The model leads naturally to a new scaling variable which is the generalization of the Feynmann's scaling variable for situations when the rest masses are not negligible. As the nuclear momentum distribution enters into the model in a very important way, our analysis constitutes in essence a semiempirical determination of the nuclear momentum distribution. Furthermore, since a single nucleon can carry a large fraction of the momentum of the parent nucleus in a cooperative manner, relativistic heavy-ion reactions can be utilized to provide valuable information on the high momentum tail of the nuclear momentum distribution which may not be obtained by other means. The extracted semiempirical momentum distribution for ^4He indicates possible evidence for nuclear correlation and final-state interactions.

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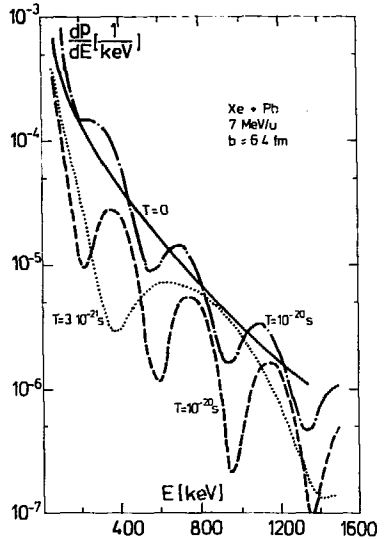
AN ATOMIC CLOCK FOR DEEP INELASTIC HEAVY ION COLLISIONS*

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We calculated the δ-electron distribution resulting from heavy-ion collisions with projectile energies above the Coulomb barrier. It is shown[1] that the life-time ($T \gtrsim 10^{-21}$s) of superheavy composite systems causes pronounced oscillations in the energy spectrum of emitted electrons. The width of the oscillations is found to be $\epsilon = h/T$. This effect can be used to measure nuclear sticking times. We have considered as an example of the systems $^{136}Xe + {}^{208}Pb$ with $E_{LAB} = 7$ MeV/u and grazing impact parameter because it allows for measurements in coincidence with a K-x-ray from the target-like fragment. Our conclusions hold qualitatively for any other superheavy system. The principal mechanism in how a nuclear time delay influences the excitation amplitude becomes most transparent in time-dependent perturbation theory for electron excitation. In this approximation we find that the probability of ionizing an electron from state i into the continuum state j for a fixed delay time T is given by

$$dP_i(\Delta E,T)/dE_j = 4|a'|^2 \sin^2[(T/2)\Delta E + \arg(a')] \quad .$$

Here a' is the amplitude after the incoming branch of the trajectory, $\Delta E = E_i - E_j$ is the energy difference between states i and j in the nuclear compound configuration. Obviously, dP_i/dE_j exhibits regular oscillations in the δ-electron energy E_j. These oscillations became slightly damped if higher-order and many-electron effects are included. The electron spectra resulting from corresponding coupled-channel calculations is shown in the figure. Without nuclear reaction time the spectrum is a smoothly falling function, while a sticking time $T = 10^{-20}$s produces oscillations with a period of 400 KeV.



We will also discuss the effects that could conceivably destroy the oscillatory pattern as seen in the figure.

*Work supported by the Bundesministerium für Forschung und Technologie, by the Gesellschaft für Schwerionenforschung and in part (G.S.) by the Deutsche Forschungsgemeinschaft (Heisenberg Program).

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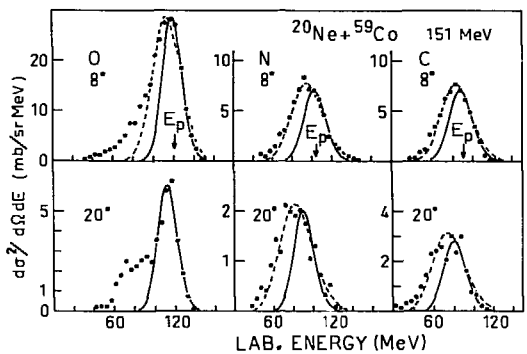
Figure: Differential emission probability versus kinetic δ-electron energy. A coincidence with created 1sσ vacancy formation is required. The dash-dotted line represents the total δ-ray spectrum ($T = 10^{-20}$s).

THE 151 MeV ^{20}Ne + ^{59}Co REACTION LEADING TO CONTINUUM ENERGY SPECTRA

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Although continuum energy spectra have been observed for many heavy-ion reactions, attempts to understand the shape of these spectra in terms of reaction mechanisms are quite recent. Beside the low-energy regime with thermal equilibration, a rapid onset of projectile fragmentation[1] probably occurs at about 15 MeV/nucleon above the Coulomb barriers. DWBA calculations[2] could describe the energy spectra for the reaction $^{40}Ca(^{20}Ne, ^{16}O)$ at 262 and 149 MeV by assuming the simultaneous occurrence of transfer and break-up reactions, with larger energy loss and wider energy distribution for transfer than for break-up reactions.

In the present work, angular distributions of inclusive spectra were measured with an ionization chamber for elements from B to Al produced in the bombardment of a ^{59}Co target by 151 MeV ^{20}Ne projectiles from the Grenoble cyclotron. A grazing angle of about 18° lab. was obtained from the measured elastic scattering angular distribution. Most of the energy spectra measured are symmetrical bell-shaped distributions. For the O fragment however, the spectra at forward angles have a long tail in the lower energy part in agreement with previous measurements[2]. Some spectra are shown in the fig., where Ep is the energy of the fragment having the projectile velocity. The O spectrum at 20° lab. has a narrow component attributable to the break-up reaction. Such a feature is not clearly observed for the other fragments. Calculations were done with the statistical fragmentation model[3]. The solid curves are obtained with a T = 2 MeV temperature while the dashed curbes come from the fit of the full distribution. The overall features of the present data are not at variance with the theoretical approach of the Texas group[2].



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KAON PRODUCTION IN RELATIVISTIC NUCLEAR COLLISIONS*

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Presently an experiment is underway to measure the spectrum of charged kaons produced in relativistic nuclear collisions at 2.1 GeV per nucleon. Although the partial cross section for kaon production is relatively small, such an experiment is of great interest because of the important new information it may provide about the nuclear collision dynamics. The positive kaons have a relatively small interaction cross section (~9 mb) with nucleons so that they are more likely to escape unperturbed once created. Since the threshold (~1.6 GeV) for their production is relatively high on the scale of presently available beam energies, the kaons are predominately produced before the initial kinetic energy is substantially degraded. They are therefore expected to be better suited as messengers of the primary violent stage of the collision which might otherwise remain quite elusive.

We have studied kaon production in relativistic nuclear collisions on the basis of a conventional multiple-collision model. Our study, which is based on a conventional multiple-collision picture, employs the linear-cascade model with two baryonic states included: the nucleon N(940) and the delta resonance $\Delta(1232)$. The baryonic cascade then involves the process $NN \leftrightharpoons N\Delta \leftrightharpoons \Delta\Delta$. Due to the Lorentz dilation factor, which is around 3, the deltas are not likely to decay until after the cascade is completed. The pions, whether created during the primary cascade or later, are expected to have too little energy to produce any kaons in their further interactions with the nucleons. We therefore expect that the dominant source of kaons is the primary baryon-baryon collisions. Since the partial production cross section for kaon is so small we may safely employ a perturbative approach in which the dynamical feed-back effect of the kaon production in the further collision process is ignored.

The quantities needed in order to generate the kaon spectra associated with a nucleus-nucleus collision are the kaon spectra associated with the various types of elementary baryon-baryon collisions. Since the experimentally available information is limited to proton induced reactions at few energies, we have developed a simple one-pion-exchange model to generalize the experimental data.

We have calculated the kaon production cross section for cases of actual experiment interest. The calculation yields kaon distributions which are nearly isotropic and centered near the mid-rapidity.

The total inclusive kaon cross sections scale approximately with the product of the projectile and target nucleon numbers. The Fermi motion of the nucleons is instrumental in producing kaons at large angles and energies. The predictions obtained from the above multiple-collision model are significantly different from what would result in a thermal model, so the kaons should be well suited for discriminating between these different pictures.

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ENERGETIC PROTONS FROM THE $^{12}C + {}^{60}Ni$ REACTION

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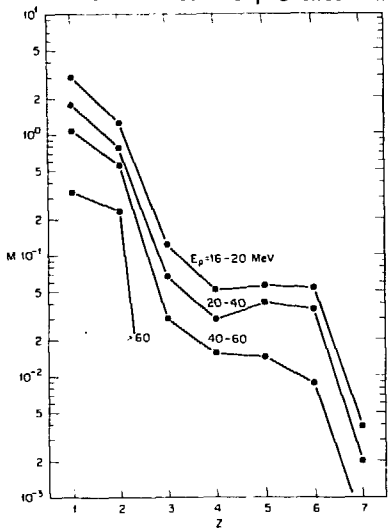
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A strong component of forward peaked protons with energies up to 70 MeV was found when ^{56}Fe was bombarded with 192-MeV ^{12}C ions.[1] To obtain information about the reaction mechanism(s) giving rise to these protons, we have measured coincidences between the protons and other charged particles with a similar reaction: 194-MeV ^{12}C on ^{60}Ni. The energetic protons were detected at four coplaner angles: 17°, 38°, -23° and -49°. The coincident particles were detected at 17°. The multiplicity M of charged particles occurring with these energetic protons was deduced. For this calculation, it was assumed that the angular distribution of the particles in the coincident mode was identical to that of the singles mode. The figure shows the extracted multiplicities versus the Z of the coincident particles for different energy gates of the energetic protons. Two pronounced features are: 1) a significant drop in M between the light ions (Z = 1, 2) and the heavier ones, and 2) a substantial decrease in M with increasing proton energy. The first feature indicates that if the energetic protons are emitted by an excited projectile-like nucleus, the part of the projectile-like nucleus not absorbed by the target usually fragments into small pieces.

From the results presented in the figure and from the assumption that the number of neutrons emitted is equal to that of the protons, we estimated the average total number of nucleons emitted in coincidence with an energetic proton. The number is ∿15 when the proton has E = 16-20 MeV and decreases to ∿3 when E > 60 MeV. This suggests that as the energy of the proton is increased, more of the projectile nucleons are transferred to the target nucleus.



Similar features were observed for a ^{12}C projectile energy of 136 MeV.

*Operated by Union Carbide Corp. for the U.S. Department of Energy under contract W-7405-eng-26.

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STUDY OF HEAVY ION REACTIONS WITH ^{12}C PROJECTILE AT 86 MeV/A

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The recent development of a beam of ^{12}C of 86 MeV per nucleon at CERN synchrocyclotron and the possibility of having various other light projectiles available in a near future (^{14}N 98 MeV/A, ^{16}O 76 MeV/A, ^{19}F 77 MeV/A) open new prospects of investigating heavy ion nuclear reactions in this little explored region of incident velocity.

The aim of the experiment reported here was to measure the energy and angular distribution of light fragments and projectile-like fragments by means of three telescopes in order to be compared to the equivalent data obtained at higher and lower incident energies, the purpose, being mostly to study the mechanism of peripheral collisions, projectile fragmentation processes, hot spot formation and promptly emitted particles.

The main telescope was made of four detectors : three diodes (Si 1 mm, Ge 2.8 mm, Ge 15 mm) with a 20 cm plastic scintillator coupled to a photomultiplier at the back of the set. The time of flight of the fragments was also measured between the target and the telescope, on a three meter flight path between two plastic scintillator foils (0.1 mm thick). This ensemble was used to identify both heavy fragments and high velocity light fragments at forward angles (θ = 2 to 30°).

The first results were obtained during a period of two weeks of 1030 MeV ^{12}C beam. The data were taken on ^{12}C, ^{109}Ag, ^{197}Au. The high quality of the beam (typical size $\sim$ 1 cm on the target with no detectable halo, divergence $\leq$ 10 mrd) allowed measurements over an angular range of 2 to 20 degrees. The elastic scattering cross-section was also measured on ^{12}C, ^{40}Ca, ^{89}Y and ^{208}Pb. The preliminary results show that the elastic scattering angular distribution on ^{12}C exhibits a typical Fraunhofer diffraction pattern, whereas it is the Fresnel type of diffraction which dominates for the ^{208}Pb target. The energy spectra of the fragments measured on the various targets are peaked at the value corresponding to the projectile velocity, feature expected from projectile fragmentation. The angular distributions of the fragments decrease exponentially, the heavier the fragment the steeper the slope, however, isobars of A = 7 and 10 have slopes markedly different. There has also been found a certain amount of ^{12}B isotope, which cannot be produced in a projectile fragmentation process, and which should arise either from nucleon exchange between projectile and target or from charge-exchange interaction (charged-pion exchange) between one nucleon of the target and one nucleon of the projectile. A few spectra have also been taken after beam degradation down to 58 MeV/A, showing rather large neutron pick up cross-section.

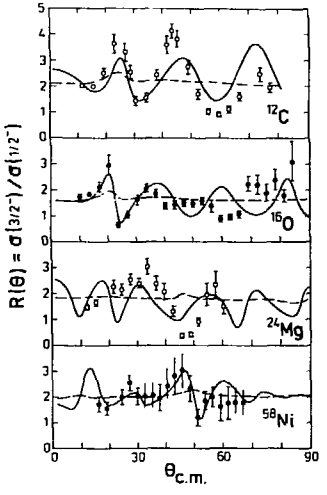
INFLUENCE OF SPIN-ORBIT COUPLING IN (^{3}He,^{7}Be) α-PICKUP†)

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The (^{3}He,^{7}Be) reaction is generally agreed to proceed via α-pickup mechanism. Nevertheless α-transfer DWBA predictions comparable to those for the case of the "classical" α-transfer-reaction (^{6}Li,d), or its inverse, are still missing. A difficulty we want to point out here in particular becomes evident from the observation that the angular distributions for the two bound states ^{7}Be$(3/2^-)_{g.s.}$ and ^{7}Be$(1/2^-)_{0.43}$ differ significantly in shape.

In order to investigate to what extent this can be attributed to spin-orbit coupling effects, the exact finite range code LOLA has been extended[1] to include SO-coupling in both the entrance and exit channels. The figure displays the experimental angular distributions of the ratio $R(\theta) = \sigma_{3/2}(\theta)/\sigma_{1/2}(\theta)$ obtained at the Hamburg isochronous cyclotron at $E(^3He) = 41$ MeV together with the relevant α-transfer DWBA predictions for target nuclei ^{12}C, ^{16}O, ^{24}Mg and ^{58}Ni. The curves represent α-pickup DWBA calculations both without (dashed curves) and with spin-orbit coupling in the entrance and exit channel optical potentials.



The main results are summarized as follows: (i) Contrary to the experimental evidence, R_{DWBA} is essentially constant when neglecting spin-orbit terms. (ii) A spin-orbit term in the ^{7}Be bound state potential reproducing the 430 keV splitting between the $3/2^+$ and $1/2^-$ states has no effect on R. (iii) Drastic changes are obtained when spin-orbit coupling is switched on for the ^{7}Be exit channel even with the rather small strength of $V_{SO} = 1$ MeV (assuming 1/A-proportionality of V_{SO} for composite particles). The effect is enhanced when the ^{3}He channel includes spin-orbit interaction simultaneously (solid curves).

†) Supported by the "Bundesministerium für Forschung und Technologie"

1) P. Lezoch, Thesis 1980 and to be published

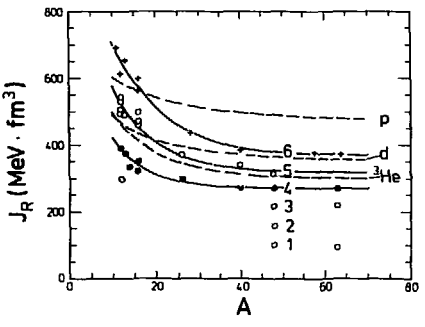
CHOICE OF "PHYSICAL" ^{6}Li OPTICAL POTENTIALS†)

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D-2000 Hamburg 50, Fed. Rep. of Germany

The volume integral per interacting nucleon pair over the real optical potential term in first approximation is expected to be independent of the mass number of the projectile. Comparison with uniquely determined values of J_R from nucleon-nucleus scattering analyses thus serves to remove the well-known discrete ambiguity in elastic scattering analyses for composite particles. On the other hand, growing work on ^{3}He scattering analyses[1] indicates a severe suppression of $J_R(^3He)$ as compared to $J_R(p)$. This is qualitatively understood in terms of Pauli blocking effects. Reliable quantitative predictions of this suppression are, however, still missing.

For the purpose of (^{6}Li,d)-DWBA analyses we are particularly interested in selecting physically meaningful potentials for ^{6}Li projectiles. We have therefore compiled the results of ^{6}Li elastic scattering analyses[2]. In the figure, the corresponding magnitudes of $J_R(^6Li)$ are plotted against target mass number for several successive discrete families. On the basis of a comparison with the magnitudes of J_R for p, d and ^{3}He projectiles (dashed lines) we suggest that it is family number 4 which represents the physical ^{6}Li potentials. For radius $R_R = 1.3 \cdot A^{1/3}$ this family corresponds to the real potential depth of $V_R \approx 150$ MeV at $A \geq 40$, whereas $V_R \approx 190$ and 230 MeV is obtained for families 5 and 6 respectively. Watanabe folding of d and α potentials through α-d cluster wave function reveals $V_R \approx 240$ MeV.



The importance of these considerations is stressed by the fact that discrete potential ambiguities appear to persist in (^{6}Li,d) α-transfer DWBA analyses[3]. The resulting spectroscopic factors vary by factors of 2 ÷ 5 for successive ^{6}Li potential families.

†) Supported by the "Bundesministerium für Forschung und Technologie"

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3) P. Lezoch et al., contribution to this conference

A-DEPENDENCE OF α-SPECTROSCOPIC FACTORS - NUCLEAR STRUCTURE OR DWBA EFFECTS?†)

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In order to trace the origins of fluctuations and uncertainties in the α-spectroscopic factors derived from experimental α-transfer data, we have initiated a systematic analysis of a large sample of angular distributions. Here we point out the existence of discrete ambiguities in DWBA analyses of experimental[1] (^{6}Li,d)-angular distributions. Some examples are presented in fig. 1, which displays FRDWBA predictions for two neighboring ^{6}Li optical potentials (no other parameter changes). Factor of 2 ÷ 5 differences in the corresponding spectroscopic factors are obtained. This is demonstrated more systematically in fig. 2, displaying spectroscopic factors for three neighboring ^{6}Li potential families together with the magnitudes of the real potential volume integral J_R characterizing the potential family.

The present results suggest that the large maximum in S_α observed previously[2] at around A ≈ 40, but not obtained here, is due to a change in the potential family.

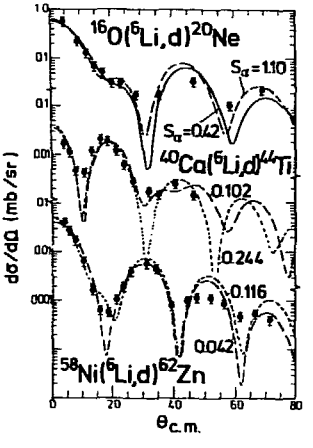


Fig. 1

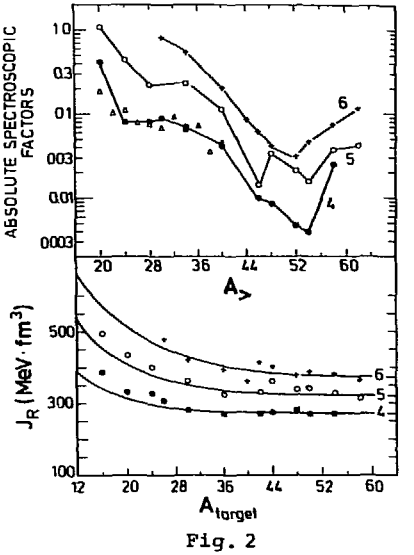


Fig. 2

†) Supported by the "Bundesministerium für Forschung und Technologie"

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THEORETICAL STUDY OF MASS DISTRIBUTIONS IN HEAVY ION REACTIONS BETWEEN SULFUR AND MEDIUM-WEIGHT NUCLEI

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The reactions of ^{32}S on ^{59}Co, ^{65}Cu, ^{74}Ge, ^{79}Br, ^{85}Rb and ^{89}Y were studied [1]) in the energy range $153 < E_{lab} < 184$ MeV. The double differential cross sections $d^2\sigma/d\theta dy$ ($y = (A_2 - A_1)/A$) show asymmetric fragmentation centered around the target mass in the case of Co and go gradually towards symmetric fragmentation in the case of heavier targets.

We try to describe these distributions in the framework of a transport model [2]). The drift coefficient is directly related to the total potential

$$U(y) = B(A_1) + B(A_2) + E_{rot}(A_1) + E_{rot}(A_2) + U_{nucl} + V_{cent} + V_{coul}$$

The sum of experimental mass defects $B(A_1) + B(A_2)$ as a function of y shows a dip centered at the entrance channel fragmentation in the case of Co and decreases towards symmetry ($y = 0$) in the other cases. Fig. 1 shows this behaviour for two systems. A careful analysis of the mass defects shows that the difference is unambiguously due to shell effects. The potential U generally behaves in the same way, at least for $\ell > \ell_{fus}$. These results are thought to explain qualitatively the experimental data.

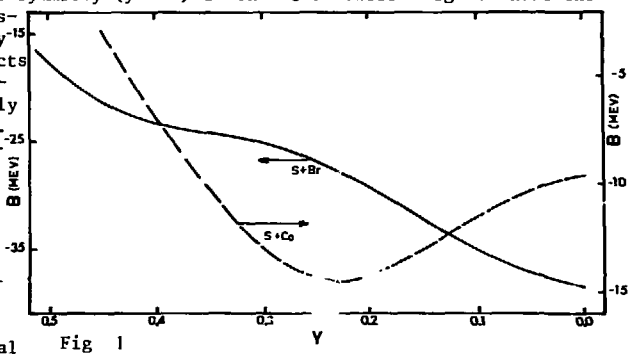


Fig 1

This is in fact confirmed by dynamical calculations in which the transport equation for the mass distribution $P(y,t)$ is coupled to classical equations of motion [3]) and solved numerically.

+ Permanent address : Institut de Physique, Université de Liège, B-4000 Sart Tilman, Belgium.

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In-BEAM γ-RAY SPECTROSCOPY ON ^{74}Kr WITH A NEUTRON MULTIPLICITY TECHNIQUE **

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^{74}Kr is expected to be an additional test of the interpretation that the lighter Kr-isotopes change their character from an axial symmetric rotator to a triaxial structure in ^{82}Kr, which is also supported by IBM calculations [1]. We studied the ^{58}Ni(^{19}F, p2nγ)^{74}Kr reaction. Because of the neutron deficient compound nucleus the p2n channel to ^{74}Kr is rather weak in this reaction. For this reason we applied a neutron-gamma coincidence technique with a large liquid scintillator with four independent segments which allowed a 1 to 4 fold neutron multiplicity measurement. With this experimental setup we achieved a good identification of the residual nuclei (fig. 1). For ^{74}Kr many unknown transitions could be identified. A preliminary level scheme of ^{74}Kr (fig. 2) was deduced from n-γ and n-n-γ yield functions (E(^{19}F) = 58 - 68 MeV) and n-γ-γ coincidence measurements. These results are in excellent agreement with the IBM prediction.

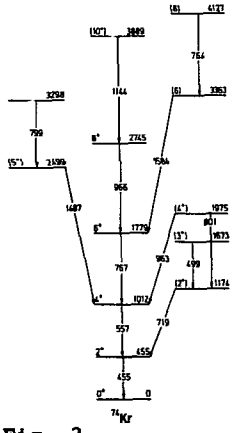


Fig. 2

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** Supported in part by the German BMFT

Fig.1: Comparison of γ-singles, n-γ- and n-n-γ-coincidences of the reaction ^{19}F on ^{58}Ni.

Fig.2: Level scheme of ^{74}Kr.

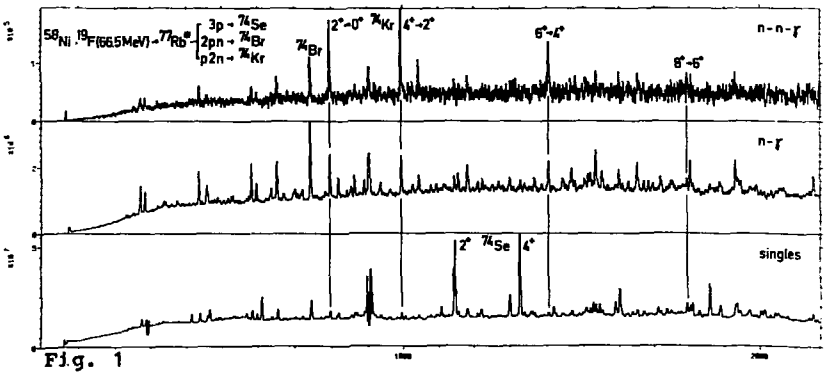


Fig. 1

A PARITY DEPENDENT POTENTIAL MODEL APPLIED TO BACKWARD ANGLE ANOMALY IN $^{9}Be+^{12}C$ SCATTERING

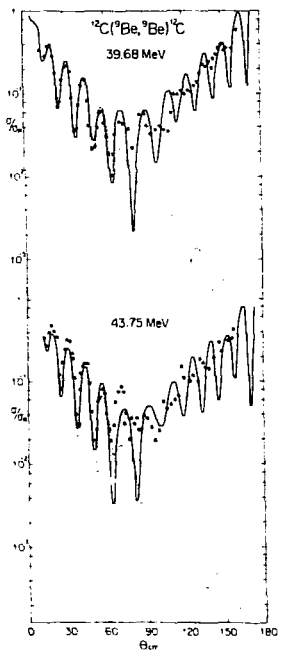
Shigeo Ohkubo

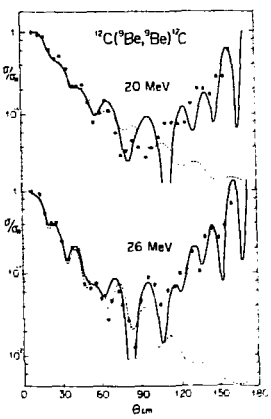
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Recent experiment of ^{9}Be scattering from ^{12}C[1),2)] have shown that anomalous increases of cross sections occurs at backward angular region. The angular distributions resemble V shape. It has been difficult to reproduce this anomalous backward rise by the usual optical potential model, which suggests other reaction mechanisms at backward angles.

A parity dependent potential model[3)], which has been proposed from the viewpoint of the Pauli principle, is applied to the $^{9}Be+^{12}C$ scattering. The interaction potential is characterized by $V(r)=V_{opt}(r)+(-)^{L} V_{ex}(r)$. The former is parity independent part and the latter is parity dependent one. For $V_{opt}(r)$ we take the potential of Ref.2). The parity dependent term Vex is assumed to be of surface type of Woods-Saxon and the potential parameters are searched to reproduce the data.

The experimental data[1),2)] at E_{Lab}=20,26,39.68 and 43.75 MeV are analyzed. The usual optical potential model calculations with V_{ex} part switched off (dotted lines) show angular distributions decreasing toward large angles. The calculated cross sections at backward angles are about a few orders of magnitude smaller than the experimental data. On the contrary the parity dependent potential model calculations (solid lines) reproduce the data satisfactorily not only at forward angles but also at backward angles. At E_{Lab}=20 and 26 MeV the backward angle oscillations are fairly well reproduced.





It is found that the parity dependent potential explains well the backward rise in $^{9}Be+^{12}C$ scattering. A preliminary coupled channel calculation shows that the backward rise in inelastic scattering of $^{9}Be+^{12}C(2^{+};4.43\ MeV)$ at E_{Lab}=39.68 MeV is also satisfactorily reproduced by the present model, while the usual optical potential model fails. The parity dependent potential model may be extensively applicable to backward angle anomaly in heavy ion scattering.

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PIONS IN THE STATISTICAL PICTURE OF HIGH-ENERGY HEAVY-ION COLLISIONS*

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Recently high-energy nuclear collisions[1] have been studied by means of a statistical model.[2] It describes the observed cross sections in terms of contributions arising from dynamically independent groups of interacting nucleons, ascribing highest entropy distributions in line with the conservation laws to each group. The model has particularly elucidated the role of finite particle number effects in inclusive proton spectra.[3] In this work the model has been extended to include the production of pions. As in Fermi's statistical theory[4] the rate of pions produced out of a group of nucleons follows from the assumption of complete equilibrium in all degrees of freedom in the system which is assumed to be confined to a given volume. Consequently and analogously to other thermo-chemical models[5] a density parameter governs the production rates. This is the only free parameter of the model. It has been chosen such as to reproduce the observed pion multiplicities at 800 MeV/A beam energy.

As a consequence of the finite number of particles involved in a heavy-ion reaction the asymptotic slopes of the one-particle spectra (protons or pions) turn out to be steeper than those calculated with models using bulk-limit distributions[5] and are in fair agreement with experimental data. Especially the dependence of the spectra on the mass of the colliding system can be explained as an effect of the respective difference in the numbers of particles involved. Furthermore, some of the scaling features of inclusive pion spectra[6] can be reproduced and seem to reflect the dominance of kinematical effects in these cases.[7] The statistical model in general proves to be superior to other models based on the equilibrium assumption in all cases where kinematical limits are being approached, e.g. for pion production under forward angles which was recently measured up to the kinematical limit.[8]

While the pion production rates still remain to be understood, the inclusive proton- and pion-spectra reflect a great deal of features typical for equilibrized but finite systems.

*Work supported in part by Bundesministerium für Forschung und Technologie, Germany, and by the Division of Nuclear Physics of the U. S. Department of Energy under contract No. W-7405-eng-48.

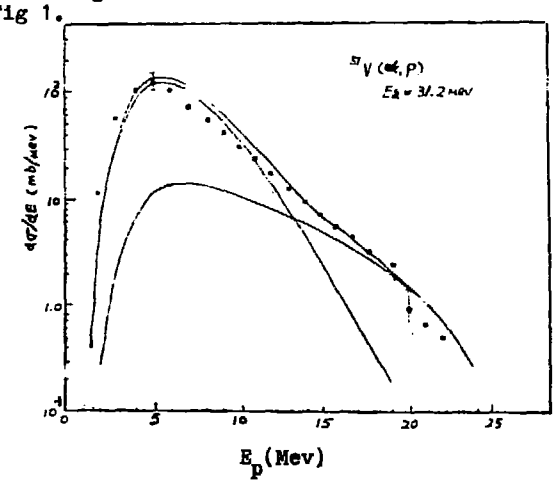
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(α,p) Reaction Induced by 31.2 Mev α Particles

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Preequilibrium emission of nucleons and other light particles in medium energy nuclear reactions induced by light projectiles has been of considerable interest in the last several years. Exciton and hybrid models successfully predict both the angle integrated spectra and the preequilibrium fraction in these reactions. But relatively few work was concerned with the angular distributions of the emitted particles. We measured spectra of protons emitted in (α,p) reactions on Al,V,Fe and Co targets at five different angles. Incident α beams were accelerated at the cyclotron of insititute of nuclear research, Shanghai, China, to an energy of 31.2 Mev. Particle identification was performed with a conventional ΔE-E telescope. In these spectra, two components, corresponding to equilibrium and preequilibrium emission can be identified. The angle integrated spectra were fitted with statistical and hybrid models. The experimental result for ^{51}V (α,p) reaction together with the theoretical calculation are given in Fig 1.



The angular distributions of emitted protons were calculated using the model proposed by Mantzouranis et,al.[1]) and compared with experimental results. Parameters used in the analysis are discussed.

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Measurement of Ejectiles in HI Reaction in the Wide Angular Range ($\theta_L \gtrsim 1.5°$)

T. Fukuda*, M. Tanaka**, H. Ogata, I. Miura, M. Inoue,
T. Yamagata***, S. Nakayama+, H. Kamitsubo++ and M. Ishihara++

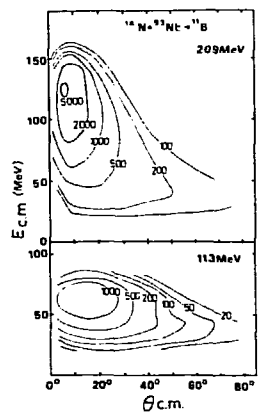
Research Center for Nuclear Physics, Osaka University
* Dept. of Phys., Osaka Univ., ** Kobe Tokiwa Junior College
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++ Institute of Physical and Chemical Research

It is customary to classify the deflection function for the deep inelastic collisions (DIC) in heavy ion reactions into two categories; orbiting and focussing. It has been argued[1] based on the classical friction model that the reaction systems with relatively large (small) incident energies with respect to the Coulomb barriers tend to show the orbiting (focussing) nature. In fact, systematic study of the differential cross section $d^2\sigma/dEd\theta$ in various reaction systems seems to support this conjecture. However such observation may often be ambiguous because of the absence of the data at very forward angles, where intense elastic scattered particles disturb the measurements.

In this experiment, we measured $d^2\sigma/dEd\theta$ in the angular range which covered forward angles down to 1.5°. The differential cross sections were detected for various products (from ^{4}He to ^{13}C) in the $^{14}N+^{93}Nb$ reaction at $E_{lab}(^{14}N)$=113, 159 and 209 MeV. The reaction products at the angular range of $\theta_{lab} \gtrsim 10°$ were identified with a conventional Si detector telescope consisting of 30 μm ΔE_1, 100 μm ΔE_2 and 5000 μm E counter. For the measurement at the very forward angles ($1.5° \lesssim \theta_{lab} \lesssim 10°$), the bending (dipole) magnet at the target and the momentum selector (quadrupole triplet magnet) were incorporated.

The typical example of the contour plots of the experimental differential cross sections $d^2\sigma/dEd\theta$ (in units of μb/MeV.rad) in the C.M. angle vs. energy plane is shown for (^{14}N, ^{11}B) reaction in the figure. The so-called quasi-elastic (QE) components are located around the grazing angle θ_{gr} with large cross sections extending to considerably large negative Q-values. In addition relatively weak components of DIC are observed for the large negative Q-values and in the wide angular range. A significant aspect is fact that the most probable deflection angle is nearly constant down to the very large negative Q-values.

This observation is obviously contradictory with the orbiting feature that the ridge of the cross section moves to and crosses the zero degree as the $|Q|$ value is increased. It is to be stressed that the same patterns of the deflection functions were generally observed for the whole reaction products irrespectively of bombarding energies. The present finding of the focussing nature rather than orbiting in the reaction studied, in which incident energies extremely exceeds the Coulomb barrier, clearly deviates from the hypothesis[1] mentioned in the beginning, casting doubt on the application of the simple classical description to reaction induced by relatively light heavy ions such as studied here.



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NUCLEAR INTERACTIONS OF HEAVY TARGETS WITH ~ 8 MeV/u-^{238}U AND 84 MeV/u-^{12}C, STUDIED WITH MICA AND CR-39 TRACK DETECTORS

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The 2π-geometry technique using uranium target and mica track detectors have been employed at the UNILAC (GSI, Darmstadt), using U-beams. One observes four- and five-pronged events. They are interpreted as double- and triple sequential fission. Comparing the out-of-plane angular distributions for double-sequential processes in the c.m.-system, we observe experimentally a "smearing-out" of such a distribution, when the uranium-energy is increased from 7.5 MeV/u up to 9.0 MeV/u. This is interpreted as an opening of many reaction channels at the higher energy which involve massive angular momentum transfers.

Using the same 2π-geometry and Pb-targets on CR-39 plastic track detectors, we carried out irradiations at the CERN-SC (Geneva) with 86 MeV/u-^{12}C ions. Preliminary results indicate, that we can study target-like fission fragments after a short etching time, while projectile-like light fragments are revealed after a longer etching time. The decicive role of the "track-induction-time" for the experiment will be discussed.

This experiment was supported by the BMFT, Bonn.

* visiting scientist from the Institute of Physics, Belgrad

** Reaktorsicherheitskommission, Köln

ANGULAR MOMENTUM TRANSFER IN DEEP INELASTIC COLLISIONS OF 280 MEV AR ON NI AS DETERMINED BY SECONDARY PARTICLE EMISSION

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and J.M.Alexander[+], T.H.Chiang[++], J.Galin, B.Gatty, D.Guerreau and X.Tarrago

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In this work, we have investigated the angular momentum transfer in deep inelastic collisions by measuring both protons and α-particles in correlation with the deep inelastic fragments. First, we have shown that most of the light particle yield could be accounted for by statistical evaporation from the detected fragment and its complement. This is nicely suggested in fig.1 where the invariant cross sections for α-particles are plotted versus parallel and transverse momenta. In any direction, the maximum of the distribution coincides with what is expected when considering evaporation from two moving sources (symbolized by the full line circles in the plot, whereas the dashed line circles simply indicate the experimental detection thresholds). Furthermore, a two dimensional fit of the data has allowed to check the evaporative origin of the light particles most accurately.

In a second step, a classical analysis of the out of plane angular distribution of the α particles has led to the determination of the spins of the emitting fragments provided their full alignment is assumed. In fig.2 the data are compared with what is expected from rigid rotation of the dinuclear composite system. A good agreement is found when the actual deformation of the composite system at scission is considered.

Finally, in a third step the proton and alpha-particle multiplicities and their ratio are being checked against standard evaporation calculations using the GROGI-2 computer code. As all these quantities depend very much on the spin of the emitter,an independent determination of the spins is attempted. In principle, a comparison between these two determinations should allow to test a possible disalignment of the DIC fragments.

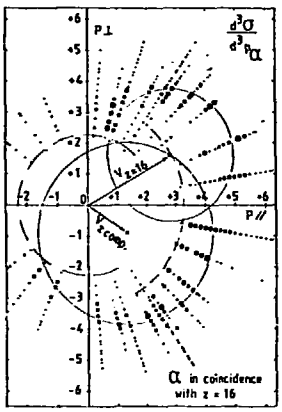


Fig.1

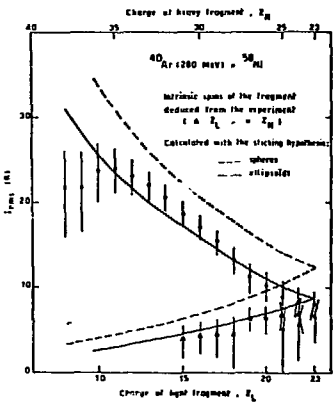


Fig.2

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VERY ENERGETIC PROTONS PRODUCED IN RELATIVISTIC NUCLEAR COLLISIONS

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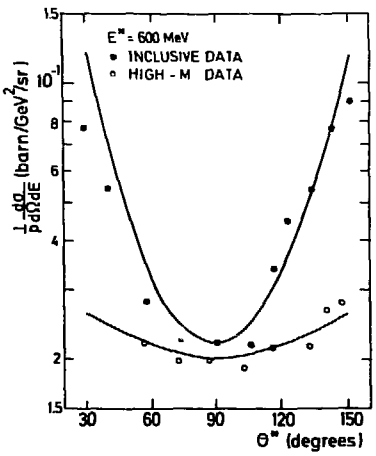
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Like in our previous work[1] the inclusive production of protons is assumed to proceed via incoherent multiple scattering. The single contribution is calculated within a covariant impulse approximation whereas the higher order collisions are described by transport equations of the Fokker-Planck type. The approach of ref.1) is generalized in two respects:
(i) We use a relativistic Green function for the transport equations.
(ii) Depending on peripheral or central collision geometry we construct two Fokker-Planck equations with different asymptotic solutions.
The peripheral limiting distribution possesses a lower temperature than the central fireball. It is centered around a non-zero average momentum in the rest frame of the colliding nuclei thus being anisotropic in this frame.

The improvements (i) and (ii) are instrumental for a satisfactory description of both inclusive and high-multiplicity (high-M) cross sections of very energetic protons. In the figure, these cross sections are shown as functions of the c.m. angle θ^* at a fixed c.m. energy E^*= 600 MeV for protons produced in an Ar+KCl-collision at 800 MeV/N. As can be concluded from the figure, our calculations are in quite good agreement with the data of ref. 2). We emphasize that for the usual Gaussian Fermi-distribution of the nucleons single scattering contributes very little to this kinematic region (E^*=600 MeV). The dominant source for the production of such high-energy protons at forward and backward angles is peripheral multiple scattering for the inclusive data,and near θ^*=90° central multiple scattering.



†Work supported by BMFT.

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LOCAL DENSITY DEPENDENCE EFFECTS ON THE SCATTERING OF HEAVY IONS AND ALPHA PARTICLES†

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The effective nucleon-nucleon interaction used in folding calculations for scattering processes is expected to show density dependence which is normally taken to be of a local character. One hopes to express this density dependence in a global fashion so that applications can be given to a variety of nuclear targets. The double-folding model provides a form for the real part of the projectile-target optical model that is given by

$$V(R) = \int d\underline{r}_1 d\underline{r}_2 \; \rho_1(\underline{r}_1)\; \rho_2(\underline{r}_2)\; v\;(\underline{s},\rho)$$

$$v(s,\rho) = v_1(s) + v_2(s)\; \exp[-\beta\rho_1(\underline{r}_1+\tfrac{1}{2}\underline{s}) - \beta\rho_2(\underline{r}_2-\tfrac{1}{2}\underline{s})]$$

where $\underline{s} = \underline{r}_2-\underline{r}_1+\underline{R}$. The view is taken that the interacting nucleons contribute to the local density ρ at their midway position. This complicates the calculation and therefore one usually ignores the s-dependence of the exponential factors in the expression for v. Such a procedure appears arbitrary with the realisation that significant contributions from v come from nucleon-nucleon separations $\sim$1-2 fm. Moreover, the densities are also known to contribute in an important way through the tails of their distributions.

We devised a method to calculate for such s-dependence and our conclusion is that the error in calculations of the differential cross-sections, ignoring the s-dependence, is of the order $\lesssim$5%, except near the scattering minima where the errors are slightly more significant and in situations where there is penetration into the nuclear interior. A full calculation is mandatory in the latter case.

We compared different forms for the density dependence. One is that developed by Jeukenne et al[1] and this bears similarity to the one proposed by Myers using a liquid-drop treatment. Another form was introduced by Day[2]. Finally, there is the M3Y interaction developed by Satchler and Love[2], which is also asserted to show some density dependence. The density-dependent features are generally of a similar nature for most heavy-ion scattering processes. We find that, as long as the angular distributions are non-oscillatory, the interaction of Jeukenne et al and the M3Y interaction show similar fits to the differential cross-section in regions where the yield is sizeable. The Day interaction, on the other hand, underestimates the yield by factors near 0.4-0.6 where σ/σ_R is of the order of 0.1. Allowance for the local-density dependence in v leads to a greater dependence in V(R) on the choices made for the densities and this points to the need for careful delineations of nuclear densities.

† This work was supported by the Science Research Council.

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NON ORTHOGONALITY EFFECTS IN HEAVY ION TRANSFER REACTIONS†

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The derivation of the DWBA result for single nucleon transfer, when put in the context of the coupled-channel formalism, proceeds on the assumption that the bound-state wave functions of the transferred nucleon are orthogonal. This is clearly not so, because of the separation of the nuclear cores. A measure of the importance of this effect is the degree of overlap of the two bound-state wave functions $\phi_\alpha(\underline{r}_1)$ and $\phi_\beta(\underline{r}_2)$, which we denote by $N_{\alpha\beta}(\underline{r}_1, \underline{r}_2)$. The peripheral nature of most heavy-ion transfers suggests that $N_{\alpha\beta}$ is small enough so as to ignore non-orthogonality. This has, however, been put to test only for a few reactions.

Our calculations proceed in the normal way leading to the DWBA result, but allowance is made for non-orthogonality. The procedure is iterative in that we stop at second-order terms that come into play in conventional coupled-channel calculations. The result is a correction to the incoming channel wave function $\Delta\chi_i$ involving three terms $\Delta^{(p)}$, p = 1, 2 and 3:

$$\Delta^{(1)} = \sum_\beta \int N_{\alpha,\beta} \int N^*_{\alpha,\beta} \chi^{(0)}_i(\underline{r}_i) \Big|_{\underline{r}_f} d\underline{r}_1 \Big|_{\underline{r}_i}$$

$$\Delta^{(2)} = \sum_\beta G^{(i)}_k(\underline{r}_i, \underline{r}'_i) \int N_{\alpha,\beta} \Delta V_i \int N^*_{\alpha,\beta} \chi^{(0)}_i(\underline{r}''_i) \Big|_{\underline{r}_f} d\underline{r}_2 \Big|_{\underline{r}_f} d\underline{r}_1 \Big|_{\underline{r}'_i} d\underline{r}'_i$$

with $\Delta^{(3)}$ similar to $\Delta^{(2)}$ except for the involvement of the residual interaction ΔV_f and a Green-function appropriate to the exit channel. $\Delta^{(1)}$ is easiest to evaluate and is similar to one calculated earlier by Goldfarb and Takeuchi for (d,p) reactions. The other terms bring in difficulties because of dependence on displaced variables. We approximate, employing the local-momentum treatment for the dependence of χ_i on the shifted variables. This has been applied with some success by Braun-Münzinger and Harney[1]. Satisfaction of the constraints on the variables bring focus on ℓ-values somewhat lower than those associated with grazing.

Our calculations cover the reactions $^{13}C(^{16}O,^{17}O)^{12}C$, leading to the ground-state ^{17}O and $^{17}O^*$, the first excited state and the $^{29}Si(^{16}O,^{17}O^*)^{18}Si$ reaction. Comparison of the $\Delta^{(p)}$ terms shows $\Delta^{(2)}$ dominance. The other two terms are small and also cancel each other out. We used conventional optical-model potentials and also the surface semi-transparent potentials of Baltz et al[2], both of which were appropriate to these reactions. The latter potentials do, however, place emphasis on partial waves favoured by non-orthogonality so that the effects become larger. Allowance for coupling to ^{17}O and $^{17}O^*$ leads to corrections as high as 5-10%. The C+O reactions are, however, particularly selective in that they involve large tails of bound-state wave functions and this enhances our corrections.

† This work was supported by the Science Research Council.

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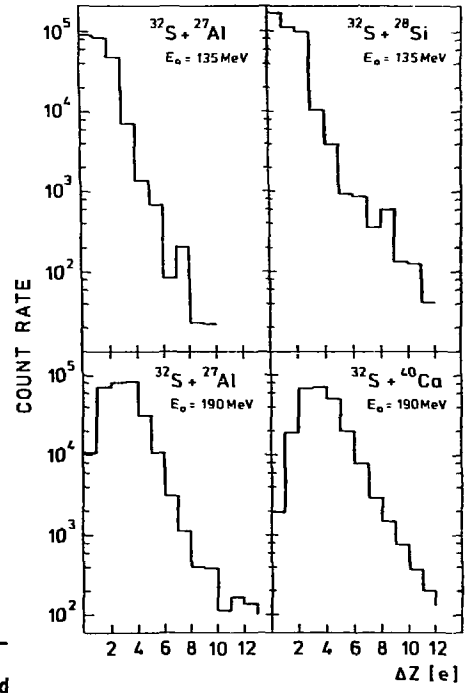
MULTI-PARTICLE PRODUCTION IN THE REACTIONS $^{32}S + ^{27}Al$, ^{28}Si, ^{40}Ca

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The multi-particle production induced by the reactions $^{32}S + ^{27}Al$, ^{28}Si, ^{40}Ca was studied at bombarding energies of 135 and 190 MeV. The experimental set-up consists of two large-area position sensitive ionization chambers (Ω=50msr) to detect two heavy reaction products in coincidence. The detectors measure for each particle a set of 5 parameters: the differential energy loss dE, the total kinetic energy E, the time-of-flight between target and ionization chamber, and two position signals. These parameters allow one to deduce the energy E, mass M, atomic number Z and the linear momentum p of each detected fragment. By means of a kinematical analysis, we can calculate the deficits of charge ΔZ, mass ΔM and linear momentum Δp to the values of a truly binary reaction. In the case of a ternary reaction, we get the total reaction Q-value and the deficits are the kinematical parameters of the third undetected particle.

The figure shows the ΔZ distribution of all detected coincidences. At the lower bombarding energy the probability of producing more than two particles is already very high (70%). At 190 MeV ^{32}S-energy, the cross section of the binary reactions decreases below 1% of all events. The element distributions for a specific charge deficit show a preferential production of fragments with even atomic number Z, if the sum of Z values of both detected heavy nuclei is also even. Structures in the Q-value spectra of the binary reactions show a selective excitation of yrast energies.



The two-particle inclusive events show, for the light undetected products, forward peaked laboratory angular distributions and energy spectra with long tails to high kinetic energies. The detailed analysis has previously been restricted to the production of α-particles. By means of Monte-Carlo simulations, the light particle emission at the lower bombarding energy can be ascribed to the sequential decay of thermalized intermediate fragments. First calculations show that the interpretation holds true too for the main part of α-production at the higher projectile energy.

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WAVE PACKET SCATTERING MODEL WITH FRICTION FOR $^{11}B+^{159}Tb$ AT 51MeV

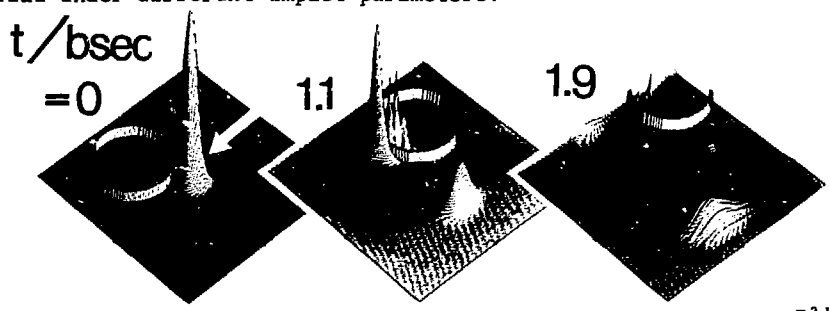
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We show that the quantum wave packet scattering model with friction[1]) is capable to explain elastic and deep inelastic scattering and fusion simultaneously. Hereby we solve the time dependent Schrödinger equation $i\hbar\dot{\Psi}=H\Psi$ in two cartesian relative coordinates between the ions with the nonlinear Hamiltonian[2])

$$H = \frac{\mathbf{p}^2}{2\mu} + V(r) + \gamma(r)\langle\mathbf{p}\rangle(\mathbf{r}-\langle\mathbf{r}\rangle)$$

which has also been derived microscopically[3]). V(r) is a realistic conservative (Coulomb plus nuclear) potential, $\gamma(r)$ is a trapezoidal isotropic friction form factor and $\langle\rangle$ denote expectation values. Initially, a Gaussian wave packet impinges on the potential under different impact parameters.



As can be seen from the series of frames above (1bsec=10^{-21} sec), the initial wave packet with angular momentum ℓ=31.5$\hbar$ splits up into three parts: The fast elastic (quasielastic) component which travels along a Rutherford trajectory, the slow deep inelastic (direct) component which loses all available energy, creeps along the potential and is then repelled by the Coulomb energy, and the fusion component which is trapped.

Cross sections and maximum and critical angular momenta are calculated with a soft cutoff formula by folding the angular momenta with the respective probabilities. As compared to results with classical trajectory calculations, the reaction cross section stays about unchanged whereas the deep inelastic cross section is enhanced and the fusion cross section and the critical angular momentum are lowered which is in rather good agreement with the experiment. Also, the differential cross section does no longer exhibit an infinity but is peaked about back angles.

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ANGLE DEPENDENT PHASE SHIFTS FOR ROTATIONAL EXCITATION

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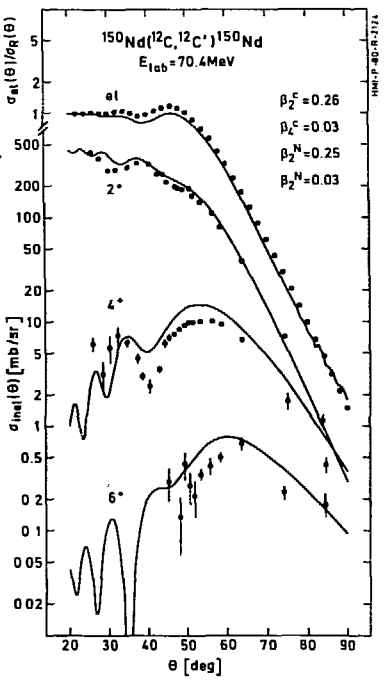
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The method of angle dependent phase shifts[1] has been applied to the calculation of the differential elastic and inelastic scattering cross sections for ^{12}C incident on the deformed nucleus ^{150}Nd at E=70.4 MeV. Transitions to the rotational levels $0^+,2^+,4^+,6^+$ in ^{150}Nd were considered. Multiple excitations play an essential role. However, a coupled channels calculation is circumvented here by writing the amplitude $S_{\ell\ell',I}$ for the excitation of the state I^+ with initial (final) orbital angular momenta ℓ (ℓ'), in the sudden approximation, as an integral

$$S_{\ell\ell',I} = \frac{\sqrt{\pi}(\ell)}{2}\int d\theta' \sin\theta' \, P_I(\cos\theta') \exp[2i\delta_{\bar{\ell}}(\theta')],$$

where $\bar{\ell}=(\ell+\ell')/2$; $\delta_{\ell}(\theta')$ is calculated as the phase shift for a θ'-dependent nuclear-plus-Coulomb potential in the target-fixed system, regarding θ' as a parameter, not a dynamical variable.

The Figure shows the experimental cross sections[2] (dots) and the corresponding results of the angle dependent phase shift calculations (solid curves). The agreement for the inelastic cross sections is of about the same quality as for coupled channel calculations with the same dynamical parameters[2]. The discrepancies visible especially in the elastic cross section can be traced back to inaccuracies in the treatment of Coulomb excitation effects.



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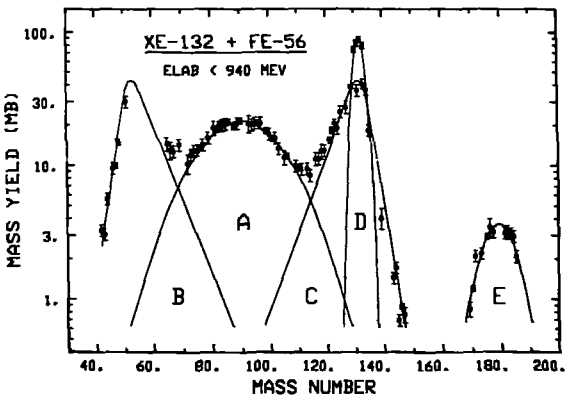
ANALYSES OF MASS AND CHARGE YIELDS FOR THE SYSTEM $^{132}Xe + ^{nat}Fe$[§]

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Evidence for a new reaction mechanism in the system 756-MeV Xe-132 + Fe-56 has been reported by Heusch, et al.[1], whose charge-yield curve exhibits only a large symmetric component in addition to the quasielastic peaks. In contrast, our radiochemical mass and charge yields from thick-target experiments at 780 and 940 MeV exhibit well-resolved components corresponding to fusion-fission, evaporation residues, deep-inelastic transfer (DIT), and quasielastic transfer. The mass yields for 940 MeV are shown in the figure. In order to shed light on possible reasons for the apparent disagreement in results, we have intensively investigated various properties of the reaction yields.

Angular distribution curves have been determined for 34 products. Those corresponding to the symmetric component are consistent with $1/\sin\Theta$, indicating that a long-lived system gives rise to these products. Those corresponding to DIT are peaked strongly forward of the grazing angle, in expected agreement with other data at this E/B of 1.79. The FWHM of the symmetric yields from liquid drop systematics is expected to be 33 $\pm$ 2 amu, and we observe 34 $\pm$ 3 amu. The presence of evaporation residues shows that at least part of the symmetric yield is fusion fission. However, estimates of Γ_n/Γ_f indicate that the symmetric yield is about 50% larger than expected. A similar excess in yield is observed in comparison with the rotating liquid drop limit where the observed limit of 94 $\pm$ 4 $\hbar$ is considerably above the expected value of 72 $\hbar$. These results are at least consistent with the hypothesis that this new mechanism[1] occurs only in a narrow energy window, and that its presence is masked in the thick-target radiochemical data. Thin-target experiments are now underway to investigate this possibility.



§Work supported by the Bundesministerium für Forschung und Technologie and the Gesellschaft für Schwerionenforschung.

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THE IMPORTANCE OF THE INELASTIC BREAK-UP MECHANISM FOR NUCLEUS-NUCLEUS SCATTERING

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We calculate in our formulation[1] of the elastic and inelastic breakup process the corresponding flux removed from the elastic channel. It is a dominant reaction mode for peripheral collisions. Especially important is the inelastic breakup mode, where one part of the projectile interacts inelastically with the target nucleus and the other part moves on essentially undisturbed. By means of unitarity we can sum over all possible kinds of inelastic processes. This mechanism is related to the mechanism of incomplete fusion as observed in heavy ion reactions at higher energies ($E/A \gtrsim 10$ MeV/A). We perform model calculations for light ion induced breakup reactions[2] on various target nuclei at energies from 10MeV/A to 40MeV/A. We calculate especially the absorption due to breakup as a function of the incoming angular momentum. Our numerical results suggest a simple parameterization of the breakup probability, which is reminiscent of the Serber picture

$$T_\ell^{b-up} = \beta\, e^{-\frac{(\ell-\ell_0)^2}{(\Delta\ell)^2}} = \beta\, e^{-\frac{(b-b_0)^2}{(\Delta R)^2}}$$

where $b = \ell/q$, $b_0 = \ell_0/q$, $\Delta R = \Delta\ell/q$ and q is the wave number of the projectile. The breakup probability has a strong peak at a partial wave ℓ_0, corresponding to an impact parameter $b_0 = r_0(A^{1/3}+a^{1/3})$, the factor β describes the strength of the break-up process which shows a saturation for sufficiently high incident energies. In our numerical calculations we find $r_0 \gtrsim 1.2$ fm remarkably independent of E and A; ΔR depends to a good degree only on the projectile-fragment combination, which leads to the "factorization property" found in very high energy heavy ion fragmentation processes[3]. This property therefore seems to be valid also for our lower projectile energies.

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FAST α-PARTICLE EMISSION IN ^{20}Ne AND ^{40}Ar-INDUCED NUCLEAR REACTIONS

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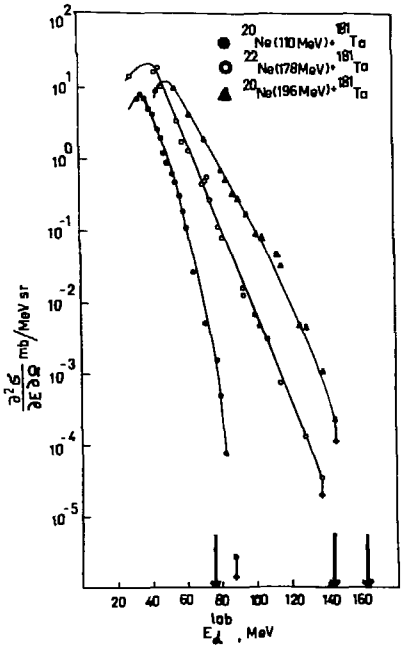
The energy spectra and angular distributions of fast charged particles emitted in nuclear reactions induced by ^{20,22}Ne and ^{40}Ar ions on ^{159}Tb, ^{181}Ta, ^{197}Au, and ^{232}Th targets at an energy of 5.5-10 MeV/nucleon have been measured. It is shown that one of the most intensive reaction channels corresponds to the emission of ^{4}He nuclei. As the energy of the ^{4}He nuclei increases, the direction of particle emission strongly correlates with that of the incident beam.

The α-particle spectra were measured in the energy range 30-150 MeV at the angle $\theta = 0^{0}$. The measurement was performed using a magnetic spectrometer used in conjunction with a ΔE-E telescope. A characteristic α-particle spectrum obtained from the reaction ^{20}Ne + ^{181}Ta at different values of the bombarding energy is shown in the figure to follow. For all the reactions investigated, the steepness of the exponential fall of the α-particle spectra turns out to be considerably smaller than the expected value calculated for an excited compound nucleus. The maximum energy of the experimental α-particle spectra can be interpreted as the transfer of the projectile energy to the α-particle, followed by the fusion of the interacting nuclei. The calculated values of $E_{\alpha}^{max} = E_{0} + Q$ (they are shown by arrows in the figure) are in good agreement with experiment.

From the analysis of experimental results it is possible to conclude that the nature of α-particle emission may be different depending on the energy and the direction of α-particle emission.

The most probable mechanism of low-energy α-particle emission, the angular distribution of which is close to the isotropic one is the evaporation of α-particles from the excited compound nucleus (composite system).

However, already in the energy region of $E_{\alpha} > 60$ MeV, this process becomes non-stationary and α-particle emission occurs rather long before the moment when the system reaches full equilibration. The limiting case of the energy transfer to the α-particle is of interest both in terms of the reaction mechanism and in terms of the possibility of producing compound nuclei with low excitation energy. Further experiments are planned to measure the characteristics of the neutron and γ-radiation accompanying energetic α-particle emission.



ON THE QUESTION OF UNIQUE SPIN ASSIGNMENTS FOR THE $^{12}C+^{12}C$ INTERMEDIATE RESONANCE STRUCTURES*

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Several theoretical concepts are presently discussed in the attempt to understand the observed intermediate resonance structures in the $^{12}C+^{12}C$ fusion reaction at energies near the Coulomb barrier . If these structures are interpreted in terms of single resonances, consistent spin assignments have to follow from all resonating exit channels.

The measurement of particle angular distributions is commonly used to determine these resonance spins, where exit channels associated with a single value of the orbital angular momentum are most useful. For this reason, the α_o exit channel in the $^{12}C+^{12}C$ fusion reaction has been used often to arrive at unique spin assignments. However, the α_6 and p_3 exit channels have similar features and therefore should lead to identical information if resonant. Furthermore, the analyses of all resonating exit channels have to yield consistent results.

Excitation functions for a large number of particle groups in the exit channels have been measured concurrently at eight detection angles (θ_{lab} = 10° - 90°) in the energy range of $E_{c.m.}$ = 2.6 - 6.3 MeV (in energy steps of 50 - 100 keV). The analyses of the data reveal contradicting features for some of the reported resonances and their reported unique spin assignments are therefore questionable.

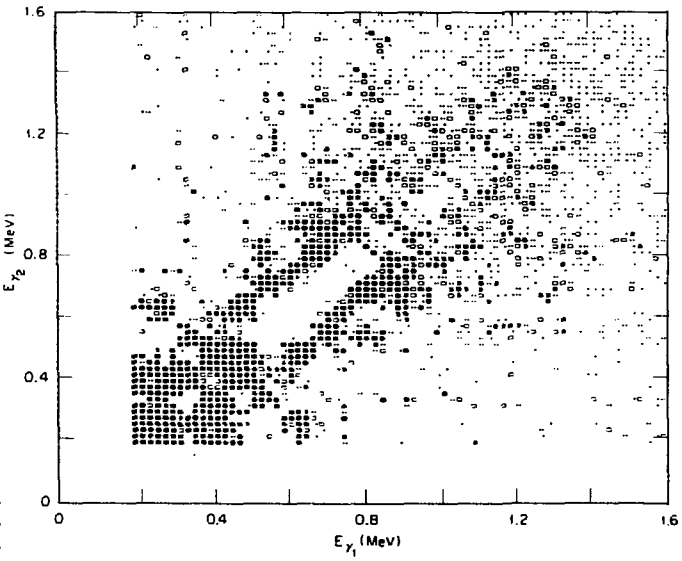
*Work supported by the Deutsche Forschungsgemeinschaft

HIGH SPIN PROPERTIES OF ^{132}Ce FROM GAMMA-RAY ENERGY-ENERGY CORRELATION STUDIES

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High spin properties of ^{132}Ce have been studied by using the ^{20}Ne induced fusion reaction. The continuum γ-rays were detected by three 12.7 x 12.7-cm NaI detectors and a 25.4 x 25.4-cm NaI total-energy detector was used for reaction channel selection. Experimental γ-ray energy-energy correlation spectra were first unfolded to remove the effects of detector response, then the standard subtraction method[1] was applied to extract the correlated ^{132}Ce spectrum shown here. The valley extending to 1.2 MeV along the diagonal indicates collective behavior in the energy region above that of the known discrete lines (0.8 MeV). From the width of the valley, one can derive a model independent value of the true collective moment of inertia. We obtained the values $2\theta/\hbar^2$=65 MeV^{-1} at $(\hbar\omega)^2$=0.25 MeV^2, and $2\theta/\hbar^2$=110 MeV^{-1} at $(\hbar\omega)^2$=0.31 MeV^2. This increase of the collective moment of inertia by nearly a factor of 2 may indicate the change of nuclear shape and/or the loss of pairing correlation at $(\hbar\omega)^2\approx$0.3 MeV^2. Further, regions of high γ-ray intensity along the diagonal (valley crossing) were observed at 0.5, 0.8, 0.9 and 1.1 MeV. The first two correspond to the known first backbending which is due to the nearly equal energies of the γ-ray from the 4^+, 12^+ and 14^+ states at about 0.5 MeV and from the 8^+, 10^+ and 18^+ states at about 0.8 MeV. The enhancement of γ-ray intensity at 0.9 and 1.1 MeV may be due to further backbendings (band crossings) at higher spins.



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*Operated by Union Carbide Corp. for the U.S. Dept. of Energy under Contract No. W-7405-eng-26.

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BACKWARD ANGLE MEASUREMENT OF DAMPED PROCESSES IN LIGHT HEAVY-ION REACTIONS

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A gaseous oxygen target was bombarded by a ^{27}Al beam to measure the backward-angle part of the angular distribution corresponding to damped projectile-like events previously studied by bombarding ^{27}Al with a ^{16}O beam.[1] Products with $6 \leq Z \leq 9$ and a Q-value window of $-15 \leq Q \leq -50$ MeV were measured at center-of-mass energies of 39 and 54 MeV. The 54-MeV angular distribution of these products in the center-of-mass system is shown in Fig. 1. A $1/\sin\theta_{cm}$ curve (solid lines in Figs. 1 and 3) gives an adequate description of this angular distribution. Estimates for a fusion-fission contribution at similar energies are much smaller than the cross sections shown in Fig. 1.[1] Most of the yield observed in Fig. 1 may then be the backward-angle portion of the deep inelastic process previously reported at forward angles. The $1/\sin\theta_{cm}$ angular distribution then supports the interpretation of deep inelastic scattering as an orbiting process.[2] Furthermore, inclusive spectra from reactions induced by bombardment of ^{12}C with ^{20}Ne have a significant damped component in the Z=6 spectrum which is shown in Fig. 2. The angular distribution at back angles for these damped events shown in Fig. 3 has the same shape as that observed for $^{27}Al + ^{16}O$.

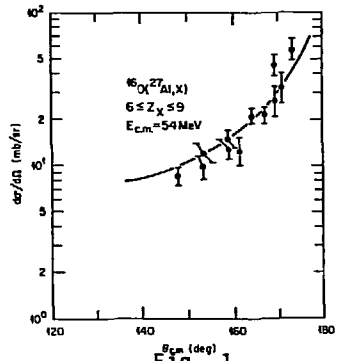


Fig. 1

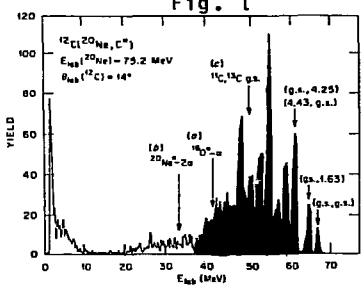


Fig. 2

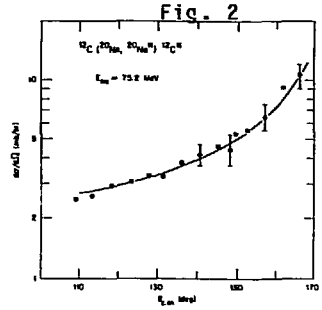


Fig. 3

*Operated by Union Carbide Corporation under Contract No. W-7405-eng-26 with the U.S. Department of Energy.

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A MICROSCOPIC ANALYSIS OF FOUR PARTICLE TRANSFER REACTIONS.

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A sistematic study of (^{6}Li,d) reactions on calcium isotopes (40-48) and (d,^{6}Li) on molibdenum isotopes (94-100) has been carried out by using a recently calculated microscopic form factor in ZRDWBA[1].
Since we can take into account correctly the configuration mixing in the residual nucleus, we can use these reactions as a spectroscopic tool. The most peculiar feature of Ca(^{6}Li,d) reactions[2] is the enhancement of the cross section in the ^{40}Ca(^{6}Li,d)^{44}Ti$_{g.s.}$ transition with respect to the other isotopes. In order to reproduce the trend of the relative transition strengths (r.t.s.) together with the shape of the angular distributions it seems necessary to allow for a dependence of the di-proton wave function on the neutron number in the residual nucleus. In particular the amount of $(0f7/2)^2$ configuration should increase with the neutron number
In the case of $^{94-100}$Mo (d,^{6}Li)[3] reactions the experimental data show that the transition strength to the first excited 0^+ state of ^{96}Zr is larger than the g.s. one, while for the other isotopes it happens just the opposite. It is suggested ir ref.[3]) that a configuration mixing simply including $(1p3/2)^2$ and $(0g9/2)^2$ with amplitudes varying with the neutron number can explain the experimental data. Our preliminary results show that additional components-like $(1d5/2)^2$ - in the 0^+ excited state wave functions are necessary in determining both the r.t.s. and the angular distributions. The role of "hot" orbitals is clearly seen in the microscopic calculation.
We have also derived a microscopic form factor to study in FR DWBA four-particle transfer among heavy ions explicitely including a detailed description of both projectile and residual nucleus. Preliminary results seem to be very promising.

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ANALYSIS OF $^{12}C + ^{16}O$ USING PROJECTION OPERATORS[†]

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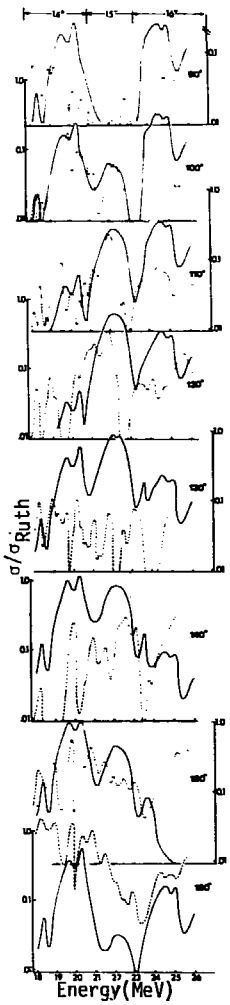
A projection operator method based on the Feshbach doorway approach is developed for low energy heavy ion scattering and applied to $^{12}C + ^{16}O$ with doorways taken as quasibound or virtual states of the reduced mass coupled to 2^+ and 3^- vibrations.

The ratio of the differential cross section to the Rutherford cross section is calculated between 18 and 28 MeV C.M. at increments of 10° between 90° and 160° C.M. The results are presented for 14^+, 15^-, and 16^+ resonances (solid lines) and compared to experiment (dashed lines) in the figure.

The calculations agree well with observation by producing many of the gross and intermediate molecular structure features. The magnitudes of the calculated and observed 14^+ cross sections are comparable. We predict a 14^+ doublet, each member of which has a width of about 400 KeV. This is comparable to the sums of the widths of the associated experimental structure. The theoretical 15^- resonance at about 22 MeV has a dip at 90° in agreement with experiment. At other angles a peak is readily apparent in our calculations and in experiment at this energy. While the observed resonance has the same structure, it appears to be fairly broad and comparable in cross section to our calculated 15^- resonance. In addition we predict a 16^+ doublet at energies of 24.7 MeV and 25.0 MeV. It is clear from experiment that two close resonances are seen at essentially these energies. The magnitudes of the calculated and measured cross sections are comparable and the combined width of our 16^+ doublet is very close to what is seen.

The resonances that result from vibrations in ^{16}O are much weaker in our model than those based on ^{12}C.

Our calculations not only yield intermediate structure which can be compared to experiment, but also indicate under which conditions such structure can be expected. The size of the doorway widths are quite important in determining whether isolated intermediate structure resonances will be observed.



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MODELING THE EQUILIBRIUM DECAY. APPLICATION OF MONTE CARLO CALCULATIONS TO THE DEEP INELASTIC COLLISION OF 168 MeV ^{20}Ne on ^{63}Cu

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A problem of current interest concerns the degree of equilibration in deep inelastic collisions (DIC). To study this we have performed Monte Carlo statistical model calculations using the computer code LILITA[1] and the assumption that the two primary fragments reach complete equilibrium. These calculations are particularly useful for predicting angular correlations between the secondary fragments and the emitted light particles and their associated energy spectra. Detailed calculations have been done for the in-plane and out-of-plane correlations between α-particles and projectile-like fragments (PLF) in the DIC of 168 MeV ^{20}Ne with ^{63}Cu. Comparisons with the experimental data of Dayras et al.[2] are shown in Fig. 1. The in-plane correlation between α-particles and carbon ions observed at θ_{lab}=25° is shown in Fig. 1a. The histograms are the equilibrium calculations decomposed into contributions from α-particles emitted by the PLF and target-like (TLF) fragments. The dashed area indicates the yield which is not accounted for by the equilibrium calculation and, consequently, may be associated with the result of non-equilibrium emission. Figure 1b shows the calculated (histogram) and experimental (dots) energy spectra of the α-particles observed in coincidence with Z=6 fragments. The higher energy group corresponds to α-particles with velocities characteristic of the projectile (V_p) and is due to non-equilibrium emission. Figure 1c shows an α-spectrum at θ_{lab}=155° where agreement with equilibrium emission is found.

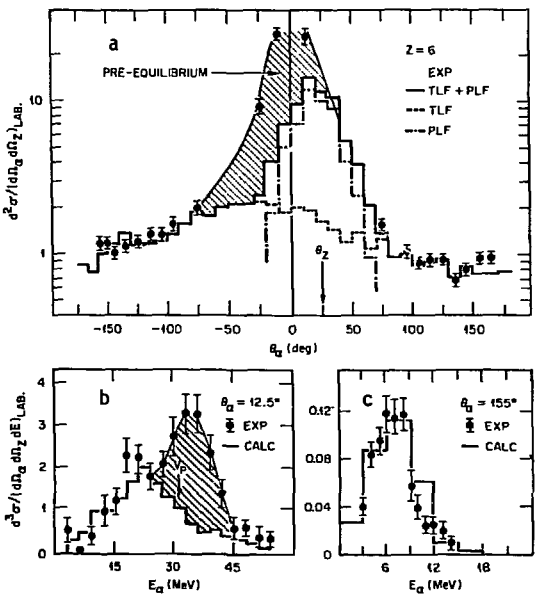


Fig. 1

*Operated by Union Carbide Corp. under Contract No. W-7405-eng-26 with the Department of Energy.

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1. J. Gomez del Campo and R.G. Stokstad, ORNL/TM-7295.
2. R.A. Dayras, K. Geoffroy, D.C. Hensley, M.L. Halbert, D. Shapira, D.G. Sarantites and J.H. Barker (unpublished).

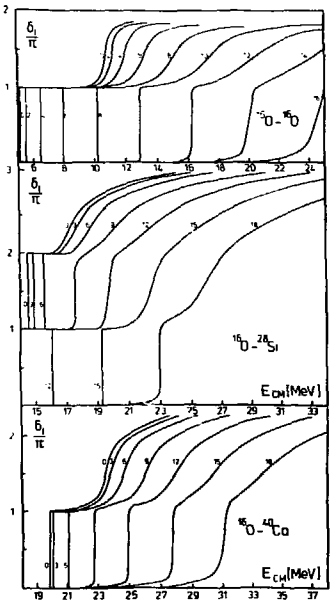
QUASIMOLECULAR AND SURFACE WAVE RESONANCES IN ELASTIC $^{16}O+^{16}O$, $^{16}O+^{28}Si$ AND $^{16}O+^{40}Ca$ SCATTERING

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Quasimolecular and surface wave resonances[1] are being discussed as possible explanations of gross structures in the excitation functions and backangle oscillations in the angular distributions seen[2], e.g., in elastic ^{16}O scattering on ^{16}O, ^{28}Si and ^{40}Ca for energies beyond the Coulomb barrier. This problem has been investigated by the one-channel generator coordinate method with scattering boundary conditions.

The internal structures of the ^{16}O, ^{28}Si and ^{40}Ca fragment nuclei were described by their oscillator shell model ground states. The effective interaction was approximated by a general central force containing two Gaussian functions. The Coulomb interaction was treated exactly, including all exchange contributions, by using the Gaussian integral representation of $1/r$.



The phase shifts for all three systems exhibit the following common features:

1.) There is a band of broad, overlapping resonances starting at about the Coulomb barrier. They follow closely the $\ell(\ell+1)$-rule of an ideal rotator, with moment of inertia θ according to

$$\theta = \hbar^2/2\mu R^2 \text{ with } R = 1.4(A_1^{1/3}+A_2^{1/3}).$$

These "surface wave" (orbiting) resonances are jointly (not individually) responsible for the above mentioned gross structure and backward oscillations.

2.) The members of the lower bands are sufficiently long-lived to be interpreted as "quasi-molecular" (pocket) resonances. They may cause some intermediate structure, either directly (higher ℓ-values) or indirectly (lower ℓ-values) via the "double resonance" mechanism, and do probe the nuclear interaction region in contrast to the orbiting resonances.

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COLLECTIVE CHARACTER OF HIGH SPIN STATES IN THE $^{116}Sn + ^{40}Ar$ SYSTEM

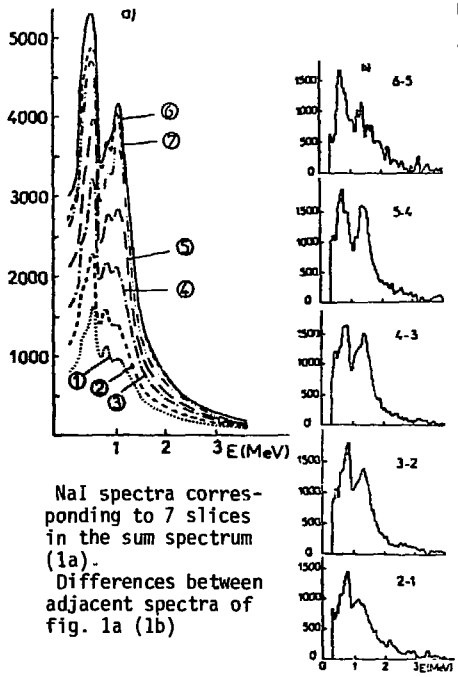
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It has been suggested [1] that high spin states ($I > 40$ h) in neutron deficient erbium isotopes ($N \simeq 84$) exhibit a collective (rotational ?) behaviour, in spite of the non collective character of low spin states [2].

We used a sum spectrometer in coincidence with two detectors located at 0° (NaI) and 90° (GeLi or NaI) with respect to the beam in order to select high spin states in the erbium nuclei produced in the reactions $^{124,119,118}Sn + ^{40}Ar$ (185 MeV). Our results for the ^{124}Sn target agree with the one from the Berkeley group [3].



NaI spectra corresponding to 7 slices in the sum spectrum (1a).
Differences between adjacent spectra of fig. 1a (1b)

Fig. 1a displays the spectra obtained with the ^{116}Sn target for adjacent slices in the sum spectrometer spectrum. They look quite different from the spectra observed with the $^{124}Sn + ^{40}Ar$ system [3,4]. The main difference is the existence in the $^{116}Sn + ^{40}Ar$ system of three bumps at about 650 keV, 1100 keV and 1300 keV, at constant energies whatever the slice number in the sum spectrum. Two bumps (650 keV and 1400 keV) have been also observed in the $^{118}Sn + ^{40}Ar$ [4] and in the $^{119}Sn + ^{40}Ar$ system. The third one (1100 keV) seems to be connected with the lower slices and then lower spins in the compound nucleus ($I < 35$ h) (see fig. 1b).

The constant energy of the 1300 keV bump, as well as the existence of a low energy bump lead to some doubt about the rotational character of the higher spin states in the neutron deficient erbium isotopes. Such a rotational character however could still exist, but then we have to consider the existence of moment of inertia sharply increasing with the spin of the nucleus.

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STUDY OF HEAVY-ION RADIATIVE CAPTURE IN THE $^{198}PT + ^{13}C$ SYSTEM

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Heavy-ion radiative capture for nuclear systems of large A is currently of interest as it provides a possible method for reproducing nuclei beyond the limit of stability, albeit with small cross sections. In an attempt to measure such a cross section in a heavy system, we have investigated the $^{198}Pt + ^{13}C \rightarrow ^{211}Po + \gamma$ reaction in the region of the Coulomb barrier energy. A 9.85 mg·cm $^{-2}$ target of pure Pt enriched to 95.83 ± 0.05% in ^{198}Pt was bombarded with 500 nA of ^{13}C 5^+ ions from the Brookhaven tandem accelerator MP7. The target was cycled into the beam for 30s periods and then out of the target area to a counting station for 40s periods using a rabbit system. During the out of beam periods, delayed α-particles were detected using an up stream surface barrier detector ($\theta_{1/2} \approx 25°$) and a downstream detector ($\theta_{1/2} \approx 20°$). Measurements were made at 60 MeV and 57 MeV bombarding energies for 15 hr time intervals. The majority of α-particles observed are identified with the 5.12 MeV weak α-branch from the 5.84 hr isomer of ^{207}Po. Smaller groups of counts are associated with 6.26 MeV α-particles from ^{210}Rn produced from a Pb impurity (<.02%). Two counts were observed which could possibly have arisen from the 7.27 MeV α-branch of the 25.5s isomer in ^{211}Po. Such an identification would lead to a cross section of $\sim$ 0.2 nb. We conclude therefore that the cross section for $^{198}Pt + ^{13}C$ capture leading to the 25s isomeric state in ^{211}Po is $\sigma < 0.6$ nb (3σ).

†This work was supported by the U.S. Department of Energy.
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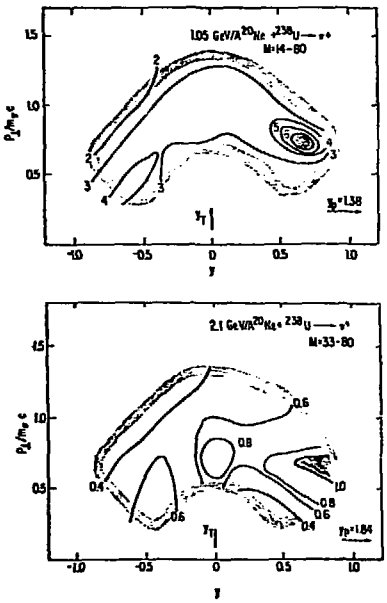
PION PRODUCTION AND CHARGED-PARTICLE MULTIPLICITY SELECTION IN RELATIVISTIC NUCLEAR COLLISIONS*

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Spectra of positive pions with energies of 15-95 MeV were measured for high energy proton, ^{4}He, ^{20}Ne, and ^{40}Ar bombardments on targets of ^{27}Al, ^{40}Ca, ^{107,109}Ag, ^{197}Au, and ^{238}U. A Si-Ge range telescope was used to identify charged pions by dE/dx and stopped π^+ were tagged with the subsequent muon decay. In all, results for fourteen target-projectile combinations are presented to study the dependence of pion emission patterns on the bombarding energy (from 240 MeV/nucleon to 2.1 GeV/nucleon) and on the target and the projectile masses. In addition, associated charged-particle multiplicities were measured in an 80-paddle array of plastic scintillators, and used to make impact parameter restrictions on the pion-inclusive data.

Broad structures occur in the π^+ spectra for ^{20}Ne-and ^{40}Ar-induced reactions at the highest bombarding energies. Examples are shown here as contours of constant cross section (1/p) $d^2\sigma/d\Omega dE$ as a function of perpendicular pion momentum and rapidity y for 1.05 and 2.1 GeV/nucleon ^{20}Ne + ^{238}U, selected on high charged-particle multiplicity, i.e., central and near-central collisions. Many features of the π^+ emission patterns can be explained in terms of the decay of isobars produced in nucleon-nucleon collisions, along with Coulomb repulsion from the spectator and participant matter. The results of more quantitative cross section comparisons of light projectile (p,α) with heavy-ion π^+ production are explained in terms of isobar-nucleon interactions in excited nuclear matter.



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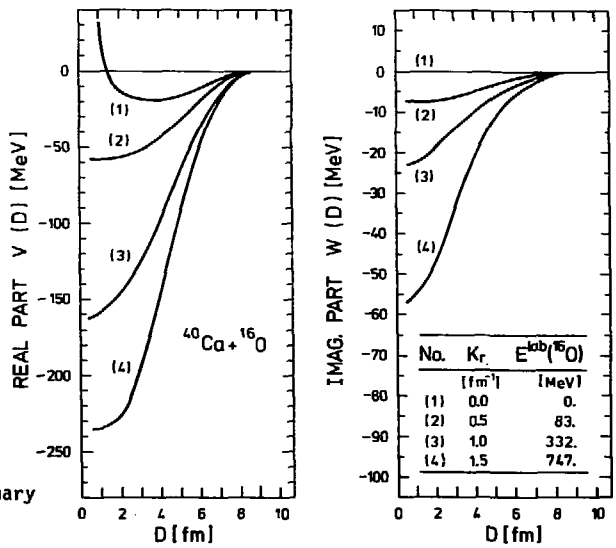
COMPLEX HEAVY ION POTENTIAL FROM BRUECKNER THEORY

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The Influence of the Pauli Principle on the energy dependence of the optical potential through modifications of the short range correlations is studied by evaluating the interaction energy of two colliding heavy ions in Brückner theory. This approach is intended for a study of high projectile energies. At low energies currently available, the excitation of surface modes is expected to give an important additional contribution.

The Bethe-Goldstone Equation is solved for two interpenetrating fermi gases and the potential energy is related to finite nuclei via a local density approximation[1]. The imaginary part is due to $2p2h$ energy conserving intermediate states.



Both real and imaginary part of the optical potential are found to increase with increasing bombarding energy, as is shown for the elastic scattering of $^{40}Ca + ^{16}O$. The reaction cross section is found to be 1.41 b and 1.52 b for E_{lab}=104 MeV and 214 MeV.

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Interactions of d, α-particles and ^{12}C Ions with Emulsion Nuclei At 2.1 and 4.2 GeV/c per Nucleon.

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In this paper we preseat the data on interactions of d-(4.2 GeV/c per nucleon)α-particles (2.1 and 4.2 GeV/c pernucleon), and ^{12}C (4.2 GeV/c per nucleon) in nuclear emulsions. NIKFI-BR-2 emulsions of size (10 cm x 20 cm x 600 μm) were exposed to the nominated beams at Dubna USSR. A total of $\sim$5000 stars in all these reactions were collected by along the track scanning. The values obtained of the mean free path λ and hence the cross-sections are analyzed in the frame work of the soft sphere model. A good agreement with that model is obtained considering the total inelastic cross-section of nucleons on free nucleons to be very near to that on bound nucleons. The average values of the different emitted charged secondaries, showers (n_s), grey (n_g), black (n_b) and heavily ionizing (n_h) particles, the correlation between them and their angular distribtions are deeply investigated. The momentum distribution of the different emitted projectile fragments is measured for a statistically good sample and identification, of these fragments into Z=1 (p,d,t), Z = 2 (α, ^3He) and Z $\geq$ 3 fragments is done. This enables to test the model of independent interactions. The average effective number of interacting nucleons from the projectile is determined in all cases.
A special attention is paid to the study of the so-called pure projectile fragmentation events (i.e. those events without any target break up of any degree). The momentum distribution of both the projectile fragments and the created mesons is studied. The dissociation of the ^{12}C into 3α-particles is also investigated.

The multiplicity distributions of emitted showers are studied in the frame of the collective tube model. The fitts are obtained for the tube parameter "σ" (effective cross-section) in the range $\sim$20-30 mb which is nearly equal to the inelastic nucleon-nucleon cross-section at the corresponding energies.

Thanks to Professor K.D. Tolstov from the JINR-Dubna USSR for supplying the irradiated emulsions.

MASS SPECTRA AND FUSION CROSS SECTIONS FOR THE ^{20}Ne + ^{24}Mg INTERACTION AT 55 MeV AND 85 MeV

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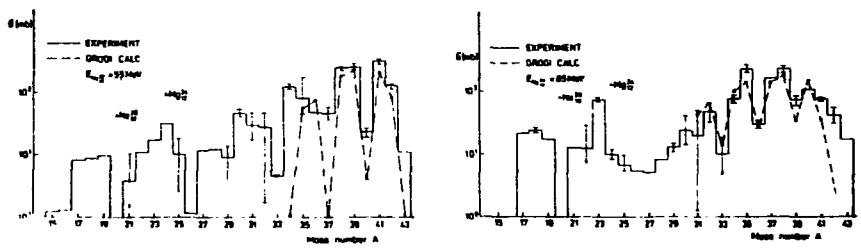
Inclusive γ -spectra from the ^{20}Ne + ^{24}Mg interaction were measured for the 55- and 85-MeV ^{20}Ne beams, accelerated at the cyclotron of Louvain-la-Neuve with the use of a 60 cm^3 Ge/Li/detector with a 2 keV resolution placed at 90° with respect to the Ne beam direction. A 0.8 mg/cm^2 ^{24}Mg target was placed on a lead backing to minimize the Doppler broadening of gamma transitions. Each gamma spectrum consisted of about 200 lines in the energy interval between 110 keV and 4 MeV. The peak fitting code SAMPO, together with a proper identification prooedure were used to obtain the mass spectra shown in Fig. 1.

Three regions are seen in these spectra:
1/ the region of evaporation residua resulting from fusion ($43 \geq A \geq 30$);
2/ the transfer reaction contribution (around A = 20 and A = 24);
3/ the light mass region ($A < 16$).

A statistical model calculation using the code GROGI[1]/which takes into account only nucleon and alpha evaporation from the highly excited ^{44}Ti compound nucleus/ reproduces the general trends of the $32 \leq A \leq 43$ mass spectra and predicts positions of the minima observed in the cross section /see Fig. 1./. The most noticeable departure from the GROGI calculation is a significant ^{43}Sc contribution in the experimental mass spectra, suggesting a competing reaction mechanism.

The fusion cross sections were caloulated by the integration of the mass spectra in the region of $30 \leq A \leq 43$. The lower A limit was determined by the GROGI calculation and the cross section isotropy was assumed for the γ -ray emission. The experimentally observed fusion cross sections were 700 mb and 1100 mb at 55 and 85 MeV, respectively.

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GAMMA RAY MULTIPLICITY IN DEEP INELASTIC COLLISIONS. PROBABLE EFFECTS OF COLLECTIVE MOTIONS.

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We have studied the γ ray multiplicity associated with the deep inelastic collisions for the Cu+Au 400 MeV system. We had three aims : i) to obtain a good precision on the absolute value of the multiplicity M_γ : indeed, in previous[1]) experiments it had been obtained that the M_γ value was too high as compared with any model (sticking or rolling). ii) to obtain the repartition of M_γ between both outgoing fragments : we used for that the kinematical properties of the Cu+Au 400 MeV reaction ; namely the fact that the outgoing fragments are emitted at 90° one from the other. The counting rate difference between two detectors located at 0° and 180° from the light fragment is then only due to the gamma rays emitted by the light one. iii) to obtain the variance associated with the gamma ray multiplicity distribution. This has been done by analysing the two fold coincidence events.

The results cannot be interpreted in terms of a simple situation like pure sticking or pure rolling. One way to understand them is to assume that collective modes like bending modes play an important role. i) The M_γ value has been again found too high : the bending mode could be responsible for the increase of the angular momentum of especially the light fragment. ii) Concerning the repartition of M_γ between the light and the heavy fragment, the results cannot be understood in terms of a pure sticking situation but agree with sticking + bending mode effects. iii) Concerning the two fold coincidences, it has been found that the FWHM of the M_γ distribution is huge (1.3 time the mean value $\langle M_\gamma \rangle$). A similar result has been obtained recently elsewhere[2]). Again this can be explained if a bending mode contribution has been added during the process.

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ENTRANCE CHANNEL EFFECT IN THE "FISSION WITHOUT BARRIER" PROCESS

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Some experimental data concerning fusion cross-sections cannot be fully understood in the framework of the rotating liquid drop model. Studying the mass distribution of "fission" products, it was shown that a large broadening is registered when fission barrier vanishes. This change was interpreted as a signature for a new mechanism intermediate between fusion and deep inelastic collisions[1]). The conditions under which such a mechanism can be observed have been already discussed[2]). Namely, the fission without barrier mechanism (as we tentatively named the process) is expected to exist only if a pocket is seen in the entrance channel sudden potential for ℓ-waves larger than the rotating liquid drop model limit $\ell_{Bf=0}$. In order to check the validity of the proposed theoretical models, we measured the evolution of the mass distribution width of the symmetric splitting component versus the bombarding energy in the $^{40}Ar+^{165}Ho$ and $^{24}Mg+^{181}Ta$ leading to the same complete fusion nucleus leading to the same complete fusion nucleus ^{205}At. Experimental values of the critical angular momentum were also deduced from the cross-sections measurements using the sharp cut-off approximation.

As theoretically expected, in the $^{40}Ar+^{165}Ho$ system :

- two mean values of mass distribution widths can be distinguished, the mean value is about 36 amu in the conventional fission range ($B_f>0$), whereas it reaches a value about 55 amu when the new mechanism competes with the fission reaction.
- a limiting value for ℓ-waves contributing to the fission without barrier is observed and corresponds to about $130\hbar$.

In the $^{24}Mg+^{181}Ta$ system, even at 340 MeV which corresponds to a critical angular momentum of about $130\hbar$ as calculated using the critical distance concept, no drastic change in the symmetric component mass distribution width is registered and the experimental critical angular momentum value agrees with the theoretically deduced limiting value of ref.2 which is slightly above the rotating liquid drop model limit.

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[1]) C.Lebrun, F.Hanappe, J.F.Lecolley, F.Lefebvres, C.Ngô, J.Péter, B.Tamain, Nucl. Phys. A321 (1979) 207.

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NUCLEAR RAYLEIGH AND WHISPERING-GALLERY WAVES EXCITED IN HEAVY ION COLLISIONS

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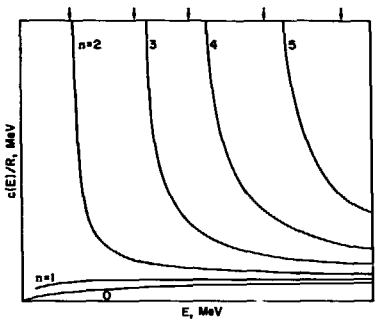


Fig. 1

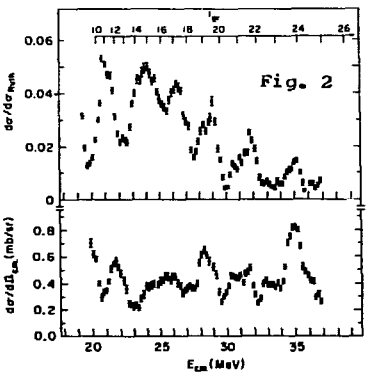


Fig. 2

The anomalous large-angle elastic scattering of heavy ions is interpreted in terms of resonances caused by phasematching of creeping waves[1]. The $^{16}O+^{16}O$ optical model of McVoy[2] gives dispersion curves for the creep-wave speeds c(E) of Fig. 1, showing Rayleigh (n = 0,1) or Whispering-Gallery wave behavior. Experimental[3] 180° resonances of $^{16}O + ^{28}Si$ (Fig.2) correspond to a Whispering-Gallery wave (Fig.3), while $^{12}C + ^{12}C$ resonances[4] have Rayleigh-wave character (Fig.4). The decay angle Θ_e of this wave is shown in the insert of Fig. 4.

+ Supported by the NSF

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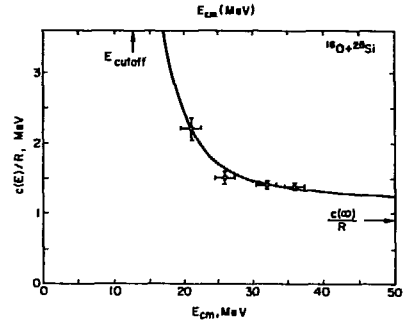


Fig. 3

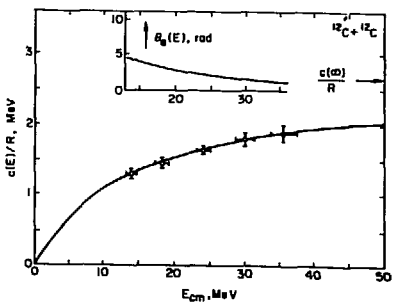


Fig. 4

NON-STATISTICAL FLUCTUATIONS IN THE $^{9}Be + ^{12}C$ SYSTEM

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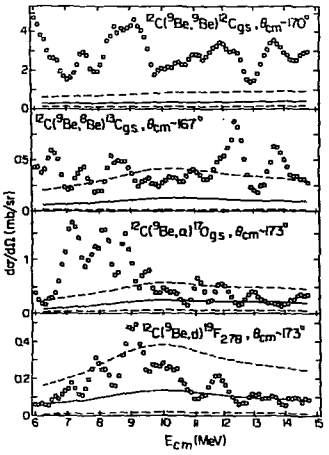
Institute of Physics, Jagellonian University, 30059 Cracow, Poland

The existence of non-statistical fluctuations or resonances in reactions between heavy ions is still one of the most striking phenomena in nuclear physics. A consideration of the number of open channels and the density of levels in the compound system[1] indicates that, apart from the well known α-particle nuclei, the $^{9}Be + ^{12}C$ system might be one of the most suitable candidates for a search for resonances; however, it is very controversial[2-3] in which way the observed structure in the excitation curves should be interpreted.

We measured, therefore, the excitation curves for many reaction channels (p-, d-, t-, α- and ^{8}Be-reactions to different states of the residues as well as elastic scattering) for different forward and backward angles in the c.m. energy range from 6 to 15 MeV. Solid state counter telescopes were used for identifying all reaction products with the exception of the ^{8}Be nuclei which were measured with a special detecting system consisting of two counters recording the α-particles from the decay of ^{8}Be in coincidence. ^{9}Be- as well as ^{12}C-ions were accelerated in the EN-Tandem accelerator of the ETH Zürich, so that the detectors could be placed always in the forward hemisphere; the energy resolution in the entrance channel, given mainly by the target thickness, amounted to 50-80 keV.

Especially at backward angles some cross sections show strong peaks. A few examples are given in fig. 1. The solid lines are predictions of the compound nucleus model with the Gilbert-Cameron level densities whereas the dashed lines indicate the range of statistical fluctuations that occur with probabilities of 1% or less; the curves were calculated under the assumption of no direct reactions. Only the excitation curves of the lightest particles can be explained by this model.

A more detailed analysis including auto- and cross-correlation functions and distribution of maxima will be presented at the conference.



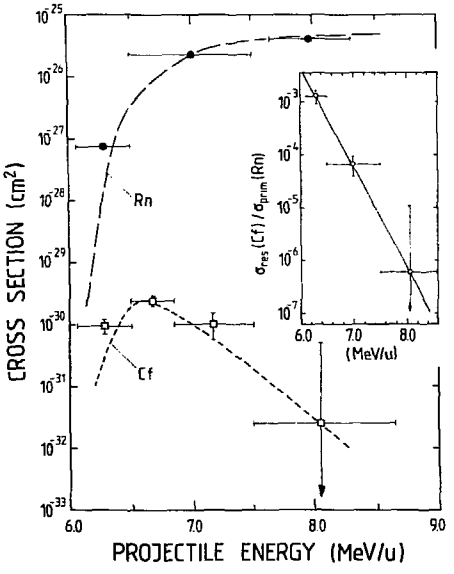
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HEAVY ELEMENT PRODUCTION IN $^{238}U + ^{238}U$ and $^{238}U + ^{248}Cm$ COLLISIONS

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Bombardments of thick ^{238}U-targets with 7.5 MeV/u ^{238}U-ions have shown[1] that this type of reaction might offer possibilities to extend the periodic system at its upper end. The measured isotope distributions have revealed[1] that only those heavy fragments deexcite without undergoing fission which are formed in the low-energy tails of the primary distributions. In order to probe the partial cross section contained in these low-energy tails, we measured production rates of Cf, Es and Fm-isotopes in the $^{238}U+^{238}U$ reaction for projectile energies varying between 1.06 and 1.4 times the barrier energy B. The resulting excitation functions for different isotopes have the same shape and peak at ~1.1xB. As an example Fig. 1 shows the integral yields for all Cf-isotopes vs. projectile energy. Also indicated in Fig. 1 are the primary yields for the light complementary element Rn. The cross section ratios $\sigma(Cf)/\sigma(Rn)$ are a measure for the average survival probability, see insert of Fig. 1. The survival probability decreases exponentially with increasing projectile energy. This behaviour is consistent with the idea that at each incident energy, the same window of low excitation energies ($E^* \leq 40$ MeV) is involved. While a higher incident energy shifts the excitation energy distribution for a given element to a higher average value, the low energy tail of that distribution moves out of the window relevant for the production of surviving actinides. Thus it is not possible to increase the heavy element production rates by increasing the bombarding energy. Actinide cross sections in the $^{238}U+^{248}Cm$ reaction at 7.5 MeV/u incident energy are presented and compared to the $^{238}U+^{238}U$ results. The potential of the $^{238}U+^{248}Cm$ reaction for the production of neutron-rich heavy actinide isotopes is discussed.



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1) M. Schädel, J.V. Kratz, H. Ahrens, W. Brüchle, G. Franz, H. Gäggeler, I. Warnecke, G. Wirth, G. Herrmann, N. Trautmann and M. Weis, Phys. Rev. Lett. 41, 469 (1978)

A MEASUREMENT OF THE CORRELATION BETWEEN TWO PROTONS EMITTED AT SMALL RELATIVE MOMENTUM FROM RELATIVISTIC HEAVY ION COLLISIONS†

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We have used a magnetic spectrometer to measure the relative momentum distribution of the two protons from the reaction $^{40}A + KCl \rightarrow p + p + x$ at 1.8 GeV/nucleon. We were motivated in part by the work of Koonin[1]) who proposed a model in which the correlation of the two protons at small relative momenta is sensitive to the size and lifetime of their source. In this model the correlation is dominated by the final state interaction of the two protons. Much of the sensitivity to the size and lifetime is due to the short range of the strong interaction between the two protons.

Data have been taken for $P_\perp$ = 230 MeV/c at rapidities of .89 and 1.62, while the beam rapidity is 1.72. Protons near the beam rapidity are expected to come mainly from the projectile remnant. From the geometry of the Fireball Model[2]) and the approximate equality of the projectile and target masses, we expect that any compound system will have a well-defined rapidity at approximately one-half the beam rapidity. We wish to see how large this compound system is and whether it lives longer than the nucleus-nucleus transit time.

It is currently believed that central collisions lead to the emission of a large number of high P_t fragments. Since the size and possibly the lifetime of the source should depend on the collision impact parameter, we have also measured the multiplicity of high P_t fragments. By studying how the correlation of the two protons changes with multiplicity, we expect to see how the size and lifetime of these sources depend on impact parameter.

At this very early stage of the analysis, we see that the correlation function has a shape very similar to that predicted by Koonin. There is evidence that statistically significant differences exist between the data at the beam rapidity and those at half the beam rapidity. Work is continuing on further analysis, especially in understanding systematic effects.

†This work was supported by the Nuclear Science Division of the U. S. Department of Energy.

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The Study on The Nucleon Exchange in Deep Inelastic Collision

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Experiments show that in DIC of heavy ions there exist correlation between total energy loss (ΔE) and the variance of elements distribution (σ_z^2), ΔE and γ-multiplicity. Such a correlation seems to show that the dissipation process of kinetic energy and angular momentum of relative motion relates closely to nucleon exchange. We think that the exchange can be divided into two different modes, the unequal one (ΔN) and equal one ($N-\Delta N$). The total number of exchanged nucleon $N \approx \sigma_A^2$. According to Einstein relation, ΔN can be obtained. Since the recoiling effect is produced by nucleon exchange, the rate of energy loss is

$$dE/dt = -[F_1(m,n)(d(N-\Delta N)/dt) + F_2(m,n)(d\Delta N/dt)]E \qquad (1)$$

where m is the exchanged mass from target to projectile; n inverse. And the angular momentum dissipation rate is [1]

$$\left.\begin{aligned} dl_1/dt &= d_1[(d\eta/dt)d_1(\dot\theta-\dot\theta_1) + (dm/dt)d_2(\dot\theta-\dot\theta_2)] \\ dl_2/dt &= d_2[(d\eta/dt)d_1(\dot\theta-\dot\theta_1) + (dm/dt)d_2(\dot\theta-\dot\theta_2)] \end{aligned}\right\} \qquad (2)$$

where $\dot\theta$ and $\dot\theta_1$, $\dot\theta_2$ is the rotation velocity of relative motion and that of fragments respectively. d_1 and d_2 is the average distance of nucleon exchange in projectile and target respectively.

Using (1), (2), ΔE and Δl have been calculated for Kr + Er system (See Figs. (1)). The interaction time was computed through a classical dynamics method. As shown in the figures, the total energy loss is only partly induced by nucleon exchange, while the angular momentum dissipation is mainly induced by nucleon exchange. And the equal exchange is more important than unequal one in both cases.

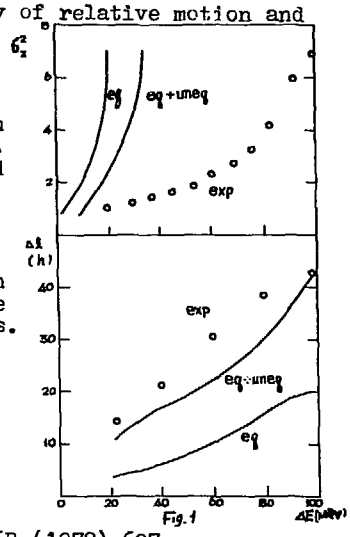


Fig.1

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Quasi Inelastic and Deep Inelastic Reaction of 71.5Mev ^{12}C on ^{27}Al

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Liu Bu Sheng Li Fa Wei Fan Guo Ying

(Inst. Mod. Phys. Acad, China)

To our knowledge not much work has so far been reported for the investigation of DIR with light systems. It is interesting to know how the individual low-lying levels are involved in these collisions. We have tried ^{12}C on ^{27}Al with 71.5Mev ^{12}C beam available from our 1.5m cyclotron. An ionization-SSD telescope was used to identify the projectile-like products B, Be and Li. The energy spectrum at different scattering angles and the contour plot in the E-θ plane measured experimentally, are illustrated in Fig.1 and Fig.2.

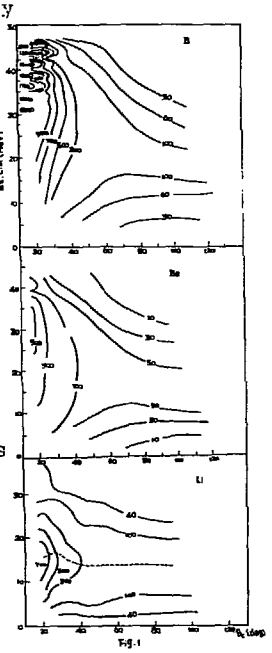


Fig.1

In the case of B-spectrum at forward angles, the highest energy peak QE probably corresponding to the ground states of the products is quite predominant. But different from heavy systems, there are a second peak at lower energy and traces of smaller ones at still lower energies superposed upon the broad DIR peak. They seem to correspond to the excited states of projectile-or target-like products. So we venture to call them the quasi-inelastic peaks QI, which are inseparable from QE peak for the case of heavy systems. The contour plot at larger angles shows the general features of DIR. From the fully damped energy of the products (see the dashed line at large angles, Fig.1) assuming that it was contributed by coulomb energy only, We obtained r_0=1.06fm which agreed with the value reported by P. Braun-Munzinger et al . Similar features have been found for the results of Be and Li. But the intensity of QE peak as well as QI peaks gets weaker and weaker as the projectile-like product moves further from the projectile ^{12}C.

From this series of experiments, we could conclude: 1) DIR also exists for light systems and 2) it seems that the development from QE to QI and then to DIR is rather a continuous process.

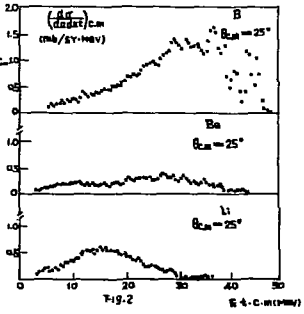


Fig.2

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A Dynamic Method for Deep Inelastic Collisions of Heavy Ions

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In order to explain the dissipation process of the energy and angular momentum in DIC, a method correlating the dynamic and diffusion equations has been developed. Considering the degrees of freedom of the relative motion, fragments rotations and mass asymmetry, we obtained the relations between the friction tensor(C_{ij}) and the diffusion tensor(D_{ij}) as follows

$$C_{\theta\theta} = \frac{D_{MM}}{(R_1+R_2)^2\, T(E_L^*, A_1)} \quad , \quad C_{AA} = \frac{T(E_L^*, A_1)}{D_{AA}} \quad , \quad C_{A\theta} = \frac{D_{AM}}{(R_1+R_2)\, D_{AA}}$$

Asumming $C_{rr}=KC_{\theta\theta}$ and then solving numerically the dynamic and diffusion equation, we have deduced the dissipation and fluctuation of the energy, angular momentum and mass asymmetry without introducing any other parameters and assumptions. The deflection function, the relation between the total energy loss (ΔE) and the variance of element distribution (σ_Z^2), the ΔE and the angular momentum loss(Δl) thus calculated are shown in Fig.1-3 for reaction $^{86}Kr\ (8.18\,MeV/u) + {}^{166}Er$. As shown in the figures, the calculated results are in agreement with the experimental data for large L waves. The calculated interaction time is in the range of $10^{-22} - 2\times10^{-21}$ s. Similar calculation for the reaction $^{136}Xe\ (8.31\,MeV/u) + {}^{209}Bi$ has been carried out and the calculated deflection function indeed exhibits the focussing effect found experimentally.

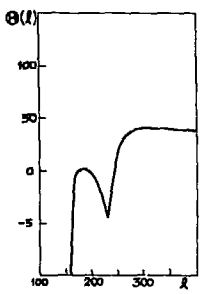


Fig.1

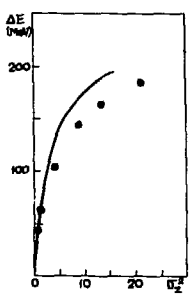


Fig.2

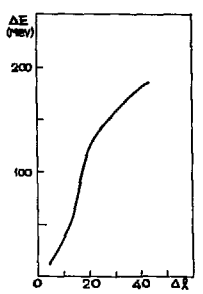


Fig.3

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A Simple Model for Studying the Stretch at Scission point in Fusion-Fission and Quasi-Fission Induced by Heavy-Ions

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(Inst. Mod. Phys. Acad. Sinica, China)

Assuming that the kinetic energy of relative radial motion of fragments can be neglected during the scission process, so that the adiabatic approximation condition is assumed to be fulfilled, and the fragments have rotationally symmetric quadrupole deformation only, we have

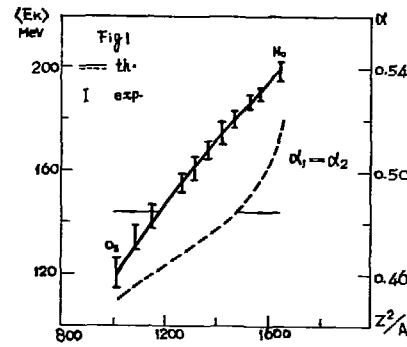
$$\frac{\partial U(\gamma,\alpha_1,\alpha_2)}{\partial \alpha_i} = 0 \qquad i=1,2$$

$$\gamma = R_1(1+\alpha_1) + R_2(1+\alpha_2)$$

which govern the motion of the fragments at scission point, where γ is the distance between the centers of mass of two fragments, α_i the quadrupole deformation (stretch) parameters, R_i the radii of spherical fragments, U the total potential energy of the system, including Coulomb, nuclear, centrifugal and deformation energy. Nuclear potential was deduced from the integral of nuclear force, the form of latter at the contact point being

$$F_N = -2\pi(\gamma_1+\gamma_2)\frac{R_1 R_2}{\left(R_1\frac{(1+\alpha_2)}{(1-\frac{\alpha_1}{2})^2} + R_2\frac{(1+\alpha_1)}{(1-\frac{\alpha_1}{2})^2}\right)}$$

which was derived by means of J.Wilczynski's method[1], but adopted to the quadrupole deformed nuclei. Solving these simple algebra equations, we can obtain the scission point stretch and evaluate the total kinetic energy of emitted fragments. The calculated results are in agreement with most experimental data for the average total kinetic energy of fragments for heavy nuclei, which are emitted in the process of fusion-fission (Fig.1)[2] and quasi-fission e. i, complete damping process of DIS (Fig.2)[3] induced by heavy-ions.



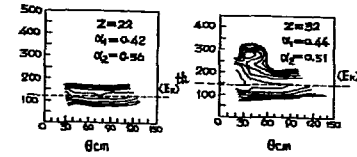


Fig 2. $^{86}Kr + ^{109}Ag$ $E/A = 7.2\,MeV/Amu$

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ON THE SIGNATURE OF LOW PARTIAL WAVES IN HEAVY-ION SCATTERING

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For many light heavy-ion systems an enhancement of the large-angle elastic cross section has been observed and it has been necessary to introduce new optical potentials in order to fit this effect. Many of these potentials give a significant internal wave contribution S^I to the elastic scattering matrix and in the WKB method[1] this contribution may be separated naturally from the barrier contribution S^B. One finds that the corresponding amplitudes satisfy $|f^I(\theta)|^2 \gg |f^B(\theta)|^2$ at backward angles. If the real part of the total potential V(r) (excluding the centrifugal term) is deep i.e. if $-\mathrm{Re}\ V(0) \gg E$ (the incident energy) then the complex internal deflection function may be written

$$\Theta^I(\lambda) \approx -\frac{2\lambda}{kR}\left\{1-\left(1-\frac{V(0)}{E}\right)^{-\frac{1}{2}}\right\} - 2\left(\frac{\bar{T}}{R_g}\right)^{\frac{1}{2}}\left\{\ln\left(\frac{\lambda_g+\lambda}{\lambda_g-\lambda}\right) - 2\,\frac{\lambda}{\lambda_g}\right\} \qquad \text{(A)}$$

where k is the incident wavenumber, R is the potential radius and $\bar{T}$ is an effective surface thickness in the barrier region. The complex grazing angular momentum is $\lambda_g = \lambda_R + i\lambda_I$ and R_g is the radius of the corresponding potential barrier. The linear part of Θ^I depends only on R and V(0) and the second term in (A) is important only near λ_R where it gives rise to a nuclear rainbow. Since Θ^I is linear for small λ, stationary-phase arguments tell us that low partial waves are important only at forward angles. Only the farside amplitude $f_I^+(\theta)$ [2] is stationary since $\mathrm{Re}\,\Theta^I < 0$, though $f_I^-(\theta)$ gives a diffractive contribution at large angles. Since large deflections are obtained only for $\lambda \approx \lambda_R$ the enhanced large-angle cross section does not necessarily imply the presence of low partial waves. The ideal method of detecting their presence would be a careful measurement of the cross section in the Fraunhofer region where f_I^+ should interfere strongly with f_B^- which is peripheral at these angles (i.e. characterized by λ_R). Since $f_I^+(\theta)$ comes from the stationary point $\lambda_I^+(\theta)$ (where $\mathrm{Re}\,\Theta^I(\lambda_I^+) \approx -\theta$) the resulting oscillations should have a period $2\pi/(\lambda_R+\lambda_I^+(\theta))$ compared with π/λ_R at large angles. Measurable differences between these two periods would unambiguously indicate the importance of low partial waves and through (A) would give some indications on the properties of the real nuclear potential.

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**Division de Physique Théorique, Laboratoire associé au C.N.R.S.

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MOLECULAR RESONANCES IN THE $^{16}O+^{16}O$ SYSTEM†

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Recent measurements on gamma-radiation[1] de-exciting the 6.13 MeV 3^-_1 state of ^{16}O, total fusion cross section data and the much older elastic scattering data for the $^{16}O+^{16}O$ system all show pronounced energy dependent structure at energies above the Coulomb barrier. A band-crossing model[2] (BCM) that has been proposed as a possible mechanism for resonances in heavy ion reaction is applied to the $^{16}O+^{16}O$ system.

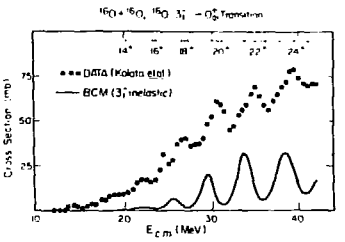


Fig. 1

The structure in the 6.13 MeV gamma-radiation yield can be understood in terms of the BCM, assuming the crossing of the elastic potential resonance band and an aligned inelastic-rotational band in which the intrinsic spin I(3ħ) and the relative angular momentum L are coupled to their maximum value, i.e., J=I+L.

Coupled-channel calculations based on this model reproduce all of the above-mentioned energy dependent structure. The structure in the gamma-radiation yield which appears to be superimposed on a monotonically increasing background, is reproduced reasonably well by the predicted 3^-_1 inelastic cross sections. (Fig. 1) In the middle panel of Fig. 2, calculated total fusion cross sections are compared with experimental data. Each oscillation in the fusion data can be understood as reflecting a shape resonance of each new grazing partial wave in the entrance channel. Calculated elastic scattering excitation function reproduce characteristic gross feature of experimental data. (Lower panel of Fig. 2)

This is the first consistent reproduction of these data. It is concluded that these data support the existence of nuclear molecular resonances in the $^{16}O+^{16}O$ system.

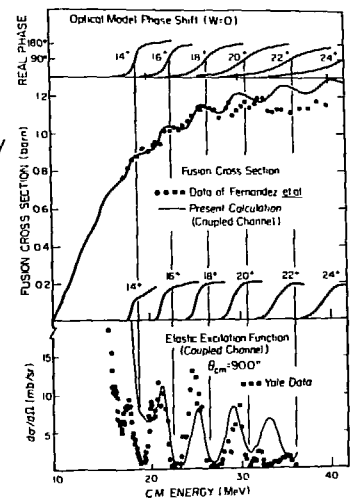


Fig. 2

†This work was supported by DOE under contract No. EY-76-C-02-3074.

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A NEW APPROACH TO THE CHARGE-EQUILIBRATION IN DEEP INELASTIC COLLISIONS OF HEAVY-IONS

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For a description of the charge equilibration process in the diffusion-phase of deep inelastic collisions (DIC) of heavy ions the Fokker-Planck-equation (FPE), as derived from a master equation or formulae obtained from gas-kinetic models are employed. The simplified version of the FPE reads

$$P_t(x,t) + v \cdot P = D \cdot P_{xx}; \quad P_t = :\partial P/\partial t; \tag{1}$$

where v and D are the drift velocity and the diffusion coefficients, respectively. Recent experimental evidence suggests that at least in some cases application of nonlinear equations might be more appropriate than the use of linear ones like e.g. (1).

Recalling that the FPE obeys the dispersion relation

$$\omega = v \cdot k - i \cdot D \cdot k^2, \tag{2}$$

it is realized that the Burgers equation (BE),

$$P_t(x,t) + (v + A \cdot P) \cdot P_x = D \cdot P_{xx}, \tag{3}$$

is a nonliear diffusion equation following the same dispersion relation and having the FPE as its linearized version.

More detailed investigations[1] show that the Korteweg-de Vries-Burgers equation (KdVBE),

$$P_t(x,t) + (v + A \cdot P) \cdot P_x + \delta \cdot P_{xxx} = D \cdot P_{xx}, \tag{4}$$

is the appropriate equation describing the whole diffusion-phase.

Starting from the hydrodynamical equations

$$\vec{P}_t(x,t) + (\vec{P}\nabla)\vec{P} = -(1/\rho) \cdot \vec{P}$$

$$\rho_t + \mathrm{div}(\rho P) = 0 \tag{5}$$

the derivation of Eq. (4) is outlined.

For the applications it turns out to be prudent to divide the diffusion process into three phases:

(i) The dissipation is predominant, i.e. $D \gg \delta$; $\delta \approx 0$;
(ii) Dispersion and dissipation are of comparable importance.
(iii) Dispersive effects are very important, i.e. $\delta \gg D$; $D \approx 0$.

Seemingly phase (ii) is skipped in most high energy collisions.

Applications of this model to experiment are discussed indicating also in which cases it may be safely substituted by linear laws.

1. E.F. Hefter, to be published

SOLITON-WAVEFUNCTIONS

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It is recalled that analogies to hydrodynamics lead us to the derivation of nonlinear Schrödinger equations (NOSE)

$$-\frac{\hbar^2}{2m}\cdot\Delta\psi - (E-V)\cdot\psi + V_{NL}\cdot\psi = 0 \qquad (1)$$

for the elastic scattering of heavy ions[1]. The nonlinearity is of the type

$$V_{NL} = C\cdot\ln(\rho/\rho_o) \simeq C\cdot(\rho-\rho_o)/\rho_o \qquad (2)$$

where $C = K/9$ gives the compressibility, ρ_o corresponds to the unperturbed density (e.g. the measured charge densities or $\Sigma|\phi_i|^2$; ϕ_i - solution of the corresponding Schrödinger equation with $\rho=0$) and $\rho(t)$ denotes the perturbed density ($\rho(t)=\Sigma|\psi_i|^2$).

The numerical solution of the NOSE will be shown to yield a good agreement of theoretical and experimental cross-sections. Furthermore, it gives rise to quite realistic values for the compressibility, i.e. K = 270 (+10; -40) MeV. More extensive calculations for different projectile-target systems and for a wider range of projectile energies are expected to reduce the error bars assigned to K.

Hence it is seen that already the traditional applications of the NOSE support the philosophy leading to its derivation. But in spite of its success it remains a "crutch" made only for a special purpose. Yet, this statement will possibly have to be modified due to some additional features of such a NOSE:

(i) In a different context[2] it has been shown to support soliton solutions that move (at least under the influence of an electromagnetic field) like real particles. The same holds e.g. for its motion in the potential well of an n-dimensional oscillator.

(ii) The solutions of the NOSE have also been quantized[3].

If the soliton solutions of the NOSE can be shown to be of any relevance to nuclear physics, then this could be interpreted as an indication that we happened to find more than just a simple model for the elastic scattering of heavy ions.

A thorough discussion of the last point constitutes the central part of the present contribution.

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PION MULTIPLICITIES IN INELASTIC NUCLEUS-NUCLEUS INTERACTIONS AND IN CENTRAL NUCLEUS-NUCLEUS COLLISIONS AT 4.5 GeV/c/N INCIDENT MOMENTUM

SKM-200 Collaboration Alma-Ata-Dubna-Tbilisi-Warsaw

/to be presented by E.Skrzypczak, Institute of Experimental Physics, University of Warsaw, Poland /

Multiplicities of negative pions from ^4He, ^{12}C, ^{16}O interactions with pure nuclear targets/li,....Pb/ placed inside the 2m streamer chamber were studied. The chamber was triggered either for inelastic interactions or for "central" collisions /with no charged fragments of the projectile emitted within a narrow forward cone/. The dependence of the average multiplicity $\langle n \rangle$ on the target mass number A_T for ^4He and ^{12}C inelastic interactions was obtained and compared with predictions of some theoretical models /Fig.1/.

The predictions based on independent nucleon-nucleon collisions approaches /MSM,SIM in which it is assumed that pions are produced mainly in the single collisions of projectile nucleons with first encountered nucleons of the target nucleus/ are consistent with our data.

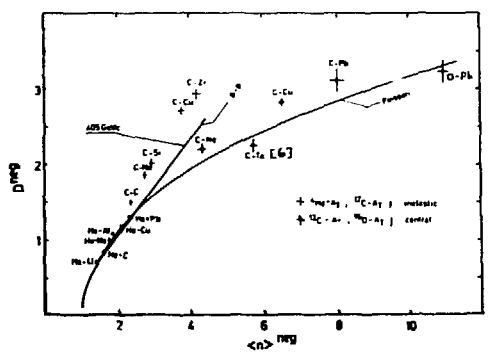


Fig. 2

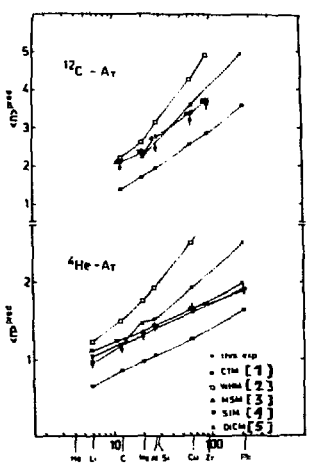


Fig. 1

The dependence of the dispersion D on $\langle n \rangle$ was obtained for "inelastic" and "central" collisions and compared with that for pp interactions /Fig.2/. The D vs $\langle n \rangle$ dependence for ^4He and ^{12}C nuclei "inelastic" collisions with nuclear targets is linear, while the dependence for "central" collisions can be described by relation : $D^2 \sim \langle n \rangle$.

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A STUDY OF ^{24}Mg STATES ≥ 20 MeV EXCITATION USING THE ^{12}C(^{16}O,α)^{24}Mg REACTION.

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Natural C targets of 2-10μgm cm^{-2} thickness were bombarded with ^{16}O ions at energies in the range 60-100 MeV using the Brookhaven National Laboratory MP7 tandem accelerator. Alpha particles were detected at 0° to the beam direction using the Q3D spectrometer. The beam was stopped by a tantulum disc at the spectrometer entrance and suitable foils placed in front of the focal plane detector. Alpha particles emitted coincident in time with those observed in the spectrometer were detected using a position sensitive Si surface barrier detector in the range 6-25°. Coincident γ-rays were detected at 90° using a 12.7 cm x 10.2 cm NaI detector. These data were analysed to give level energies, level widths, α-branching ratios, α-angular distributions and upper limits for γ-decay partial widths. Results for the strongest excited states based mostly on measurements at two bombarding energies are shown in the table. The result that different branching ratios are observed at two energies for α-groups corresponding to 20.91 and 21.29 MeV excitations suggests that doublets separated by less than 13 keV occur at these energies. The α-decay branching ratios were compared to statistical model calculations and shell model calculations of high spin states made by Whitehead and Watt[1]. The statistical model results are in poor agreement and indicate that states below and above E_x = 25 MeV selectively populated the ^{20}Ne 4.25 MeV and 8.78 MeV states respectively. On the other hand general agreement is observed between the data and the calculations of Whitehead and Watt. However these calculations indicate that more than one ℓ-value should be involved in the α-decays which would give rise to structure in the α-angular distributions. Contrary to this we find no evidence of these structures within the accuracy of our measurements.

Percentage α-Decays to ^{20}Ne States

Ex(^{24}Mg) MeV	Γ keV	0.0MeV (0⁺)	1.63MeV (2⁺)	4.25MeV (4⁺)	8.78MeV (6⁺)
17.12	<13		18		
19.3		15	1	71	
20.17	35±9	2	1	92	
20.4		2	2	91	
20.91[a]	<13	6	22	72	
20.91[b]	<13	2	9	83	
21.29[a]	<13	2	17	58	
21.29[b]	<13	3	55	37	
21.85	<13	2	17	58	
22.89	<13		26	33	
24.37	21±7		1	66	
25.18	163±6		24	15	31
26.05	<13		2	8	67
26.45	115±20				77

a) 78MeV ^{16}O ions b) 80MeV ^{16}O ions.

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SEARCH FOR LOW ANGULAR MOMENTUM CUTOFF IN THE FUSION OF $^{27}Al + ^{28}Si$*

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Time-dependent Hartree-Fock calculations have predicted that in the fusion of $^{28}Si + ^{28}Si$ and $^{16}O + ^{40}Ca$ at high center of mass energy there exists a critical angular momentum ℓ_{crit} below which no fusion occurs.[1] To investigate this possibility we have measured the mass distribution of the fusion evaporation residues in the reaction $^{28}Si + ^{27}Al$ at E_{cm}=67.8, 80.1 and 92.4 MeV. The ^{28}Si beam was produced by the BNL three-stage MP tandem and the fusion products were detected in a time-of-flight spectrometer. At the three energies the angular distribution of the evaporation residues was measured from $\theta_{lab}=3^{o}$ to $\theta_{lab}\sim22^{o}$. The cross sections for the heaviest residues ($M\geq46$) are presented in the table. The error on the absolute cross section is estimated to 10% whereas the error on the relative cross section for various masses at a given energy is less than 5%. The heavier masses originate mainly from the decay of the lowest partial waves and are expected to be the most sensitive to the presence of a low ℓ_{crit}. The measured cross sections are compared in the table to the calculated cross section assuming no low ℓ_{crit} and assuming a low ℓ_{crit} corresponding to the prediction of TDHF for $^{28}Si + ^{28}Si$ at equivalent center of mass energy. The evaporation calculations were done using the code CASCADE.[2] In all the calculations the maximum angular momentum leading to fusion was adjusted to reproduce the total measured fusion cross section. At all energies the agreement between the measured and calculated cross sections is better when no low ℓ_{crit} is assumed. This is particularly evident at the highest energy where the evaporation calculations imply a strong signature for a low ℓ_{crit} near that predicted by TDHF.

E_{cm} (MeV)		ℓ_{crit} (ħ)	MASS 46	47	48	49	50	51	$\sum$46-51
						σ(mb)			
67.8	exp.		90	208	168	60	120	26	672
	th.	0	121	171	191	50	110	17	660
	th.	9	143	151	190	40	87	15	626
80.1	exp.		117	149	47	69	34	2.2	418
	th.	0	104	180	52	78	40	<1	454
	th.	15	61	159	48	34	25	<1	327
92.4	exp.		140	68	50	43	9	<1	310
	th.	0	140	79	45	57	2	<1	323
	th.	20	83	71	6	19	1	<1	180

*Supported in part by the Division of Basic Energy Sciences, U.S. Department of Energy under contract No. DE-AC02-CH00016 and the National Science Foundation.

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STUDY OF THE ALPHA-DEUTERON CLUSTER REPRESENTATION OF ^{6}Li FOR THE FINITE RANGE DWBA ANALYSIS OF (^{6}Li,d) REACTIONS

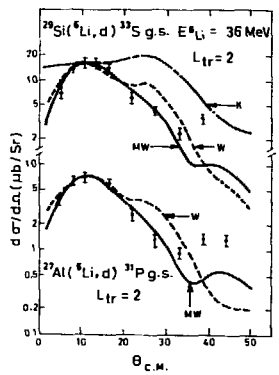
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The alpha-deuteron cluster representation of ^{6}Li to be used in the finite range distorted wave Born approximation analysis of (^{6}Li,d) reactions is yet not free from uncertainities[1,2]. For the relative motion wave function $\psi_{\alpha d}$ including antisymmeterization effects and effective interaction $V_{\alpha d}$ between them, various forms are being tried. In the present paper we report the results of the study of the dependence of the EFR-DWBA analysis with several forms of $\psi_{\alpha d}$ and $V_{\alpha d}$ by comparing the calculations with the (^{6}Li,d) reaction data[1] on sd shell nuclei ^{27}Al, ^{29}Si and ^{31}P. These EFR-DWBA calculations were performed with the program LOLA in DEC-10 computer.

The Woods-Saxon form of $V_{\alpha d}$ introduced by Kubo et al[3] with the corresponding single node wave function $\psi_{\alpha d}$ is not found to fit the data as shown by the curves K in the figure. Nor is the Kubo form of $\psi_{\alpha d}$ modified by an empirical Jastrow factor successful. Similarly the Eckart function for $\psi_{\alpha d}$ with the corresponding potential[4] is also not fitting the data.

The form introduced by Watson et al[5] with zero node wave function $\psi_{\alpha d}$ generated by a Woods-Saxon potential with a hard repulsive core with parameters V_0 = -45.25 MeV R_0 = 2.0 fm a = 0.7 fm R_{core} = 1.25 fm, gives the curves marked W in the figure. This fit is also deviating significantly from the data though the first maximum is predicted at the correct angle. Finally we find that when the Watson form is modified by reducing the hard core radius to 0.6 fm with depth V_0 = -27.26 MeV (to have the correct binding energy) the resulting LOLA predictions (curves MW) are found to fit the data satisfactorily. The different choices of suitable optical model parameters in the analysis do not alter this conclusion. The curves are shown normalised at the peak angle. The variation of relative ground state to ground state spectroscopic strengths for odd-A sd shell nuclei obtained in an earlier analysis[1] with a different form of $\psi_{\alpha d}$ and $V_{\alpha d}$ are not significantly altered with the form MW referred above though the absolute cross sections are predicted to be more by a factor of 3.



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TARGET FRAGMENT ENERGIES AND MOMENTA IN THE REACTION OF 4.8 GeV ^{12}C AND 42 GeV ^{20}Ne WITH ^{238}U+

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Fragmentation of a ^{238}U target nucleus by relativistic heavy ions, has, since initial studies[1] revealed large yields of fragments with $160 \leqslant A \leqslant 190$, held the promise of showing us unusual, perhaps collective, aspects of relativistic nuclear collisions. We felt that measurement of the target fragment momenta, energies and angular distributions as a function of projectile energy would allow us the best opportunity of studying these effects. In this work, we report the results of such a measurement for the reaction of 4.8 GeV (0.4 GeV/A) ^{12}C and 42 GeV (2.1 GeV/A) ^{20}Ne with ^{238}U.

Thin (~25 mg/cm^2) foils of ^{238}U were irradiated with 4.8 GeV ^{12}C and 42 GeV ^{20}Ne beams at the LBL Bevalac. The fractions of ~80 different target fragments recoiling forward or backward out of the target (F or B, respectively) were measured along with the fraction stopping in the target foil using radioanalytic techniques. Known range-energy relationships along with the simple two-step vector model[2] of nuclear reactions were used to deduce the target fragment momenta and energies. In addition, crude angular distributions of the target fragments were measured in the 42 GeV bombardment.

In the lower energy bombardment, the fragments are emitted forward to a degree not observed in any reaction involving relativistic protons with ^{238}U. At the higher energy, the F/B ratios are near unity with the angular distribution of a typical "fission fragment" such as ^{99}Mo being isotropic, while a light product ^{43}K shows a sidewise peaked angular distribution. The mean fragment kinetic energies and momenta are roughly the same at the two bombarding energies. These effects are similar to those observed in proton induced reactions but greatly enhanced in magnitude. In the complex variation of fragment momenta with their N/Z ratio, one finds evidence for the fission of A ~ 120 species formed by deep spallation of the target and evidence for the presence of a partial deep spallation origin of typical "fission fragments" such as ^{99}Mo, ^{112}Pd, etc. Comparison of these results with predictions of both the intranuclear cascade calculations of Yariv and Fraenkel and the firestreak model shows the cascade model predictions to grossly overestimate the target fragment momenta, while the firestreak model calculations are in better agreement with the data.

+This work was supported in part by the Nuclear Physics Division of the U.S. Department of Energy.

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UNIFIED DESCRIPTION OF STATISTICAL AND VIBRATIONAL EXCITATIONS IN DEEP-INELASTIC COLLISIONS WITHIN A BROWNIAN MOTION THEORY

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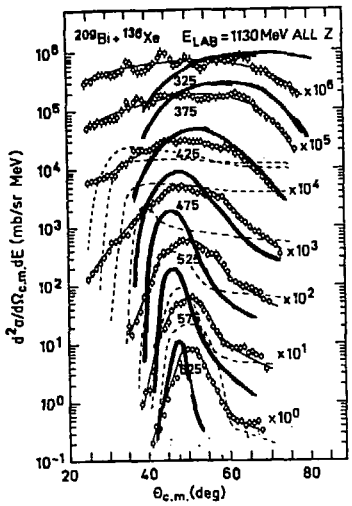
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The projection operator technique of Mazur and Oppenheim[1] introduced into the theory of Brownian motion and used by Gross[2] to describe the relative motion in deep-inelastic collisions can be generalized in such a way that the simultaneous treatment of the relative motion and of collective vibrational degrees of freedom is possible. Using the Markoff approximation and evaluating the Liouville propagator by expansions in $(m/M)^{1/2}$ and $(m/D_\lambda)^{1/2}$ (where m= nucleon mass, M= reduced mass, D_λ= mass parameter of the vibrational state λ) a multidimensional Fokker-Planck equation is derived, where friction and diffusion coefficients are microscopically given by the corresponding force-force correlation functions.

As a first application the resulting Fokker-Planck equation is solved for the focussing reaction Xe+Bi (E_{Lab}=1130 MeV) by taking only into account the quadrupole deformations and using the phenomenological parameters of Ref.[3]. The figure shows a comparison of our calculation (solid lines) with experiment and with a calculation of Weidenmüller et al.[4] where no deformation is included (dashed lines). In contrast to Ko[5] we found that it is not sufficient to use only damped vibrators, because in that case the observed focussing is destroyed in our calculations. Only the inclusion of frictional coupling terms between the relative motion and the vibrational modes, which occur in the theory in a very natural way, reestablish focussing. The inclusion of vibrations gives no fusion for the Xe+Bi system in agreement with experiment and opposite to the classical calculations of Ref.[3].



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HEAVY-ION INDUCED MULTIPLE ROTATIONAL EXCITATIONS WITHIN THE CLASSICAL S-MATRIX THEORY

P. Fröbrich[+], P. Kaufmann, and K. Möhring

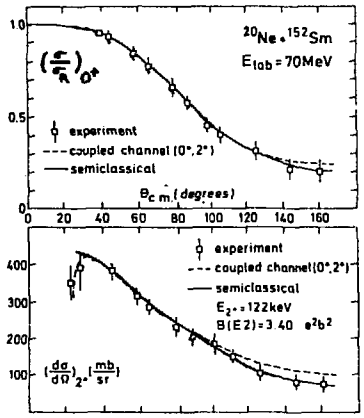
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The classical S-matrix theory (CSM) as developped in molecular physics[1]) was previously applied to multiple Coulomb excitation of a rigid rotor in backward heavy-ion scattering[2]). However, calculating angular distributions the uniform CSM has been proven to be very tedious[3]) and an integral representation fails because of caustic problems[4]). In order to obtain angular distributions in a simple way we therefore introduce the following modification into CSM. Only the planar (helicity conserving) aspect of the reaction is treated without further approximation. In this case the integral representation turns out to be valid and is easily evaluated. The out of plane motion is described in a quantal sudden approximation leading to analytical corrections of the planar semiclassical expressions.

The figure shows results for the Coulomb excitation of ^{152}Sm by ^{20}Ne. The experimental data and the quantal coupled channel analysis (including only 0^+ and 2^+ in Sm) are taken from ref.[5]). The better agreement of CSM with the data for backward angles clearly demonstrates the necessity to include also higher rotational states as done in CSM. Our results are in agreement with a deBoer-Winther (BW) calculation.

In applying our approach to very heavy systems we find deviations from BW for the higher spins. Because neither quantal calculations nor experimental data are available to us, a conclusion is hardly possible. There are, however, indications that our integral representation may not describe classically forbidden transitions.

We also performed calculations including a nuclear excitation of the rotor.



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A Detailed Study of the Reaction Mechanism for ^{12}C on ^{209}Bi at 61.1-73.0 MeV*

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Liu Guoxing, Sun Chichang, Guo Junsheng, Jin Genming
J.D.Garrett**, Wu Enchiu and Yang Chengzhong

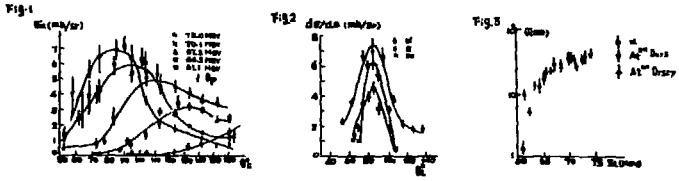
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In heavy-ion collisions the division of the reaction cross section, σ_R, between the various competing mechanisms is a subject of considerable current interest. We have measured $\sigma_{el}(\theta)$, σ_f, evaporation and recoiled residue, σ_{ER}, (^{215}, ^{214}, ^{214m}Fr and ^{209,210,211}At) and transfer (σ_α, σ_{Li}, σ_{Be} and σ_B) cross sections for ^{12}C + ^{209}Bi at incident energies near the Coulomb barrier, using ΔE-E, mica track, thin SSD detectors and He jet technique.[1)-6)]

The σ_R obtained from OM-analysis of the elastic scattering agrees very well with the sum of the measured reaction cross sections.[7)] To fit the experimental σ_{ER} and σ_f, the initial spin distribution of the compound nucleus was calculated from transmission coefficient and the competition between σ_{ER} and σ_f, by a statistical model analysis from which an S-wave B_f of 6-7 MeV for ^{211}Ac is deduced.[7)] Thus the general features of the ℓ-dependent reaction mechanism were well described.

The most interesting result of this series of experiments is perhaps the establishment of a sizable direct ^8Be transfer process $^{209}Bi(^{12}C,\alpha)^{217}Fr^*$. The residue $^{217}Fr^*$, left in ground state after 2n-evaporation, decays into ^{211}At by alpha emission. This is evidenced by 1) the shape of the alpha energy spectrum (peaked at Q_{opt}), 2) the angular distribution of alphas(peaked at grazing angle, Fig.1&2), 3) $\sigma_\alpha \sim \sigma_{sum\,At}$, (Fig.3), 4) the energy balance and 5)probably by ruling out alpha transfer(^{12}C,^8Be). This reaction mechanism was first suggested by R. Bimbot et al.

The cross section extracted from the upper limit of the isotropic part of the alpha angular distribution is consistent with the measured cross section of ^{214m}Fr. So this isomeric isotope may have been produced by the reaction $^{209}Bi(^{12}C;\alpha,3n)$ by α-evaporation.



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*The experiments were done jointly by several research groups of IMP,Lanzhou.For the full name list of the authors,see original papers cited above.

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EVIDENCE OF SEQUENTIAL α-DECAY OF ^{16}O AND ^{20}Ne IN THE REACTIONS $^{27}Al(^{16}O,C\alpha)$ AND $^{27}Al(^{16}O,^{16}O'\alpha)$ AT 88 MeV

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We reported previously[1] the dominance of the deep-inelastic (DI) process in the scattering and multinucleon transfer reactions $^{16}O+^{27}Al$ at 88 MeV. In order to elucidate the reaction mechanism in more detail, angular correlations between heavy ejectiles ($3\leq Z\leq 8$) and α-particles were measured.

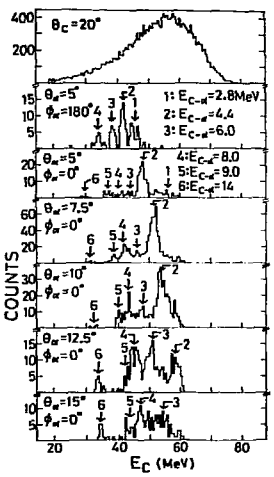
88 MeV beam bombarded an aluminum foil of 460 μg/cm^2 thick. A heavy-ion counter telescope was fixed at $\theta_{HI}=20°$, near the grazing angle 17°.

In C-α coincidence, the final state of $^{12}C(g.s.)+^{27}Al(g.s.)$ was observed most clearly. The energy spectra of coincident carbon ejectiles leaving both ^{12}C and ^{27}Al in the ground states are presented in the figure. Some peaks observed in these spectra were found to be due to the sequential α-decay of excited ^{16}O nuclei ($E_{C-\alpha}$=2.8, 4.4, 6.0, 8.0, 9.0, 14 MeV, i.e., $E_x(^{16}O)$=10, 11.6, 13.2, 15.2, 16.2, 21 MeV) from the kinematical consideration. For other final states of ^{12}C and/or ^{27}Al, the sequential α-decay of $^{16}O^*$ was also found at forward angles of θ_α.

For the O-α case, the sequential α-decay of $^{20}Ne^*$ was observed at forward θ_α. Peaks are found at $E_{O-\alpha}$=2.5, 4.0, 5.5, 7.3 and 10.5 MeV. ($E_x(^{20}Ne^*)$=7.2, 8.7, 9.2, 12.0, 15.2 MeV).

At larger θ_{HI}, i.e., $\theta_{HI}=30°$, the ratios of coincident/singles of yeilds of both C and O decreased as compared to those at $\theta_{HI}=20°$. This fact reflects that the sequential α-decay of projectile-like fragment decreases with the increase of θ_{HI}.

The present results are to be compared with those of Harris et al.[2] at 65 MeV, where the dominance of the contribution of the sequential α-decay of $^{31}P^*$ (E_x=14.5 MeV) was seen in C-α coincidence. This difference should be due to the fact that at $E_{lab}\leq 70$ MeV, the fusion reaction process dominates[3] whereas at $E_{lab}\geq 70$ MeV, the non-fusion process plays an important role[1),3),4].



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QUANTAL FLUCTUATIONS IN INELASTIC HEAVY ION COLLISIONS

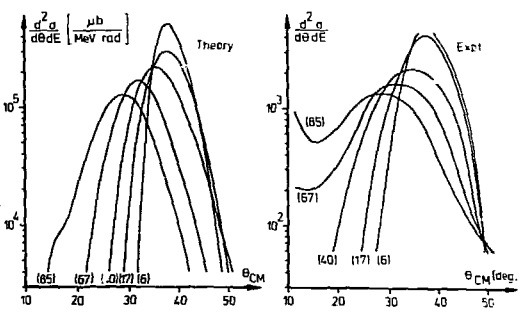
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In a collision of two heavy ions the finite spreading of the double differential cross section $d^2\sigma/d\theta dE$ for a given energy loss is usually attributed to statistical fluctuations as described by classical diffusion models. In the quasi-elastic region, where the collision time is very short, this classical interpretation always leads to fluctuations which are too small in comparison with experiment and in fact vanish in the limit of grazing collisions with zero energy loss.

In this contribution we present a quantum mechanically consistent calculation of $d^2\sigma/d\theta dE$ for the collision $^{40}Ar + ^{232}Th$ at E_{CM} = 323 MeV. The description of the relative motion of the two nuclei is based on the Wigner transformed reduced von Neumann equation which can be regarded as a quantum mechanical generalisation of the classical Fokker-Planck equation and has been discussed in ref.[1] for relative motion in one spatial dimension. The evaluation of the cross section from the asymptotic behaviour of quantal Wigner functions $\rho^{\ell}_{\ell}(R,P)$ makes use of a generalisation of JWKB phase shifts to dissipative collisions.

In the present calculation, the dissipation of angular momentum was neglected and the radial motion was treated in the local harmonic approximation, but quantal effects associated with the coherent superposition of all partial waves were included without approximation. The figure shows $d^2\sigma/d\theta dE$ for values of energy loss of the projectile from 6 to 85 MeV in comparison with the experimental data[2]. The discrepancy with respect to the absolute magnitude of the cross section is due to the restriction of the experimental data to the K-channel. Without any adjustable parameter the calculation reproduces the spreading of 10^0 to 20^0. In contrast, calculations based on a classical Fokker-Planck equation[3] yield a spreading of less than 5^0 for energy losses up to about 80 MeV.



We conclude that the large spreading of $d^2\sigma/d\theta dE$ for small energy losses can be accounted for in a natural way by quantal fluctuations arising from the interference of the various partial waves.

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STUDY OF $^{24}Mg(^{32}S,^{16}O)^{40}Ca$+

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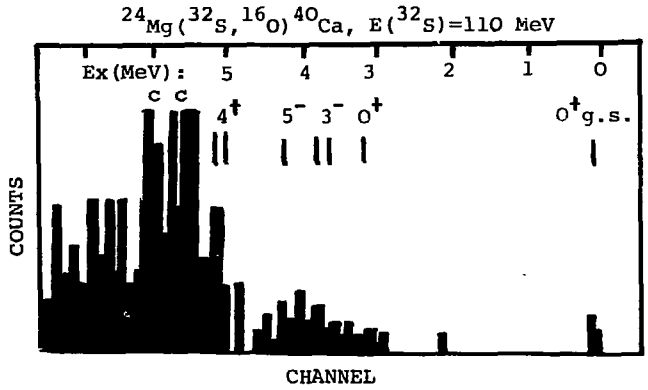
L. Harwood

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Cluster exchange has been proposed as a mechanism to explain heavy-ion scattering resonances and other phenomena[1]. The cluster overlaps required, e.g. for $^{28}Si \rightarrow {}^{16}O + {}^{12}C$, are rather large (> 10 %) compared with simple estimates[2]. Such large overlaps should result in significant direct cluster transfer ($\sigma > 1$ μb/sr) at high bombarding energies. We have studied the reaction $^{24}Mg(^{32}S,^{16}O)^{40}Ca$ at BNL with $E(^{32}S) = 80$ to 170 MeV. A spectrum is shown below. Although the ^{40}Ca (g.s.) and low-lying levels are formed in this reaction, the cross sections are quite small ($\lesssim .1$ μb/sr) and fall off with increased bombarding energy and angle (for angles $< 40^{o}$). While the bombarding energy dependence is consistent with a compound nuclear process, the angular distributions indicate incomplete fusion. Neither feature indicates much direct ^{16}O transfer (or ^{8}Be pickup) and set a limit of $S \lesssim 0.1$ % for the product of ^{16}O cluster overlaps in ^{32}S and ^{40}Ca.

+Supported in part by the N.S.F. BNL is operated by U.S.D.O.E.

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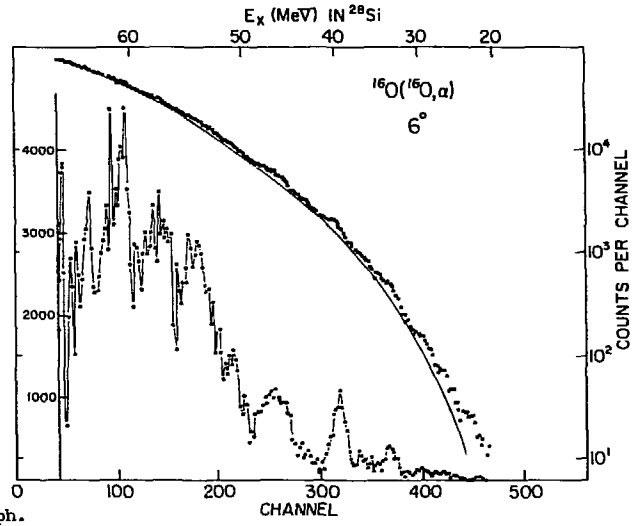
THE $^{16}O(^{16}O,\alpha)$ REACTION TO CONTINUUM STATES*

T. Yamaya, R. E. Tribble, D. M. Tanner, N. Takahashi, E. Takada, and K. Nagatani

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Recently the $^{12}C(^{16}O,\alpha)$ reaction has been studied[1,2]. The alpha-energy spectra obtained at forward angles showed pronounced structures on top of a large continuum. The structures were found to be correlated with the known intermediate resonance-like states observed in ^{12}C-^{12}C reactions. The $^{13}C(^{16}O,\alpha)$ reaction did not show any structure in the continuum, which is consistent with the lack of resonances observed in ^{12}C-^{13}C reactions.

We have now extended the study of this reaction to other target nuclei and present here the results of the $^{16}O(^{16}O,\alpha)$ reaction. The experiment was performed by bombarding an ^{16}O gas target with a beam of 139-MeV $^{16}O^{4+}$. (The beam energy is quoted for the center of the target.) The alpha particles were detected by a 1.2 m gas proportional counter in the focal plane of an Enge split-pole magnetic spectrograph.



A spectrum obtained at a laboratory angle of 6° is shown in the figure. The total alpha spectrum is shown with logarithmic scale, and a spectrum resulting from a background subtraction is given below the total spectrum with linear scale. (A curve used to subtract the background is shown also.) A series of structures that extends to very high excitation energy in the residual nucleus ^{28}Si is clearly visible. These structures disappeared when ^{14}N gas was substituted for ^{16}O gas in the target cell.

There have been a number of experimental and theoretical investigations of intermediate-structure resonance states in the ^{12}C-^{16}O system. Conflicting results have produced a very confusing picture, however. Thus, it is not possible to correlate directly the structures observed here with resonance-like states in ^{28}Si. In particular, no data are available for resonance-like states above 50 MeV excitation in ^{28}Si. Based upon the results obtained for the $^{12}C(^{16}O,\alpha)$ reaction, we suggest that the structures observed at very high excitation in the $^{16}O(^{16}O,\alpha)$ reaction may indeed represent resonance-like states that have a strong ^{12}C-^{16}O cluster component.

*Supported in part by the National Science Foundation, the Robert A. Welch Foundation and the A. P. Sloan Foundation.

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INCIDENT ENERGY DEPENDENCE IN THE $^{12}C(^{16}O,\alpha)$ REACTION*

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Recently we reported results for the $^{12}C(^{16}O,\alpha)$ reaction at an incident energy of 145 MeV[1]. The energy spectra obtained at forward angles showed pronounced structures in the continuum. These structures were found to be closely correlated to intermediate resonance-like states observed in ^{12}C-^{12}C reactions. This strong correlation implied that the $^{12}C(^{16}O,\alpha)$ reaction might proceed as a "direct" reaction that populates states with ^{12}C-^{12}C cluster structures. If indeed this is the case, such reactions provide an entirely new approach to the study of exotic structure states.

At an incident energy of 145 MeV, the structures were somewhat obscured by a large underlying continuum yield of alpha particles. We expect that part of the continuum yield arises from compound evaporation; the compound nucleus has a large forward momentum in the laboratory system thus yielding high energy alpha particles as it decays. In order to investigate the interplay between the underlying continuum and the pronounced structures, we have investigated the energy dependence of the reaction by increasing the bombarding energy. Data have now been obtained for incident energies of 181 and 229 MeV. The structures persist at higher bombarding energies but the cross sections decrease more rapidly than that of the continuum. The transition probability to low lying states in ^{24}Mg also becomes quite small.

Qualitatively, these features can be understood from simple reaction dynamics if we assume a ^{12}C cluster transfer. Thus Q-value and angular momentum matching appear to dictate the angle and energy dependence of the cross sections to these structures, just as has been observed in somewhat more conventional heavy-ion transfer reactions.

A quantitative understanding of the process, including a better description of the underlying continuum, will require a detailed theoretical study.

*Supported in part by the National Science Foundation, the Robert A. Welch Foundation, and the A. P. Sloan Foundation.

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FRAGMENTATION OF ^{40}Ar AT 118 MeV/NUCLEON*

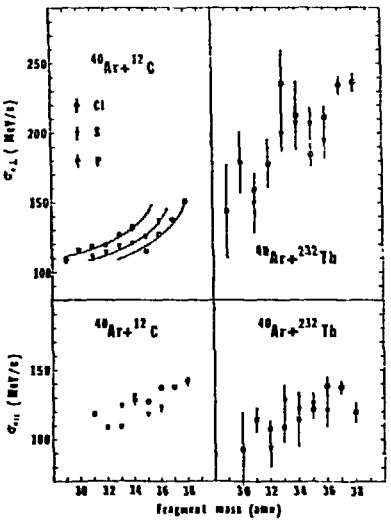
R. Legrain†, T. C. Awes‡, H. J. Crawford, C. K. Gelbke‡, D. E. Greiner, H. H. Heckman, J. M. Kidd‡, P. J. Lindstrom, J. Mahoney, D. K. Scott‡, T. J. M. Symons and G. D. Westfall

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Experimental studies of the fragmentation of ^{16}O and ^{40}Ar projectiles[1,2] at high energies have shown that the parallel momentum distributions of projectile fragments can be well described by a statistical model of the fragmentation process.[3] In this model the width, σ, of the distributions is parameterised by the expression $\sigma^2=\sigma_0^2 \frac{(A-F)F}{(A-1)}$, where A and F are the projectile and fragment masses and σ_0 is related to the internal momenta of the nucleons. However, recent results for ^{16}O fragmentation at 100 MeV/nucleon have shown that in order to explain the transverse momenta, it is also necessary to include the dispersion due to deflection of the projectile in the field of the target.[4]

We report here the measurement of the transverse and parallel momentum widths for fragments produced in the reaction of 118 MeV/nucleon ^{40}Ar on ^{12}C and ^{232}Th targets. The fragments were detected in a multielement Si(Li) detector telescope mounted in a large (∿7m) vacuum tank, allowing angular resolution of better than 0.5°. The momentum widths obtained for Cl, S, and P isotopes are shown in the figure.

In ref. 4, the transverse widths were parameterized using the expression: $\sigma^2 = \sigma_{l1}^2 \frac{(A-F)F}{A-1} + \sigma_{l2}^2 \frac{F(F-1)}{A(A-1)}$ where σ_{l2} reflects the orbital dispersion. Our results are consistent with this expression assuming a real nuclear potential of 50 MeV. However, we have clear evidence that the value of σ_2 depends on the charge of the outgoing fragment in contradiction to this model. The fits obtained for the ^{12}C target are shown on the figure assuming σ_{l1}= 94 MeV/c and values of 173, 206 and 244 MeV/c for σ_2 in the use of Cl, S and P respectively. This suggests that final state interactions of the outgoing particle with the target should also be included in the model.



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‡Cyclotron Laboratory, Michigan State University, Michigan 48824.
‡Naval Research Laboratory, Washington, DC.

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PARTICLE EMISSION FROM THE PRE-EQUILIBRIUM STATES IN HEAVY-ION REACTIONS

T. Otsuka and K. Harada

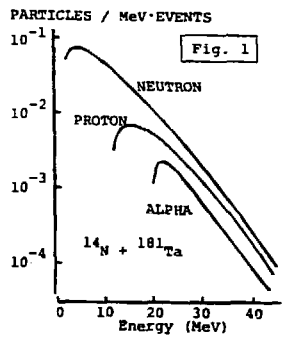
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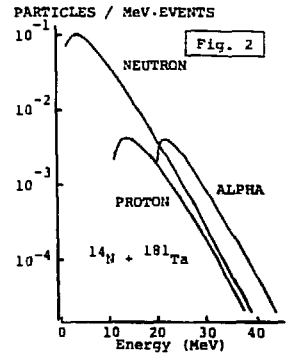
Particle emission from the pre-equilibrium states in heavy-ion reactions is studied in terms of the exciton model[1,2]. We consider reactions between relatively light projectile of mass number 10~20 and much heavier target of mass number >100. The kinetic energy of the projectile is assumed to be ~10 MeV/nucleon. In this type of reactions, two major characteristics are known in experiments; Energy spectra of emitted particles can be fitted well by temparature ~several MeV, and alpha emission is enhanced compared to proton emission, etc.[3]

Among various possible processes in heavy-ion reactions, we consider a process that fusion between the projectile and the target takes place. Since the projectile itself is a nucleus as a many-nucleon bound system, it is expected that a finite time is needed to complete the fusion process.

We extend the exciton model so as to include this effect ; nucleons are transfered one by one from the projectile system to the (heated) complex one with finite time intervals. Energies are also provided when nucleons are added. In parallel with this particle and energy transfer, the equilibration and the particle emission are going on, which are evaluated by the fermi gas estimate and by the detailed balance argument, respectively.[4]

Let us consider the reaction $^{14}N+^{181}Ta$ as an example. In Fig. 1, shown are energy spectra of emitted protons, neutrons and alphas calculated by assuming that fourteen nucleons are added to ^{181}Ta simultaneously with excitation energy 98 MeV, forming the initial exciton state with 14 particles and 0 hole. The energy spectra in Fig. 2 are, on the other hand, obtained from the assumption that nucleons are added one by one with a constant time interval 2.5×10^{-23} sec. Each transfered nucleon provides the excitation energy 7 MeV, and the total is 98 MeV. When the last nucleon is transfered, the equilibration has been achieved to some extent, and the average number of excitons is already 22.8.





In comparison between Figs. 1 and 2, it is noticed that the alpha emission is enhanced due to the finite time effect in fusion. States with many excitons favour the alpha emission because of the Q-value difference, while states with smaller number of excitons but higher excitation energy favour the proton and the neutron emissions due to the final state density difference.

Temparatures extracted from derivatives of the energy spectra are lower in Fig. 2 than in Fig. 1, and are rather consistent with experimental ones[3].

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Problems associated with spin assignments of "Heavy Ion Resonances" in the $^{12}C+^{12}C$ reaction*

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Since the discovery of the resonances in the $^{12}C+^{12}C$ reaction - almost twenty years ago - such structures were also found in other systems. Several alternative theoretical concepts are presently discussed to yield eventually an understanding of those resonance structures. If these phenomena are interpreted in terms of resonances an unique spin assignment should be expected.

Particle angular distribution measurements are commonly used to measure these spins, where exit channels with an unique ℓ-value bear the most valuable information. Due to this fact in the $^{12}C+^{12}C$ reaction the α_0-exit channel was often used to determine the spins of the resonances. However, the α_6 and p_3-particle groups have similar qualities and should therefore yield identical angular distributions. In addition the analysis of all other resonating exit channels should give at least consistent results. Moreover, the angular distributions at the resonances should be significant compared with that of the adjacent background.

Excitation curves for all observable charged particle transitions are measured in the c.m. energy range of 2.6 - 6.3 MeV in steps of 50 - 100 keV at 8 angles between $\theta_{lab} = 10^{\circ}$ and 90°. These data are discussed in terms of the considerations outlined above. The results show that for some resonances contradicting features are observed and therefore a unique spin assignment or the assumed resonance mechanism is questionable.

*Work supported in part by the Deutsche Forschungsgemeinschaft

ANGULAR CORRELATION MEASUREMENT FOR THE REACTION $^{12}C(^{16}O,\alpha_1)^{24}Mg(\alpha_2)^{20}Ne$

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In order to investigate highly excited states of ^{24}Mg embedded in the continuum region, an angular correlation measurement has been made on the reaction $^{12}C(^{16}O,\alpha_1)^{24}Mg(\alpha_2)^{20}Ne$. At high excitation energies, a sharp peak in α particle spectra might be contributed by several overlapping states with different spins. To make a spin determination more reliably, we used the systematics of experimental data obtained at several bombarding energies corresponding to intermediate resonances in the $^{12}C+^{16}O$ entrance channel.

Results of spin assignments are listed below with spins determined in earlier works[1,2,3]. A remarkable feature is that selectively populated doublets exist at $E_x(^{24}Mg)$=12.13, 12.42, 14.12, and 15.12 MeV. These doublets were identified by careful comparison of the angular distributions of α_2 and branching ratios obtained at six different incident energies with each other. It is noticed that doublets are differently populated at E_{cm}=24.3 MeV where a resonance is observed in the $^{12}C(^{16}O,^{12}C)^{16}O^*(0^+6.05\ MeV)$ reaction and at other energies including resonances in the above reaction leading to 3^- 6.13 MeV state.

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Present work	Gobbi et al.	Fifield et al.	Young et al.
Ex of ^{24}Mg(MeV): $I^\pi(E_{cm})$	Ex: $I^\pi(E_{cm})$	Ex: $I^\pi(E_{cm})$	Ex, $I^\pi(E_{cm})$
12.13±0.08: 3^-(24.3)			
12.13±0.08: 4^+(25.9,26.5)	12.10: 4^+(20.6)		
12.42±0.08: 4^+(24.3)	12.45: 7^-(20.9)		
12.42±0.08: 5^-(23.8,26.5)		12.83: 6^+(20.3)	
13.03±0.08: 5^-(24.3,25.4 25.9,26.5)	13.07: 5^-(20.9)	13.42: 6^+(20.3)*	
13.82±0.08;(5^-)(25.4)		13.75: 5^-(20.3)	
		13.84: 6^+(20.3)*	
14.12±0.08: 4^+(24.3)		14.14: 8^+(20.1,20.7)*	
14.12±0.08;(7^-)(25.4)			
	14.41: 4^+(20.6)		
15.12±0.08: 4^+(25.4)			
15.12±0.08: 7^-(24.3)		15.17: 7^-(21.7)*	
15.50±0.08: 6^+(24.3)			
16.02±0.08: 6^+(24.3,25.8)	16.7: 6^+(20.6)		
16.16±0.08: 6^+(25.9,26.5)		16.30: 8^+(20.6)*	
	16.59: 6^+(20.9)	16.46: 7^-(20.3)	
16.85±0.08: 6^+(24.3,25.4)		16.55: 8^+(20.3,20.6,21.1)*	
		16.55: 9^-(20.3)*	17.60: 6^+(22.5)
		16.84: 8^+(20.6)*	
17.70±0.10: 6^+(25.9)			17.9: 6^++4^+(22.5)
			17.9: 8^+(22.5)*

DEPENDENCE OF ANGULAR DISTRIBUTIONS OF EJECTILES ON Q-VALUES AND NUMBER OF TRANSFERRED NUCLEONS IN THE REACTIONS $^{16,17,18}O + ^{27}Al$ AND $^{19}F + ^{27}Al$

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We reported the angular distributions $d^2\sigma/d\Omega dQ$ of isotopes $8 \geq Z \geq 3$, emitted from the reactions $^{16}O + ^{27}Al$ at 88 MeV[1] together with the systematics of optimum Q-values. We extended the study to the reactions $^{17}O + ^{27}Al$ at 86.4 MeV, $^{18}O + ^{27}Al$ at 88 MeV and $^{19}F + ^{27}Al$ at 95 MeV. Indicent energies were chosen so as to give a nearly equal effective c.m. energy, $E_{cm} - V_c^i \simeq 35$ MeV.

O^{+7} and F^{+8} beams bombarded a self-supporting Al foil, 200 $\mu g/cm^2$ thick. Ejectiles $Z \geq 2$ are identified in both Z and A.

The energy spectra of ejectiles are, in general, of a single bump. As in the case of $^{16}O + ^{27}Al$, in almost all the reactions, c.m. angular distributions are well reproduced by an equation of a form

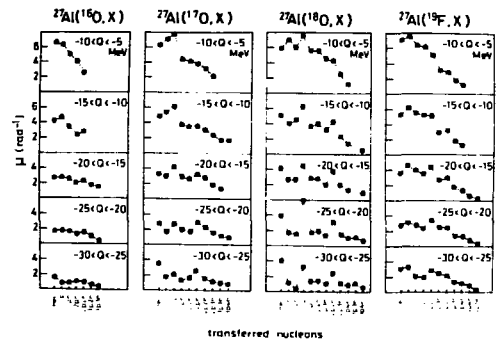
$$d^2\sigma/d\Omega dQ = A \exp(-\mu\theta)/\sin\theta$$

where dQ was taken as 5 MeV energy intervals in Q-values. The values of μ are given in the figure.

In $^{16,17,18}O + ^{27}Al$ reactions at $-15 \geq Q \geq -30$ MeV, i.e., in deep inelastic (DI) reactions, μ's are almost constant for each Q-interval, except in a few reactions from $0 \leq n \leq 7$, n being the number of transferred nucleons. The most striking features are in $^{18}O + ^{27}Al$, where μ's are exceptionally larger for ejectiles $^{18}O(n=0)$, $^{17}N(n=1,p)$, $^{14}C(n=4,2p2n)$, compared with neighbouring ejectiles. In these reactions, we obtain fast decaying angular distributions, which suggest that a more direct-like process takes place[1),2)]. Irregular features in these reactions are also seen in the systematics of energy-integrated $d\sigma/d\Omega$ vs. Q_{gg}, Q-values corresponding to the two-body reactions leaving both final products in the ground states.

Such irregularities are observed not in $^{16}O + ^{27}Al$ reactions, but in $^{17}O + ^{27}Al$ and $^{19}F + ^{27}Al$ reactions. In $^{19}F + ^{27}Al$ case, larger μ-values are found again for $n=0(^{19}F)$, $n=1(^{18}O)$ and $n=4(^{15}N)$, while in $^{17}O + ^{27}Al$ system, larger μ-values are obtained for $n=0(^{17}O)$, $n=1(^{16}N)$ and $n=3(^{14}C)$, instead of $n=4(^{13}C)$.

These features are not related to Q_{gg}-values nor to separation energies. More detailed study in connection with other incident beams and the same target is in progress.



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DETERMINATION OF THE SIZE OF THE PION EMISSION VOLUME IN COLLISIONS OF RELATIVISTIC NUCLEI

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The size of the pion emission volume in high-energy collisions can be determined by the interference method [1]. Our preliminary result for the radius of the emission volume of negative secondary pions for C + Ta collisions at p/A = 4.2 GeV/c, based on about 200 events, was [2] $r = (3.3 \pm 0.6)$ fm. On the basis of the increased sample of about 600 events we obtain $r = (3.0 \pm 0.5)$ fm. This result is in agreement with $r = (4 \pm 1)$ fm obtained at Berkeley for Ar + BaI_2 and Ar + Pb_3O_4 interactions at E/A = 1.8 GeV [3].

We will also present the estimate of the size of the pion emission volume in C + C collisions at the same incident momentum per nucleon, as well as an attempt to determine the corresponding lifetime.

[+]To be presented by J. Bartke

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2. N. Angelov et al., JINR, E1-12548, Dubna, 1979
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NEW RESULTS ON ANGULAR MOMENTUM TRANSFER FROM SEQUENTIAL FISSION IN 255 MeV Ar+Bi AND 435 MeV Ni+Pb DEEP INELASTIC COLLISIONS

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J.C. Steckmeyer and R. Chechik+

Communication presented by G. Bizard

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The first experiments[1][2] on angular momentum transfer in deep inelastic collisions from sequential fission agree with the fact that the target like fragment spin is aligned along the normal to the reaction plane and its value reaches a limit compatible with the sticking hypothesis for deformed nuclei. Nevertheless they disagree on the depolarisation mechanism since an anisotropy in the in plane angular distribution of the fission fragments is observed only in the experiment of Dyer et al[2].

We present new data obtained at ALICE (Orsay) on angular momentum transfer in deep inelastic collisions from sequential fission. The light fragment was identified in a solid state ΔE.E telescope, the coincidence fragments were detected in a position sensitive parallel plate detector which measured its $\frac{\partial E}{\partial x}$ and time of flight. With these informations, we can separate without ambiguity the deep inelastic events followed by a sequential fission of the target like reaction products from the other mechanisms. The fission fragment velocity distributions in the center of mass of the target like Pb, Bi are in good agreement with the published results[1] ; they show clearly the existence of an intermediate system which behaves like a resonance decaying by fission.

From the out of plane angular distributions peaked in the reaction plane, we confirm that the target like Bi, Pb intrinsic angular momenta are aligned along the normal to the reaction plane and reach a limit compatible with the sticking condition for the deformed nuclei coming from the composite system created in the initial reaction.

The in plane angular distributions $W(\phi_{CM})$ shown in figure 1, are clearly anisotropic. These results are fully compatible with the Dyer et al published experiment[2] and are in disagreement with the 7.5 MeV/A Pb+Ni experiment[1] (same energy in the CMS as our experiment) that has found an isotropic in plane angular distribution. Nevertheless we can remark that this last experiment presents its in plane angular distribution integrated over a large angular domain of the Ni like reaction product, whereas in our experiment and Dyer's et al one the projectile like reaction fragment was detected in a narrow angular domain.

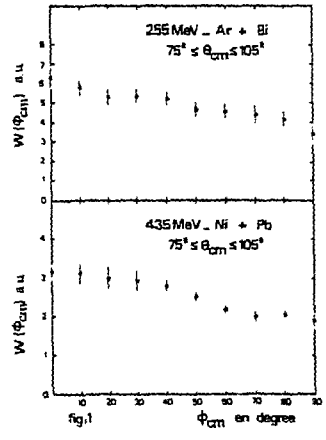


fig.1

+ Present adress : Weizmann Institute of Science, Rehovot, Israël

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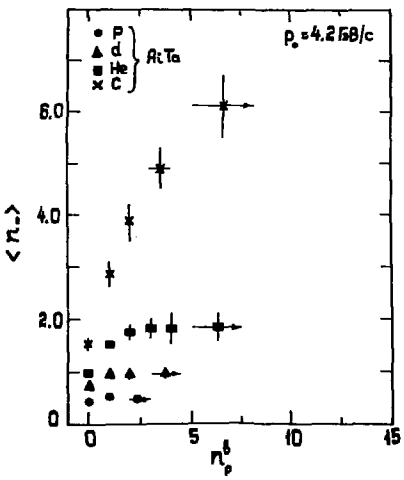
CORRELATIONS BETWEEN MULTIPLICITIES OF PIONS AND PROTONS IN COLLISIONS OF RELATIVISTIC NUCLEI

2m Propane Bubble Chamber Group +

Joint Institute for Nuclear Research,
Dubna, USSR

In an experiment carried out by the collaboration [1]) the interactions of relativistic protons, deuterons, helium-4 and carbon-12 nuclei with the tantalum target were recorded in the Dubna 2m propane bubble chamber with three thin tantalum plates inside the chamber volume. For protons several beam momenta between 2.2 and 9.9 GeV/c were used, for other projectiles the beam momentum was 4.2 GeV/c. The multiplicities of negative pions and those of protons emitted into the backward hemisphere were determined. Detection conditions in the chamber set a lower limit of momentum for protons at about 240 MeV/c which means that the majority of them are above the evaporation spectrum. The average multiplicity of the backward-emitted protons was found to increase both with beam momentum in p-Ta collisions and with the mass number of the incident nucleus for fixed incident momentum. However, this rise is slower than that of the multiplicity of negative pions and resembles very much the rise of the total number of "grey" tracks emitted in nucleus-nucleus collisions [2]).

Correlations between the multiplicities of negative pions and backward-emitted protons for various nuclei incident on the tantalum target are shown in the figure. For helium and carbon beams there is a well-pronounced correlation. A similar investigation for proton beams at various momenta shows that in this case such a correlation appears at higher incident momenta.



+To be presented by J. Bartke

1. Alma-Ata - Baku - Belgrade - - Bucharest - Budapest - - Cracow - Dubna - Moscow - - Prague - Sofia - Tashkent - Tbilisi - Ulhan-Bator - - Varna - Warsaw - Yerevan Collaboration

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MOMENTUM DISTRIBUTION OF PARTICLES EMITTED FROM COLLISIONS OF RELATIVISTIC NUCLEI AT P/A = 4.2 GeV/c

Alma-Ata - Baku - Belgrade - Bucharest - Budapest - Cracow - Dubna - Moscow - Prague - Sofia - Tashkent - Tbilisi - Ulhan-Bator - Varna - Warsaw - Yerevan Collaboration +

Momentum and rapidity distributions of secondary particles in nucleus-nucleus collisions at p/A = 4.2 GeV/c are studied as a function of the mass numbers of incident and target nuclei. The data come from the Dubna propane bubble chamber with tantalum plates exposed to beams of light relativistic nuclei: protons, deuterons, helium-4 and carbon-12.

As our earlier results on secondary pion multiplicities in collisions of relativistic nuclei [1-3] suggest the dominance of the independent nucleon collision mechanism, the spectra are presented in the laboratory frame and in the frame corresponding to nucleon-nucleon collisions. They are compared between themselves and also with the spectra for elementary nucleon-nucleon collisions.

Special attention is given to "central" collisions which have been defined as having no charged fragments of the projectile within the 4^{o} forward cone.

+To be presented by J. Bartke (Dubna/Cracow)

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MULTIPLICITIES OF SECONDARY PIONS IN RELATIVISTIC NUCLEUS--NUCLEUS COLLISIONS AND THE DISTRIBUTION OF THE NUMBER OF INTERACTING NUCLEONS OF THE INCIDENT NUCLEUS

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Investigation of multiplicities of negative pions produced in the collisions of relativistic nuclei with nuclear targets has shown that the multiplicity distributions for nucleus-nucleus (A_i+A_t) collisions are relatively wider than those for nucleon-nucleon (N+N) collisions with the same average multiplicity [1]. The explanation of this effect can be obtained on the basis of the independent collision model. Assuming that nucleons of the incident nucleus interact independently in the target, one obtains the following expression for the dispersion $D_{A_iA_t}$ in terms of the quantities characterizing N+A_t collisions, $\langle n\rangle_{NA_t}$ and D_{NA_t} :

$$D^2_{A_iA_t} = \langle \nu_i \rangle D^2_{NA_t} + \langle n\rangle^2_{NA_t} D^2_{\nu} \quad .$$

Here $\langle \nu_i \rangle$ is the average number of nucleons of the incident nucleus which interacted in the target and D_ν is the dispersion of the ν_i distribution, P_ν .

The data of the Dubna 2m Propane Bubble Chamber Collaboration, in which non-interacting charged projectile fragments were identified among the secondary particles, make possible a numerical check of the above formula, as both $\langle \nu_i \rangle$ and D_ν can be obtained from the fragmentation data in an independent way [2]. The results of this check will be presented.

It has been shown by Gulkanian and Korchagin [3] that in the case of an incident nucleus with charge Z the moments of the P_ν distribution up to the Z-th order can be calculated from the fragmentation data. This would provide information on the form of the P_ν distribution.

The P_ν distribution (ν_i= 1, 2, ... A_i) can be obtained if the fragmentation data are supplemented with the data on pion multiplicities in groups of events with a given number of interacting protons. The corresponding results [4], again based on the data of the Dubna 2m Propane Bubble Chamber Collaboration, will be presented and compared with theoretical calculations using the geometrical model [5]. In the case of incident carbon nuclei the method of regularization has to be used in order to obtain a physically sensible, smooth solution.

[+] On leave from Institute of Nuclear Physics, Cracow, Poland

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Excitation Functions of $^{40}Ca + ^{16}O$ Inelastic Scattering

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There have been many observations of resonant-like gross structures in excitation functions of heavy ion elastic scattering at far back angles, and also in alpha-transfer reactions. Generally, both the nuclear and the Coulomb terms contribute for heavy ion elastic scattering. The interference of these two terms were found in the analysis of $^{28}Si + ^{16}O$ to produce proper oscillations for the excitation functions at 90° and 180°.[1] A dominant contribution of the nuclear interaction could be seen measuring the cross sections at very forward angles in the inelastic scattering of the 4.49-MeV 5^- state in ^{40}Ca.[2]

We have measured the inelastic scattering of 5^- and $(3^- + 2^+)$ states to isolate and study the nuclear term contribution. These data may be compared to the 180° excitation function of the $^{40}Ca + ^{16}O$ elastic scattering,[3] which shows a resonant-like gross structure.

We used an ^{16}O beam from the BNL Tandem accelerator facility and the QDDD magnetic spectrograph. In order to find the first peak in the angular distributions the cross sections were measured in a narrow angular range at forward angles at several incident energies. The excitation functions of the inelastic scattering were measured on the first peak between E_{Lab} = 50 and 70 MeV. There is no resonant-like structure except for the slight structure seen at low energies, which is partly due to the discrete angle changes. The open circles in Fig. 1 are the data of the excitation function of $^{40}Ca + ^{16}O$ elastic scattering at 180°. Clearly, there is no correlation between them. A reasonable fit to the detailed structure of the elastic scattering can be obtained by introducing a parity-dependent potential[1] (C_i= -0.05) in addition to the potential ST1 in ref. 3). This potential predicts little structure for the present inelastic scattering and monotonic increase in cross sections which roughly agree with the data. Therefore, the structure of 180° elastic scattering may be not due to a presence of isolated pure resonances.

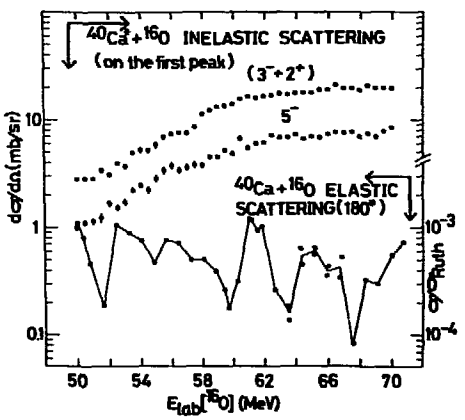


Fig. 1

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ANGULAR MOMENTUM TRANSFER IN HEAVY-ION REACTIONS FROM 7 TO 50 Mev/A†

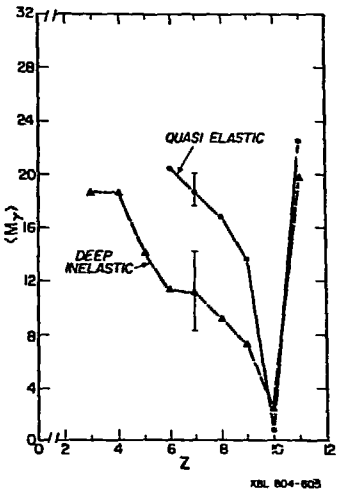
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A survey has recently been undertaken to investigate angular momentum transfer in the reaction $^{20}Ne+^{181}Ta$ from 7 to 50 Mev/A using continuum heavy-ion γ-ray multiplicity techniques.

Preliminary analysis of the data indicates the γ-ray multiplicity $\langle M_\gamma \rangle$ reaches values roughly consistent with the sticking limit for a rigidly rotating dinuclear complex at the 7.7 Mev/A bombarding energy. The $\langle M_\gamma \rangle$ increases only slightly over the entire range of bombarding energy from 7.7 to 17.1 Mev/A. As the bombarding energy is increased to 22.4 Mev/A $\langle M_\gamma \rangle$ is observed to decrease significantly to peak values of ca. 12. Preliminary results from 40 and 50 Mev/A bombarding energies yield multiplicities of approximately the same magnitude. This decrease in $\langle M_\gamma \rangle$ with increasing projectile kinetic energy is thought to be consistent with a short interaction time resulting in a smaller angular momentum transfer.

The dependence of $\langle M_\gamma \rangle$ with the detected charge of the projectile like fragment has been investigated and is shown in the figure, v.i., at 17.1 Mev/A (16° lab) for the region of the total kinetic energy typically associated with the "deep inelastic." The increase observed in $\langle M_\gamma \rangle$ with asymmetry is likely evidence of fragmentation, the larger asymmetries being associated with fragments from projectile breakup which are correlated with large partial waves and hence large angular momentum transfer. For the quasi elastic region of the spectrum $\langle M_\gamma \rangle$ rises sharply from near zero at Z=10 to approximately 22 for Z=11 and 14 for Z=9. This asymmetry in $\langle M_\gamma \rangle$ with Z is believed to reflect a difference in angular momentum transfer for fragmentation products with Z less than that of the projectile and for mass transfer products with Z larger than that of the projectile.



†This work was supported by the Nuclear Science Division of the U. S. Department of Energy.

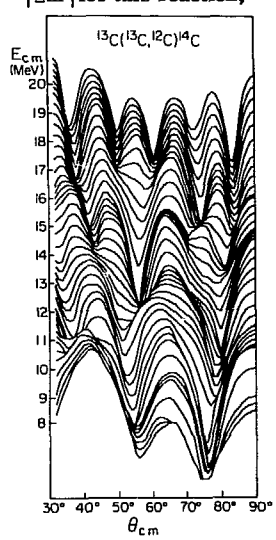
SEARCH FOR SINGLE-PARTICLE MOLECULAR ORBITAL EFFECTS IN THE $^{13}C + {}^{13}C \rightarrow {}^{12}C + {}^{14}C$ REARRANGEMENT REACTION*

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Although some observations suggest that nuclear single-particle molecular orbital (MO) effects may occur, no direct confirmation of their existence has been established. We have identified the single-neutron transfer induced by the scattering of $^{13}C + {}^{13}C$ as a reaction which might be quite sensitive to the occurrence of nuclear MO effects. By comparing the low order approximations to the atomic and molecular coupled-channel methods in a simple model for this reaction, we find that the ratio of the magnetic substate contributions to the reaction cross section may be a useful probe of the details of the transfer process. In particular, if MO effects such as the mixing of asymptotic configurations and energy level shifts occur, they are predicted to modify (enhance) only the $\Delta\ell = 0$ transfer strength from the DWBA prediction. As one example, polarization of the neutron orbit toward the line connecting the cores would intrinsically enhance the likelihood of a normal ℓ-transfer, $\Delta\ell = 0$. The $\Delta\ell = 0$ transition, however, occurs only via recoil effects. Motivated by this consideration and also by the possibility that MO effects (if they occur) could result in anomalies in the energy dependence of the transfer probability, we have made extensive measurements of the energy and angle dependence of the spin-averaged cross section for the $^{13}C + {}^{13}C \rightarrow {}^{12}C + {}^{14}C_{g.s.}$ ($\Delta m = 0, 1$) reaction. (Note: $\Delta\ell = \Delta s = |\Delta m|$ for this reaction, where s is the channel spin.)

Absolute cross sections were measured at eighteen energies in the interval $16.0 \leq E_{Beam} \leq 50.0$ MeV. At each energy, angular distributions consisting of approximately ninety data points spread over the angular region $32^{o} \leq \theta_{c.m.} \leq 100^{o}$ were obtained. The transfer data are characterized by dramatic oscillations with rather large peak to valley ratios in both the angular distributions ($\sim$10:1) and excitation functions ($\sim$3:1). An energy-angle surface plot generated from the experimental data is shown in the figure. DWBA calculations were carried out using our $^{13}C + {}^{13}C$ optical potential [1] for the entrance and exit channel distorted waves. Unlike the experimental observations the calculations show a rather smooth angular distribution in the range $30^{o} \leq \theta_{c.m.} \leq 60^{o}$ due to the incoherent addition of the $\Delta\ell = 0$ and $\Delta\ell = 1$ contributions which are generally out of phase. Individually these components show oscillations more characteristic of the data, and a relative enhancement of the former would provide better qualitative agreement with the data in regard to the correct phasing. Other details of the energy dependence of the experimental angular distributions are not correctly reproduced by either component of the DWBA cross section. These and other observations suggest that a single-step mechanism is not an adequate representation of the transfer process under study.



* Work supported by D. O. E. Contract No. DE-AC02-76ER03074

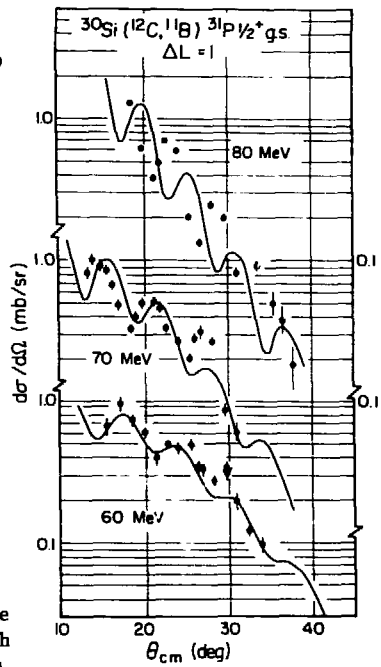
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ENERGY DEPENDENCE OF THE $^{30}Si(^{12}C, ^{11}B)\ ^{31}P_{1/2}$ + g.s. L=1 REACTION*

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There has been interest in recent years in a certain class of heavy-ion induced single nucleon transfer reactions, namely those cases where the final state is populated through the unique transfer of one unit of angular momentum. Some of these reactions, when studied at energies well above the Coulomb barrier, exhibit diffractive angular distributions which are exactly out of phase with distorted-wave Born approximation (DWBA) predictions. The problem arises because the DWBA predicts that the m = 1 components will dominate the cross section, while the data indicate that it is the m = 0 term which is largest. The $^{30}Si(^{12}C, ^{11}B)^{31}P_{1/2}$ + g.s. reaction exhibits this anomalous behavior at an incident energy of 80 MeV.[1] Coupled-channel calculations for this system were not able to significantly improve the description. In an effort to study this case further, the same reaction has been measured at lower energies. The resulting angular distributions and the corresponding DWBA predictions are shown in the figure together with the original 80 MeV results. Note that the 60 MeV calculation is in fair agreement with the data, while the 70 MeV data seem to show the beginnings of the problems encountered at 80 MeV. We have been unable to reproduce this energy dependence (the change from m = 1 to m = 0 dominance) with a normal DWBA treatment. A similar situation has been reported for the reaction $^{40}Ca(^{13}C, ^{14}N)^{39}K$(2.53 MeV, $1/2^+$).[2] A strong and very energy dependent spin-orbit optical potential could probably produce improved fits, but the use of such a potential is not well founded. The onset of molecular orbital effects might produce such behavior[3], and these data are expected to prove to be a useful set for the investigation of this subject. This approach is further indicated since the data for the population of the $1d_{3/2}$ state at 12.7 MeV (with one less radial node in the final-state wavefunction) are well reproduced by the DWBA at all three energies studied.



* Work supported in part by D.O.E. Contract No. DE-ACO2-76ERO3074

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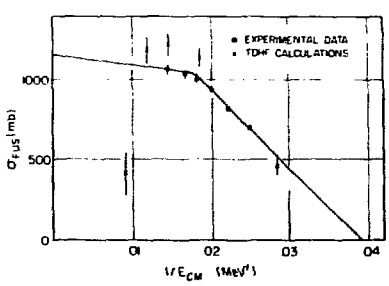
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FUSION OF $^{28}Si + ^{28}Si$ *

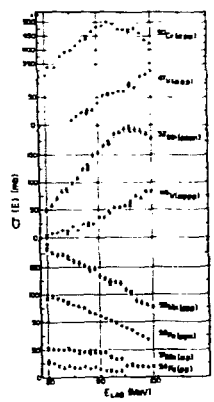
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The fusion of $^{28}Si + ^{28}Si$ has been measured over a range of bombarding energies from E_{LAB} = 80 to 140 MeV. The gross features of the fusion cross-sections are in accord with expectations based on systematics, showing the tendency for the cross-section to saturate at the higher energies as shown in Figure 1. The values of the cross-sections are well reproduced by entrance channel model calculations[1] (solid line) and are in fair accord with the results of TDHF calculations[2] (crosses). More detailed studies of the energy dependence of the fusion cross-section, made using both charged particle and γ-ray techniques, show some evidence for the existence of structure similar to that observed in higher systems such as $^{12}C + ^{12}C$ and $^{16}O + ^{16}O$. The results of the γ-ray work are shown in Figure 2; the yields of ^{50}Cr and ^{47}V showing structure while those of other residual nuclei do not. A correlation analysis of yrast cascade γ-rays in ^{50}Cr shows, however, that there is a 10% probability that the observed structure arises as a result of statistical fluctuations in the data. A more detailed experiment is therefore required before a definitive statement regarding the nature of this structure can be made.



1



2

* Work supported by D. O. E. Contract No. DE-AC02-76ER03074

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PRE-FUSION EMISSION AS THE POSSIBLE REACTION MECHANISM IN THE $^{12}C + ^{12}C$ SYSTEM

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and

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Recently, angular distributions for the $^{12}C(^{12}C,p)^{23}Na$ reaction have been measured[1] for three energies near 30 MeV (lab), where no pronounced structure has been observed in excitation functions.

Several of the observed 70 states of the ^{23}Na nucleus exhibit unexpected patterns in angular distributions. Two examples may be seen in Fig. 1 for states at 5.533 MeV and 2.982 MeV. The solid lines show the Hauser-Feshbach model results multiplied by a factor of 0.7 obtained by the normalization to the angle-integrated cross sections for known states.

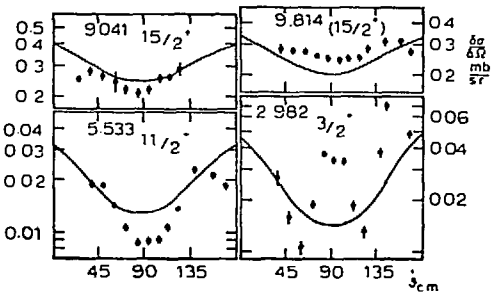


Fig. 1. Examples of angular distributions from $^{12}C(^{12}C,p)^{23}Na$ reaction at E_{lab} = 30 MeV.

Possible explanation of the observed features could be obtained if one assumes the emission of protons from the deformed $^{12}C + ^{12}C$ system followed by fusion of the remaining nucleons. According to the two-center shell model result[2] the single particle levels of such a system are strongly disturbed by the $^{12}C + ^{12}C$ interaction. Due to the Pauli principle, at the close distance of two ions one can expect to excite a nucleon to neighboring, distorted, single particle level. If the proton is emitted from one of such levels its angular distribution has to be influenced by the level's characteristics. In a case when a proton escapes from a $d_{5/2}$ shell, the l=2 wave should dominate the shape of angular distributions for low spin, positive parity residual states. Such a behavior is observed for the 2.892, $3/2^+$ state as well as for the 2.391, $1/2^+$ state, and for the 8.815 MeV state which can be identified with known 8.822, $1/2^+$ state.[3]

In case of the $3/2^+$ level some l=4 yield is observed, as expected. For higher spins the structure of angular distributions may be disturbed by the influence of other partial waves as well as by the emission from other shells.

The analysis is still in progress but the proposed reaction mechanism, if confirmed, may influence the interpretation of other reactions in which the pre-fusion nucleons could be emitted.

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PROMPTLY EMITTED LIGHT PARTICLES IN ^{16}O INDUCED REACTIONS AT E/A ≃20 MeV

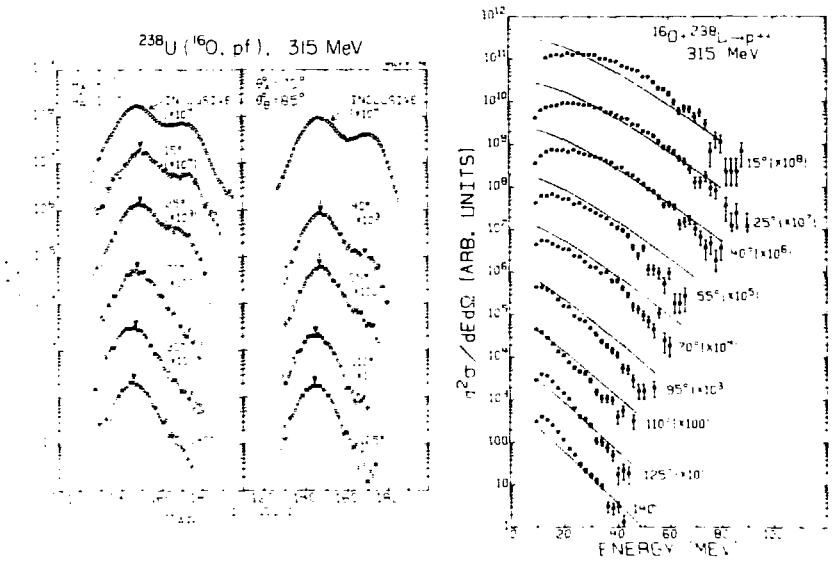
T.C. Awes, B.B. Back,[†] H. Breuer,[††] C.K. Gelbke, B. Glagola,[†] G. Poggi, and V.E. Viola, Jr.,[††]

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The production of promptly emitted light particles (p,d,t,α) has been investigated over a large range of laboratory angles for ^{16}O induced reactions on Au and U targets at 315 MeV beam energy. By simultaneously measuring the folding angle θ_{AB} between two coincident fission fragments it is possible to discriminate "peripheral" and "central" collisions in terms of the momentum transfer to the target residue prior to fission[1]). Our main experimental findings are: 1) Energetic light particles are predominantly produced in "central" collisions where the major part of the beam momentum is absorbed by the target residue. "Peripheral" collisions contribute only at forward angles. This fact is illustrated in Fig. 1 which shows the θ_{AB} distributions that are observed for the emission of protons at various laboratory angles. (The maxima at $\theta_{AB} \simeq 150$ are associated with "central" collisions[1]). 2) Over a large range of angles and energies, the emission of energetic protons is consistent with thermal and nearly isotropic emission from a rest frame that moves with approximately half the beam velocity, see Fig. 2. (The curves in Fig. 2 correspond to Maxwellian distributions of temperatures T=7.8 MeV and velocity v=0.08c.) 3) The ratios of p:d:t:α cross sections increase strongly with increasing emission angle in the laboratory. The data will be discussed in terms of various models, including precompound, hot spot, fireball and coalescence models.

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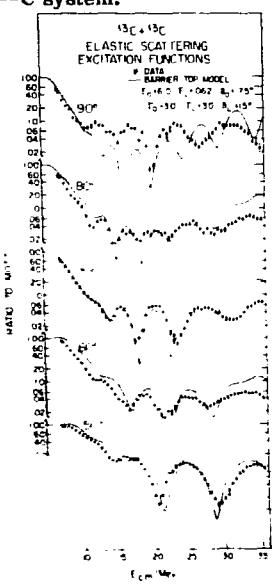
THE ELASTIC SCATTERING OF $^{13}C + ^{13}C$ †

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The elastic scattering of $^{13}C + ^{13}C$ is of interest not only because of its connection to the search for single-particle molecular orbital phenomena in the $^{13}C + ^{13}C \rightarrow ^{12}C + ^{14}C$ reaction,[1] but also because of the insight it provides concerning the excitation function gross structures observed in neighboring systems and the occurrences of collective molecular configurations in the $^{12}C + ^{12}C$ system.

We have measured $^{13}C + ^{13}C$ elastic scattering differential cross sections for $\theta_{c.m.} = 50^o$, 60^o, 70^o, 80^o and 90^o at 1 MeV energy increments (lab) over the range $E_{Beam} = 14.0$ to 72.0 MeV. Background due to $^{12}C + ^{13}C$ elastic scattering was eliminated by using a kinematic coincidence technique to identify events corresponding to the $^{13}C + ^{13}C \rightarrow ^{13}C + ^{13}C$ reaction. The measured excitation functions show gross structure oscillations very similar to those observed in $^{12}C + ^{12}C$ (energy averaged), $^{14}N + ^{14}N$, and $^{16}O + ^{16}O$ elastic scattering. This behavior is obviously not an elastic exchange phenomenon and we have found that a shallow surface-transparent optical potential ($V_0 = 16.0$, $r_{0r} = 1.35$, $a_r = 0.45$; $W_0 = 0.22 \times E_{c.m.}$, $r_{0i} = 1.35$, $a_i = 0.30$) can satisfactorily reproduce the important features of the experimental data. Studies of the elastic S-matrix elements indicate, however, that this potential is consistent with strong absorption within the barrier.



The characteristics of strong absorption within the barrier and surface transparency are ideal conditions for orbiting. In fact, we have found that the barrier formalism[2] when applied to our $^{13}C + ^{13}C$ optical potential describes the major features of the elastic data. barrier top model calculations were carried out using analytic expression: $\eta_L = |S_L| = (1 + e^{2\pi\varepsilon})^{-1/2}$ with $\varepsilon(E, L) = (L - L_{orb}(E))/\Gamma(L)$, for the magnitude of the elastic S-matrix elements. The values of $L_{orb}(E)$ and $\Gamma(L)$ were determined for our $^{13}C + ^{13}C$ potential using the barrier top prescription and were parametrized as $\Gamma_{orb}(E) = \sqrt{(E-E_0)/E_L} - \frac{1}{2}$ and $\Gamma(L) = \Gamma_0 + \Gamma_L/(L+1)$. A slowly and smoothly varying real nuclear phase, δ_L, was included using the parametrization $\delta_L = 4\eta_L(1 - \eta_L)[\delta_0 + \delta_L L(L+1)]$. The excitation functions calculated with the listed values for the barrier top parameters are compared to the data on the figure. The agreement with the experimentally observed gross structure oscillations is quite good and we conclude that the oscillations are related to the geometrical properties of the colliding nuclei.

† Work supported by D.O.E. Contract No. DE-AC02-76ER03074

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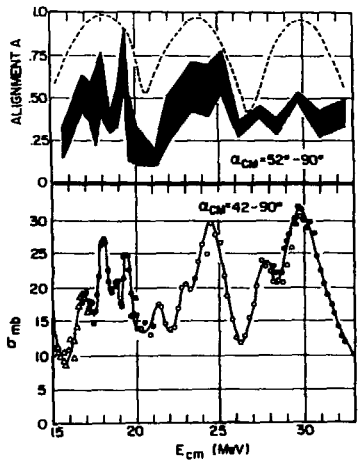
SPIN ALIGNMENT IN $^{12}C + ^{12}C$ INELASTIC SCATTERING*

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Both resonant and non-resonant reaction mechanisms have been proposed in attempts to explain the narrow, intermediate, and broad structures observed in the $^{12}C + ^{12}C$ system. For example, Phillips et al.[1] have found that structures a few MeV wide observed in the differential and total cross sections of $(0^+, 2^+)$ inelastic scattering are consistent with a non-resonant diffraction model. A consequence of that model is a strong alignment of the intrinsic spin of the excited residual nucleus at energies corresponding to broad maxima in the cross section. In order to provide new experimental information useful to judge this and other theories, we have measured the degree of alignment in the reaction $^{12}C(^{12}C, ^{12}C)^{12}C^*(Y_{4,44})^{12}C$.

The alignments were deduced from co-planar particle-gamma angular correlations. Choosing the quantization axis perpendicular to the reaction plane, only m = 0, ±2 are allowed. Spin alignment A is then defined as $A = P(+2) + P(-2)$, where P(m) is the probability of populating magnetic substate m. Angular correlations were measured for 18 particle angles α and 21 energies E. The deduced alignment $A(E, \alpha)$ is found to be only weakly dependent on α for most energies, so we average $A(E, \alpha)$ and present it as the shaded region in the figure. The width of the shading indicates ±1 standard deviation from the angle-averaged A(E); thus, for a given energy the alignments for roughly two-thirds of the measured particle angles fall within the shaded band. The dashed line is the prediction of the diffraction model over the same angular region. Also included for reference is the angle-integrated cross section $\sigma(E)$; lines are drawn to guide the eye. Note that the diffraction model correctly indicates the envelope of A(E), but that A(E) has richer structure -- e.g., maxima at $E_{cm} = 16.9$, 18.0, 19.4, and 27.5 MeV -- that is also reflected in $\sigma(E)$, but cannot be accounted for in the simple diffraction picture.



We are currently pursuing a more detailed comparison of the diffraction model to the data, as well as calculating the predictions of the band-crossing model[2] and other theories.

* Work supported by D.O.E. Contract No. DE-ACO2-76ERO3074

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UPGRADED SMALL-ANGLE PION SPECTROMETER STUDIES AT BEVALAC

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Following measurement of the dramatic π^-/π^+ ratio enhancement at beam velocity by our three-slit focal plane spectrometer,[1] we extensively upgraded the spectrometer for continuous energy and angle measurement. The new spectrometer features a 3-plane multiwire proportional chamber (MWPC) in the focal plane with an identical MWPC behind that, followed by a large 11-element scintillator range telescope.

Runs with the spectrometer covering from 0° to 15° lab ^{20}Ne and ^{40}Ar at energies from 285 MeV/n to 550 MeV/n were made. Later runs ranging in angle to 30° lab were made with the above beams at energies from 400 Mev/n to 1050 MeV/n.

The π^- peak was shown to track just slightly below beam velocity over the energy range where it could be measured. The π^- peak falls to less than half value at 3.5° in the lab system for 550 Mev/n $^{40}Ar+^{12}C$ and is nearly symmetric in $P_{\|}$ about the peak. With heavier targets the peak becomes skewed toward lower momenta, with the peak becoming a shoulder with a uranium target. The π^+ cross section is suppressed near beam velocity, though the dip seems less sharp in $P_{\|}$ than the π^- enhancement.

Theoretical treatments of the Coulomb effects have been made[2,3], and they offer hope of deducing the time evolution of charge distributions in heavy ion collisions. The same phenomenon in the target frame has been reported and theoretically analyzed earlier[4].

Other interesting features of pion production and the role of Coulomb effects are being deduced also in our work from π^-/π^+ ratios of isospin symmetric collisions.

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OVERVIEW OF PION PRODUCTION MECHANISMS BY HEAVY IONS

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Data on pion production by heavy ions are still sparse, but certain general features emerge that allow us to speculate on mechanisms. Production of low energy π^+ in collisions of two mass-20 systems at 0.8 and 0.4 Gev/n shows forward-backward peaking characteristic of free proton-proton collisions[1,2] while for production by mass-40 systems at 1.05 GeV/n that feature is suppressed[3]. Preliminary data at 0.25 GeV/n shows near isotropy for mass 20.

These features suggest a two-component interpretation with (1) anisotropic component from quasi-free nucleon-nucleon collisions in the nuclear surfaces and (2) isotropic, Boltzmann-like component from multiple collisions. The anisotropic component (1) is prominent only for light systems with larger surface-to-volume ratios, and for bombarding energies above the free-nucleon threshold of 0.3 GeV/n. Component (2) shows a limiting slope[4] more representative of fireball temperature than nucleon spectra, which are more sensitive to collective flow[5].

Coulomb effects are large in the enhancement of π^- and suppression of π^+ near beam (and target, or rest) velocity[6]. Coulomb effects likely shape the low-energy π^+ peak or ridge near 90° c.m. More data are needed to assess details and to test hypotheses of collective blast wave influence[5] and possible dibaryon resonance roles[2].

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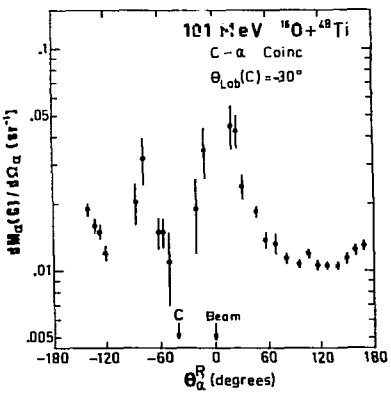
PRE-EQUILIBRIUM α-EMISSION IN DEEP INELASTIC ^{16}O + ^{48}Ti COLLISIONS.

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Investigating the deep inelastic (DI) collisions in the reaction 101 MeV - ^{16}O + ^{48}Ti, we have measured the angular correlations of light particles (p and α) in coincidence with the strongly energy damped projectile-like ions. A 101 MeV ^{16}O beam was used to bombard an enriched ^{48}Ti target. Projectile-like particles were detected in a gas-ΔE,Si-E telescope at θ_{lab} = -30°. To measure p and α angular correlations, we used a position-sensitive Si-detector, combined with an ionization chamber, which spanned an in-plane angular range of 40°. For small forward angles, a triple Si-telescope counter was used.

Data analysis was based on the search of α-emission following carbon DI events from the sequential reaction $^{16}O + {}^{48}Ti \rightarrow C + Cr + Q_2 \rightarrow \alpha + C + Ti + Q_3$. The sequential character of the process was established by checking that these events peak in a window of constant Q_2 and Q_3 values as a function of α-particle angles. We found mean values of -41.1 MeV and -31.7 MeV for Q_2 and Q_3. Usualy the C-α coincidences were concentrated in an easily identified wide peak in the C-energy vs α-energy plane. However problems arise on the negative angle side : (i) In the vincinity of the carbon direction an important yield from the oxygen break-up partly hides the DI peak and complicates the spectrum. This has been partially overcome by selecting coincidences in a region where possible ^{16}O excitations fall below 9.2 MeV. (ii) For some backward angles the threshold effect on the detected α-energies has been corrected by extrapolating the spectra to zero. The angles where these corrections are most serious appear with larger error bars in the figure which shows the obtained differential C-α multiplicities. In the figure the multiplicities are evaluated in the rest frame of the recoiling Cr ions from the first reaction step, as have also been the angles θ_α^R with the reference to the beam axis.



The angular behavior and yield of the α-multiplicities have to be compared with those obtained in the nearby ^{16}O + ^{58}Ni system[1]). The main difference is a smaller width for the pre-equilibrium α emission ($\sigma_\theta \approx \pm 20°$). The enhancement in the yield around θ_α^R = -80° may be attributed to a possible shadowing effect of α-particles emitted in the Carbon direction. Data for protons and α-^{16}O DI events are under analysis.

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TWO PION CORRELATIONS IN HEAVY ION COLLISIONS

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Since the pioneering work of Goldhaber et al[2)], the technique of pion interferometry has often been used to measure the size of the pion source region in elementary particle collisions. Recently Fung et al[2)] have employed this method to measure the size of the pion source in relativistic heavy ion collisions. We have independently examined the reaction 1.8 Gev/A ^{40}Ar + KCl $\rightarrow 2\pi^- X$ with greater momentum resolution than Fung et al, in an attempt to extract further quantitative information from the two-pion correlation function.

Over 6,000 pion pairs were momentum analyzed in a magnetic spectrometer system. Ths two-pion correlation function was formed by dividing the pair distribution function by a suitable background distribution. This correlation function shows an enhancement at low relative momentum, in accord with Bose-Einstein statistics. It is necessary to make corrections for both the pi-pi and the pi-nucleus Coulomb interaction. These corrections are made in the formalism of Gyulassy and Kauffmann.[3)] The necessity for Coulomb corrections results from both our high-momentum resolution and from the interdependence between these corrections and extraction of source parameters.

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L-DEPENDANCE IN THE $^{12}C(^{6}Li,t)^{15}O$ EXCITATION FUNCTION FROM 5 TO 9 MeV/n

L. Kraus and I. Linck

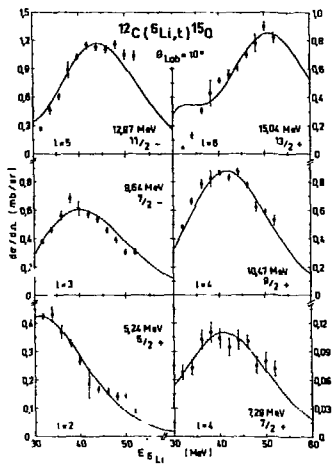
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The excitation function for the reaction $^{12}C(^{6}Li,t)^{15}O$ has been studied with a telescope at 10° for $E_{^{6}Li}$ = 32 to 52 MeV.

Angular distributions were measured from θ_{cm} = 12° to 95° at $E_{^{6}Li}$ = 48 MeV for the most strongly excited states in ^{15}O. When the logarithms of the differential cross sections for these states are plotted against $\log q^2$, one obtains a straight line showing a q^{-4} dependance which is very reminiscent of the result obtained [1] from the angular distribution of the $^{12}C(^{12}C,^{9}Be)^{15}O$ reaction at 114 MeV.

The excitation curves for individual ^{15}O levels are somewhat bell-shaped. The position of the maximum of a given cross section curve is characteristic of the ℓ transferred, rather than being the signature of the final spin. For instance, for the $\ell = 4$ transfer, the curve for the $7/2^+$ level at 7.2 MeV is similar in form and position to the corresponding curve for the $9/2^+$ level (cf. figure). The spin information is evidently contained in the magnitude of the cross section, where it is observed that the $\ell + 1/2$ state is more strongly populated than the $\ell - 1/2$ state.

Although Brink's [2] semi-classical model would not usually be applied in the present case, it is able to reproduce the observed features provided that an effective interaction radius is used instead of the real nuclear radius. These effective radii are not arbitrary but to a good approximation have the form $r_0(2\ell + 1)$ and thus are determined by the ℓ transferred. The nuclear structure information enters into the normalization factor for each curve.



While the energy dependance of direct reactions has proved to be an important tool in nuclear structure studies [1], the present results obtained with ^{6}Li ions do not agree completely with all the conclusions recently given for ^{20}Ne induced reactions [3]. Other Li ion-light target systems under study show similar results to those presented here.

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TIME-DEPENDENT SINGLE-PARTICLE METHOD FOR HEAVY ION COLLISIONS*

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We discuss formal and physical aspects[1]) of the time dependent single-particle method (TDSPM)[2]) and apply it to the collision of ^{18}O on ^{118}Sn at E_{lab}=60 MeV and to the $^{16}O+^{16}O$ system at E_{lab}=20, 50, 80, 150, 300 and 1000 MeV.

The formalism of TDSPM is derived from that of the time-dependent Hartree-Fock (TDHF) method via the linearization of the Lagrangian around the ground state densities of the nucl i. The resulting physical picture is that of two nuclear spherical wells moving on real and complex trajectories. The nucleons in these wells can either be excited, transferred, emitted or simply remain in their original state. We predict the probability for each of the above outcomes by solving a time-dependent Schroedinger equation for every nucleon involved in the process.

An advantage of the linearized TDSPM over the more exact TDHF is that the exit channels are clearly defined and thus it is possible to make a direct comparison with experimental differential cross-sections. However, TDSPM is not fully self-consistent and does not account for large deformations. As compared to more empirical models, TDSPM provides a microscopic, non-perturbative and unified description of quasi-elastic, deep-inelastic and fusion reactions.

We calculate the ion-ion optical potentials, and find them to be deeper when the nuclear deformation is taken into account as compared to their folding value obtained in the sudden limit. Their real part varies slightly with energy, whereas their imaginary part proves to be strikingly local and energy independent. The calculation of deflection functions provides a classification of the reactions according to their central or peripheral nature and shows which part of the optical potential is probed during a reaction. Energy and angular momentum losses are found to be large even for fairly peripheral collisions. They occur in TDSPM at the final stage of the reaction. For a given incident energy, the ratio of radial to tangential friction coefficients turns out to be independent of the trajectory, but it increases rapidly with energy. This dependence holds also for the drift velocity coefficient used in the description of heavy-ion collisions as relaxation phenomena.

Finally we indicate how the Lagrangian linearization technique can be applied to other time-dependent mean field nuclear phenomena (e.g. fission).

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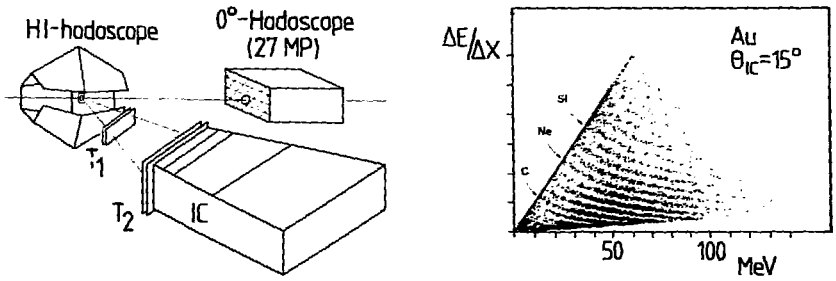
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COLLECTIVE EFFECTS IN ^{12}C-INDUCED REACTIONS AT 86 MeV/u

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The ^{12}C beam of 86 MeV/u at the CERN SC was used to irradiate different targets between ^{9}Be and ^{238}U. Outgoing fragments of the target nucleus heavier than Li were investigated using a large-area position-sensitive ionisation chamber in the energy range between 0.5 and 20 MeV/u and at laboratory angles between 15^0 and 110^0. In order to obtain information on the impact parameter, i.e. the inelasticity of an event, the forward region between 1.5^0 and 10^0 was covered with 27 plastic scintillators to measure possible fragments of the projectile. The high intensity of the ^{12}C beam (>10^{10} p/s) rendered it possible to use thin targets and to look for coincidences between heavy fragments. This was done using ten position-sensitive parallel-plate detectors covering a solid angle of 2π around the target. The experimental setup is shown in fig. 1 (1.).



Already the first results display strong collective effects: In the reaction ^{12}C-^{12}C, despite the high velocity ($\beta = 0.4$), large momenta of over 1 GeV/c are transfered to the ^{12}C nucleus without leading to a breakup. The high intensity of C as compared to B or Be rules out an explanation due to Fermi motion.

With heavy targets, such as Au or U, two components can be distinguished:

(1) Heavy fragments (A > 40) which are relatively slow (≈1 MeV/u) and result from a binary fission of the target nucleus. These events are observed both for peripheral and central collisions; for the latter the energies are slightly higher and the relative angle indicates high momentum transfers from the projectile to the target nucleus.

(2) Light fragments ($7 \leq A \leq 40$) with energies of 5-15 MeV/u which result preferentially from central collisions (see fig. 2 (r.)). The energies of these fragments are rather independent of angle but their intensities are strongly forward-peaked. Although these fragments have high momenta, they are most probably produced rather cold, as can be deduced from the absence of an odd-even staggering and their N/Z ratio reflecting the N/Z ratio of the target nucleus.

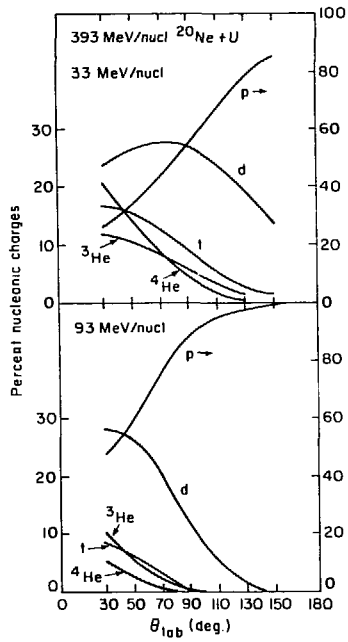
Concluding, the observation of nuclear fragments allows to measure momentum and energy transfer separately and thus to distinguish between current models.

CLUSTER PRODUCTION EFFECT ON THE INCLUSIVE PROTON AND NEUTRON YIELDS IN RELATIVISTIC NUCLEAR COLLISIONS[+]

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The emission of clusters (d, t, ^{3}He, ^{4}He) in heavy ion collisions at high energy has been measured, along with proton inclusive cross sections. Reactions with heavy target (Ne, Ar on U) show a higher cluster to proton yield ratio than equal mass systems like Ar+Ca, at fixed incident energy per nucleon. Thermal models make the same general prediction because Ar+U has more extended low temperature zones than Ar+Ca. The figure for Ne+U shows that deuteron formation dominates all the other composite products except for the "evaporation domain". The single proton yield amounts to only about 30 % (right hand vertical scale; left hand scale for cluster abundance) of the total emitted proton charges, at forward angles and for E/A $\leq$ 50 MeV. This may explain the observation[1] that single neutron yields far exceed single proton yields in Ne+U. The number of p and n bound up in clusters is about equal, thus enhancing dramatically the N over Z excess of U, as far as the remaining free nucleons are concerned. Ne+Al or Ar+Ca should thus not show such an enhancement in the single n: single p ratio.



[+]supported by the U.S. DOE and by BmFT, W. Germany

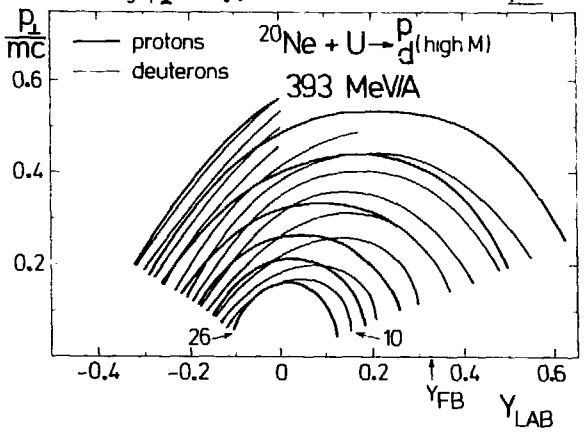
1. W. Schimmerling et al., Phys. Rec. Lett. 43 (1979) 1985

DEUTERONS AND TRITONS FROM CENTRAL AND PERIPHERAL HEAVY ION HIGH ENERGY COLLISIONS+

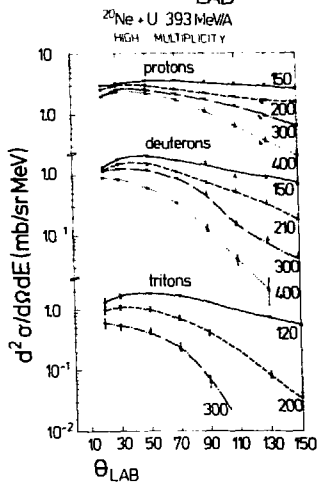
H.H. Gutbrod, G. King, Ch. King, W.G. Meyer, A.M. Poskanzer, A. Sandoval, R. Stock, J. Gosset, Nguyen Van Sen, G.D. Westfall, and K.L. Wolf

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Deuteron and triton emission from relativistic nuclear collisions has been investigated, selecting for mostly central and mostly peripheral reactions by requiring a high and low associated multiplicity of charged particles. Fig. 1 shows the contour lines of constant invariant cross section in the plane of $p_\perp$ vs. y_{lab} for protons and deuterons from central Ne+U collisions. The set of deuteron lines exhibits a more pronounced asymmetry (deviation from approximate semi-circular shape). The cross section drops about twice as fast as for protons, both with increasing $p_\perp$ and y, when the same momentum per nucleon is considered. Fig.2 shows that the asymmetry of the deuteron contour lines corresponds to sidewards peaking and forward suppression in the angular distributions for various bins of the laboratory momentum per nucleon. This effect is more pronounced than for protons, with the structures shifted forward in the Lab. for d and t. The peaking cannot be reproduced in the firestreak model.



The coalescence model has been applied successfully to the relative p-d inclusive cross sections [1,2]. The present data for Ne+U at 393 MeV/A are reproduced reasonably well with the ansatz $d^2\sigma(d)/d\Omega dE_d$ $(E_d=2E_p) = C(d^2\sigma(p)/d\Omega dE)^2$, with C=0.14±0.045. The multiplicity cutoff, defining high multiplicity events, was the same for protons and deuterons. The measured proton cross sections were employed to determine C.



+This work was supported by U.S. DOE and by BMFT, Germ. Fed. Rep.

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PROTON EMISSION IN CENTRAL AND PERIPHERAL RELATIVISTIC NUCLEAR COLLISIONS[+]

R. Stock, H.H. Gutbrod, W.G. Meyer, A.M. Poskanzer, A. Sandoval, J. Gosset, Ch. King, G. King, Ch. Lukner, Nguyen Van Sen, G.D. Westfall, and K.L. Wolf

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Proton emission was studied with beams of p, He, Ne and Ar at 0.25 to 2.1 GeV/A on targets from Al to U. Central and peripheral reaction cross sections were obtained by high and low charged particle multiplicity selection. In central collisions of Ne and Ar with heavy targets, angular distributions show a forward emission suppression or even a sidewards enhancement from 150 to about 400 MeV/c proton laboratory system momenta (Fig. 1), whereas peripheral collision exhibit 0^o peaking at all proton momenta covered. Central collisions of equal size nuclei are dominated by fireball-type decay (Fig. 2), plus a remaining spectator component because the yield is dominated by nonzero impact parameters even in the high multiplicity selection. In addition there should always be a direct component, from the interpenetration of the dilute nuclear surfaces of Ar and Ca.

On heavy targets, central collisions form a slow, nonisotropically decaying system heavier than the fireball or firestreak. The projectile seems to be "stopped down" inside the target nuclear matter, up to the highest Bevalac energies. This is expected because the momentum equilibration length should be much smaller than the U diameter even at 2 GeV/A. The emission patterns observed in central Ne+U reactions agree qualitatively with a recent hydrodynamical model calculation[1] for $b \leq 0.4\ b_{max}$.

[+]work supported by the U.S. DOE, and by BMFT, W. Germany

1. H. Stöcker et al., Phys.Rev.Lett.44(1980)725

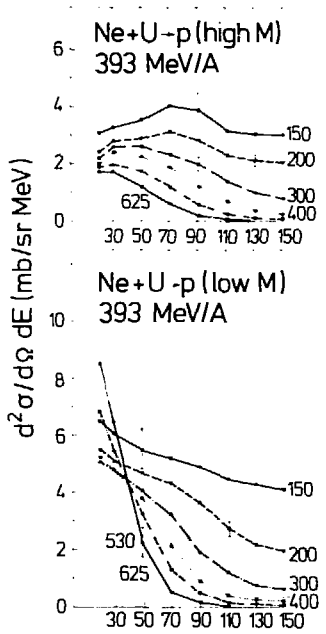


Fig. 1

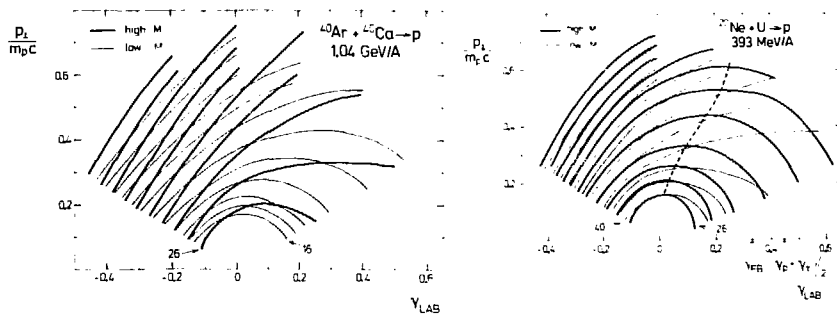


Fig. 2

ENERGY DEPENDENCE OF MULTI PION PRODUCTION IN HIGH ENERGY NUCLEUS-NUCLEUS COLLISIONS

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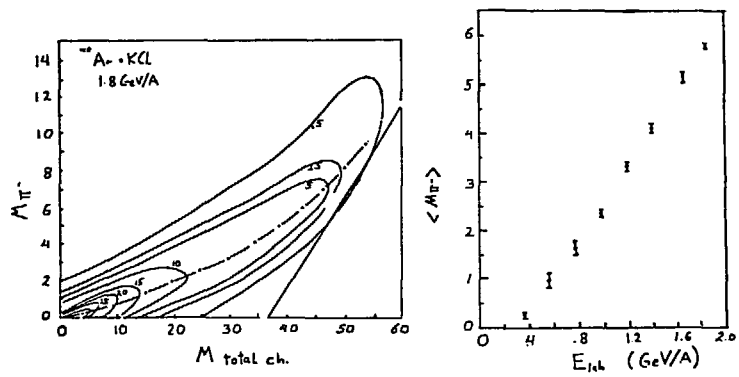
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There are many fundamental questions in the interaction of high energy heavy ions that have not had a definitive experimental answer: is a fireball being formed? What is the pion production mechanism? What is the energy flux in pions and their multiplicities? Is there a signature of the first, most compressed state of the interaction? Answers to some of these questions can be given by more exclusive measurements of the reaction products.

Exclusive π^- and charged-particle production in collisions of ^{40}Ar on KCl are studied at incident energies from 0.4 to 1.8 GeV/A using the Berkeley Streamer Chamber.[1] The correlation between the π^- and the total charged particle multiplicity lies along a narrow ridge that reaches up to the total desintegration into singly charged fragments and pions. For central collisions the mean π^- multiplicity increases linearly with the bomdarding energy with no marked discontinuities due to the $\Delta(3.3)$ resonance. Thermal models overestimate the observed pion production by a factor of 2.

Results from the momentum reconstruction for π^- are discussed in a separate contribution[2].

1. J.P. Brannigan et al. Proceedings of this conference.
2. R. Stock et al, ibid.



This work is supported by the Ministerium für Forschung und Technologie and the Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Dept. of Energy. under contract no. 7405-ENG-48

*of projectile and target

MARKOVIAN AND NONMARKOVIAN EFFECTS IN HEAVY-ION REACTIONS AT 10-200 MEV PER PARTICLE*

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The transition probability from an entrance channel i to an exit channel f that corresponds to a heavy ion reaction contains markovian and nonmarkovian contributions. The markovian part is independent of the ratio y between the duration of a nucleon-nucleon collision and the elapsed time between two successive interactions. The nonmarkovian part contains explicit y-dependence. The increase of the nucleon-nucleon mean-free path at about 20 MeV per nucleon of the projectile shifts the weight from the markovian component to the nonmarkovian one. This fact causes that the width of the mass distribution becomes independent of the incident energy. This result seems to be in qualitative agreement with existing data (1)

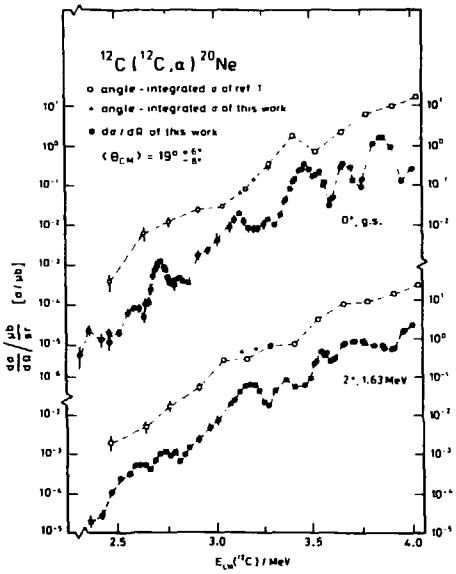
*Work supported by the Division of the Nuclear Physics of the U.S. Dept. of Energy under contract no. 7405-eng-48.
**On leave of absence from Departamento de Fisica Facultad de Ciencias Exactas y Naturales, 1428 Buenos Aires, Argentina.

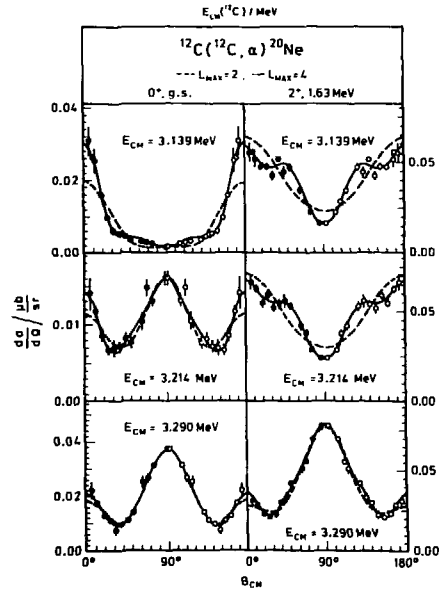
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Y. P. Viyogi et al, Phys. Rev. Lett. 42, (1979) 33.

EXCITATION FUNCTIONS AND ANGULAR DISTRIBUTIONS OF THE $^{12}C+^{12}C$ REACTION AT EXTREME SUB-COULOMB ENERGIES

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The energy and angular dependence of the reactions $^{12}C(^{12}C,\alpha)^{20}Ne$ and $^{12}C(^{12}C,p)^{23}Na$ have been measured for astrophysically important energies from 2.31 - 4.01 MeV (cm). More than 10 μA particle beam from the Bochum Dynamitron tandem and selfsupporting wobble targets of 12 - 20 μg/cm^2 thickness surrounded by a LN cool trap were used. Protons and α particles were measured with two annular detectors near 180° and 0°, respectively, and with large-area surface barrier detectors.

In the upper figure differential cross sections for the ^{20}Ne-g.s. and 1.63 MeV α transitions at a mean cm angle of 19° (dots) are compared with angle-integrated cross sections at 3.14, 3.21 and 3.29 MeV (crosses) and with the total cross sections of ref.[1] (circles). No indication of "absorption under the barrier" has been seen in agreement with ref.[2], an effect which is caused by an error in absolute energy of ref.[1]. However, correlated, resonance-like structures have been found at 2.72, 3.14 and 3.48 MeV.

Angular distributions were obtained near the 3.14 MeV structure which has also been seen in the total cross section [1,2]. Data and Legendre-polynomial fits (lower figure) change drastically within 150 keV and indicate a dominant contribution of the l=4 partial wave. This resonance with its surprisingly large l value is the lowest in energy for which a spin determination has been performed so far.

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A STUDY OF THE ^{12}C (^{6}Li,p) ^{17}O REACTION

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The nucleus ^{17}O has been investigated using the multinucleon transfer reaction ^{12}C (^{6}Li,p) ^{17}O at E = 28 MeV. Angular distributions have been measured for states up to an excitation energy of 12.5 MeV. Some of the distributions are shown in figure 1. Although they show evidence of forward peaking many do not fall off at backward angles as rapidly as might be expected from a single step direct reaction. The report will discuss the possible reaction mechanism for the ^{12}C (^{6}Li,p) ^{17}O reaction.

Of special interest are four strongly excited states at E_x = 8.47, 11.81, 12.0 and 12.4 MeV, figure 2, the possible structure of these states will be discussed.

Figure 1

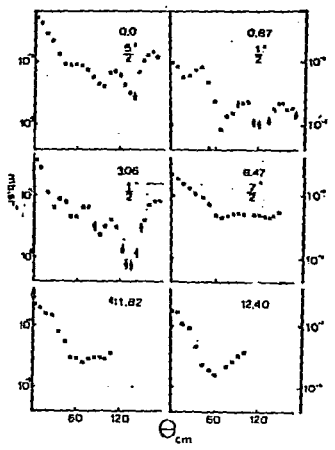
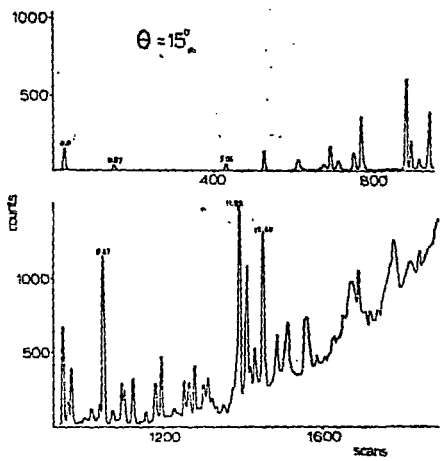
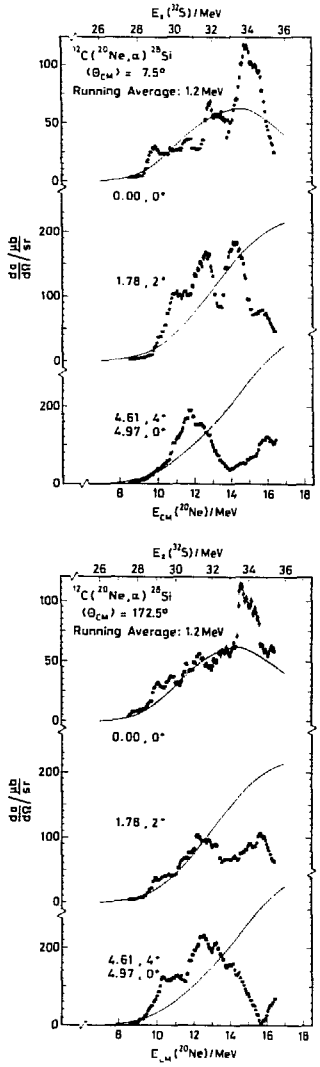


Figure 2



A STATISTICAL-MODEL AND FLUCTUATION ANALYSIS OF $^{12}C(^{20}Ne,\alpha)^{28}Si$ EXCITATION FUNCTIONS AND COMPARISON WITH THE $^{16}O(^{16}O,\alpha)^{28}Si$ REACTION

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Excitation functions of the $^{12}C(^{20}Ne,\alpha)^{28}Si$ reaction have been measured at mean cm angles of 7.5° and 172.5° (symmetric w.r.t. 90° cm) in the range of ^{20}Ne energies from 7.6 - 17.6 MeV (cm), corresponding to $E_x(^{32}S)$=26.6 - 36.6 MeV. To be more sensitive to deviations from pure compound-nucleus mechanism, data were obtained in steps of 110 keV (cm) with a novel technique using two annular detectors simultaneously.

Whereas the $^{12}C+^{20}Ne$ elastic scattering near 90° (cm) is smoothly varying with energy, there are strong fluctuations in the energy dependence of the α-particle groups leading to the ^{28}Si g.s., 1.78 MeV 2^+ state and 4.61/4.97 MeV $4^+/0^+$ doublet. The figure shows a comparison of the energy averaged data with the Statistical-Model predictions (solid lines).

Besides some deviations between theory and experiment near $E_x(^{32}S)$=34 MeV, there appears to be a fair agreement with the Statistical Model. The discrepancies consist in a big bump at 34 MeV in the g.s. transition which is closely correlated in energy at the two statistically independent angles and which is correlated with a structure observed in the $^{16}O+^{16}O$ elastic scattering (with l_{graz}=12 ħ). The observed decrease of cross sections for the excited states cannot be reproduced likewise.

A detailed fluctuation analysis, consisting of the calculation of autocorrelation-, angular correlation- and cross correlation functions, reveals evidence for non-statistical contributions, although strong correlations have not been found. After correction for FRD errors an average coherence width of 200±70 keV has been extracted from the different autocorrelation functions and from a Fourier analysis of the excitation functions. This value has to be compared with $\langle\Gamma\rangle$=76 - 100 keV (±25 keV) found from the $^{16}O(^{16}O,\alpha)^{28}Si$ reaction at the same compound-nucleus excitations by other authors. Possible explanations for these unexpected results will be discussed.

§Supported by the BMFT, Bonn, Germany.

HEAVY-ION ONE-NUCLEON TRANSFER REACTION USING THE POLARIZED INTRINSIC STATES*

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Many heavy-ion reactions have been successfully interpreted in terms of the distorted wave Born approximation and the intrinsic wave functions describing the isolated nuclei. However, the wave functions of one nucleus can be polarized by the field of the other nucleus during the collision. This effect is expected to become significant in the one-nucleon transfer reactions leading to weakly bound single particle states.[1] Actually, the conventional DWBA approach failed to describe such transitions.[1,2]

We assumed an adiabatically polarized intrinsic wave function only for the final target $\phi(r,R)$, which was obtained by solving the inhomogeneous Schroedinger equation,

$$(T_r - \varepsilon)\ \phi(r,R) = -(U(r) + \hat{Q}\ U_2\ (r_2))\ \phi^{(0)}(r) \qquad (1)$$

with $\langle\phi^{(0)}(r)\,|\,\phi(r,R)\rangle = 1$. If we switched off the field $U_2(r_2)$ of the other nucleus, the solution reduced to the unperturbed wave function $\phi^{(0)}(r)$. The operator $\hat{Q}$ excluded the occupied states in the core nuclei and the diagonal component $\phi^{(0)}(r)$.

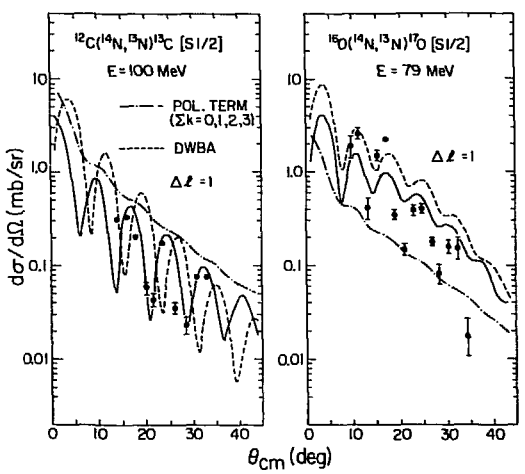
The transition amplitude for the one-nucleon transfer reaction was obtained as

$$T = \langle\chi_f^{(-)}\ \phi_f(r,R)\ |\ U(r)\ |\ \phi_i^{(0)}(r_2)\chi_i^{(+)}\rangle, \qquad (2)$$

$$= -(\hbar^2/2\mu)\ \langle\ 2\nabla_R\chi_f^{(-)}\ \nabla_R\phi_f(r,R) + \chi_f^{(-)}\nabla_R^2\phi_f(r,R)\ |\ \phi_i^{(0)}(r_2)\chi_i^{(+)}\rangle \qquad (3)$$

in the prior and post representations, respectively. Delic et al.[1] used $U_2(r_2)$ instead of $U(r)$ in Eq. (2) without justification. (This leads to enormously large cross section they obtained.) We also note that we can get an expression similar to that used by Seglie et al.[3] if we average the additional term of the optical potential over the angle $\hat{R}$.

We applied the present formalism to the $(^{14}N,^{13}N)$ reactions[4,5] leading to the $1/2^+$ states in ^{13}C and ^{17}O employing the prior-representation (2), and introduced no additional free parameters. The result of the exact finite-range calculation is shown by the solid lines in the figure. We have obtained a good agreement to the experimental data. The spectroscopic factors C^2S for the target nuclei ^{13}C and ^{17}O was found to be 0.4 and 0.9, respectively.



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COLLECTIVE SIDEWAYS FLOW OF NUCLEAR MATTER AND BOUNCE OFF EFFECT IN RELATIVISTIC HEAVY ION COLLISIONS

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High energy (E_{LAB} >> 10 MeV/u) heavy ion collisions are investigated in a nuclear fluid dynamical model. We discuss the influence of the properties of the nuclear equation of state at high densities and strong thermal excitation on the reaction dynamics.

We predict that sideways emission of matter will occur and that nuclear residues will obtain large transverse momenta.[1] For collisions of equal nuclei at small impact parameters we expect four-jet-events, due to "bounce-off" fragments, and the explosion of the remaining, highly excited matter perpendicular to the scattering plane.

For the collision of a small projectile with a heavy target the flow of Mach-shock-matter at a characteristic angle to the beam direction is predicted. At intermediate impact parameters the possibility of using the bounce-off effect to study the nuclear equation of state is investigated. (See fig. 1).

We present recent experimental data (mostly obtained in 4π counters) which support the prediction of high compression phenomena. These experiments were performed by selecting events of high multiplicity of low and intermediate energy fragments, which indicate nearly central collisions. He-fragments and also protons are observed, which, following their angular and energy spectra, can not be attributed to evaporative emission from a source moving along the reaction axis.

We propose to search for phase transitions in nuclear matter by looking for threshold increases in the excitation functions of the pion multiplicity, the temperature, the emission of pion bremsstrahlung, the pion multiplicity distribution, the emission angle of Mach-shock-matter, and the transverse momentum tranfer in the bounce-off effect.

Finally we discuss the formation of quark matter at very high energies. In this process rapid oscillations of the expanding dense quark matter may lead to pulsed emission of matter. These oscillating quark blobs may explain the abnormally enhanced geometrical cross-sections observed recently in secondary collisions of projectile fragments with target nuclei.

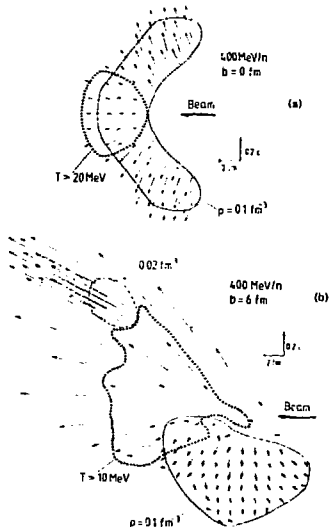


Fig. 1. Density and temperature contours and velocity field (arrows) in the scattering plane at a late stage of the reaction Ne+U at 400MeV/u. (a) Central collision; (b) Intermediate impact parameter b=6 fm.

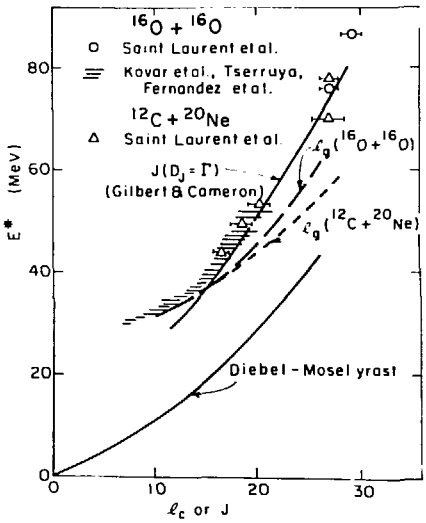
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ANGULAR MOMENTUM DEPENDENT LEVEL DENSITY LIMITATIONS TO FUSION*

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Recent results on the fusion cross sections for several pairs of reactions leading to the same compound nuclei indicate that at bombarding energies somewhat above the Coulomb barrier the fusion cross section may be determined by properties of the compound nucleus. If all l values up to a sharp cutoff l_c are assumed to be responsible for the fusion cross section, the l_c values deduced from the experimental cross sections for different entrance channels leading to the same compound nucleus are the same for a given excitation energy. This behavior for the $^{16}O + ^{16}O$ and $^{12}C + ^{20}Ne$ entrance channels to the ^{32}S compound system is illustrated in the figure. The horizontal bars[1-3] and open circles[4] represent l_c values for the $^{16}O + ^{16}O$ entrance channel, while the triangles[4] are for the $^{12}C + ^{20}Ne$ system. A similar behavior can be shown for the ^{28}Al compound system.



We have previously suggested[6] that a plausible necessary condition for fusion to occur is that the compound nucleus have overlapping levels for all angular momenta which can lead to fusion. It has been shown that this criterion can account in a natural way for both the absolute magnitude and gross strucuure of the fusion excitation function for the $^{12}C + ^{12}C$ system. This same criterion, expressed in sharp-cutoff form by $\Gamma/D_J=1$, accounts nicely for the l_c values observed for forming the ^{28}Al and ^{32}S compound nuclei. The upper full curve in the figure gives the J value for ^{32}S for which $D_J=\Gamma$, assuming the level density expression of Gilbert and Cameron[7], and taking Γ from fluctuation studies. This level density criterion[6] is similar to the statistical yrast line concept introduced more recently by Lee et al.[8] and is able to account for the trends in the maximum fusion cross sections for reactions between a number of p and sd shell nuclei.

*This work supported in part by the U.S. Department of Energy

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LOW ENERGY FUSION OF ^{12}C-^{12}C SYSTEM

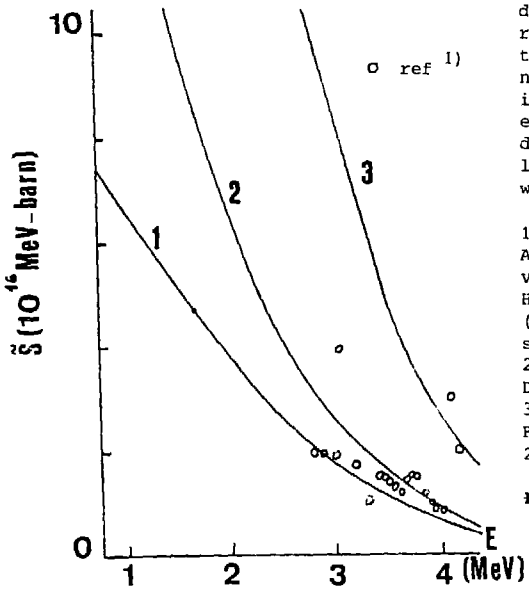
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The ^{12}C-^{12}C reaction rate at CM energies as low as 1 MeV is one of the basic quantities needed for the study of stellar evolution[1]. Recent experimental data have shown that this cross section was overestimated at energies between 2.8 and 4. MeV. We present here a new calculation based on the adiabatic time-dependent Hartree-Fock method (ATDHF). This method enables one to determine both the collective mass and potential of a heavy-ion system. An application to the ^{12}C-^{12}C system[2] has shown that the ATDHF mass is very different from the reduced mass value when the ions are touching and present sharp peacks. Masses and potentials are available for two configurations of the ions: with their symetry axis along (V_a and M_a) or perpendicular to (V_t and M_t) the collision axis. We have used these results to determine the reaction cross section by a straigthforward generalisation of the WKB method. The 0^+ ground-state of ^{12}C has been approximated by averaging the potentials and the inverse of the masses[3]

$$V_{0^+}=(V_a+2\,V_t)/3$$

The astrophysical $\tilde{S}$-factor ($\tilde{S}(E) = E\,\sigma(E)\,\exp(2\pi\eta - 0.46\,E)$) is presented in the figure for three cases: 0^+ ground-state with the ATDHF mass (curve 1) and with the reduced mass (curve 2), triaxial configuration with the ATDHF mass (curve 3). Results for the axial configuration are two orders of magnitude too low. Results for the triaxial configuration overestimate $\tilde{S}$. This show the importance of constructing a good approximation of the ^{12}C ground-state. In this case, results are in fair agreement with experiment, especially when the ATDHF mass is used. Above 4 MeV, the astrophysical factor is underestimated because the resonances have not been taken into account. The ATDHF mass reduces the cross-section by a factor 2 at low energy. It represents a blocking effect due to the self-consistent rearrengement of the orbitals when the ions are in contact. It is not surprizing that this effect is very important at low energies. The astrophysical factor predicted at 1 MeV is therefore much lower than the one predicted when a constant mass is used.



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* Chercheur qualifié FNRS

FUSION REACTION STUDIES OF TRANSURANIC NUCLEI

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Studies of the symmetric fragmentation observed for asymmetric target-projectile systems show that the memory of the ingoing channel configuration is completely lost and that the angular distribution of the products is nearly isotropic. This indicates the presence of a capture mechanism which leads to interaction times considerably longer than the collision time of the deep inelastic process.

In order to investigate systematically the process as a function of system and bombarding energy we have bombarded targets of ^{26}Mg, ^{27}Al, ^{48}Ca, ^{50}Ti and ^{64}Ni with ^{208}Pb projectiles at 4.8, 5.0, 5.2, 5.9, and 6.5 MeV/u. The data were collected using a position-sensitive parallel-plate ring counter. A monotonic evolution of the symmetric fragmentation as a function of the total mass of the system and projectile energy is observed. The cross section for the symmetric mass fragmentation has been extracted under the assumption of a

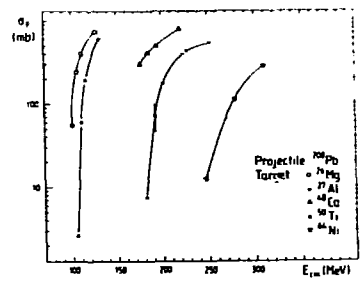


Fig. 1

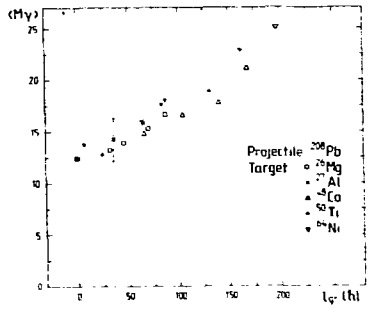


Fig. 2

constant $d\sigma/d\theta$ angular distribution and is plotted in fig. 1 as a function of the center of mass energy. In addition the γ-multiplicity $\langle M_\gamma \rangle$ for the symmetric mass fragmentation was measured using a 4"x5.5" NaI-crystal. The results for $\langle M_\gamma \rangle$ are shown in fig. 2 as a function of the calculated grazing angular momentum of the ingoing channel.

So far the distributions measured as a function of mass-asymmetry, angle, energy and average $\langle M_\gamma \rangle$ display characteristics similar to the fusion-fission process: a symmetric mass fragmentation, an almost isotropic angular distribution and total kinetic energy values satisfying the Viola systematics. The measured total reaction cross section is however, at high bombarding energy, considerably larger than the one predicted from the angular momentum limit of the liquid drop model.

RAPIDITY DISTRIBUTIONS FOR PIONS PRODUCED IN INELASTIC NUCLEUS -NUCLEUS INTERACTIONS AT 4.5 GeV/c/N INCIDENT MOMENTUM

SKM-200 Collaboration: Alma-Ata - Dubna - Tbilisi-Warsaw

/to be presented by E.Skrzypczak, Inst. of Experimental Physics, University of Warsaw, Poland/

The pion production has been studied in a 4 π geometry by use of a streamer chamber /with pure nuclear targets/ exposed to beams of relativistic ^{4}He nuclei from the Dubna synchrophasotron. The multiplicities, transverse momenta and rapidities of negative pions obtained for Li, C, Al, Cu target nuclei and their correlations were studied.

Fig. 1 shows that the dependence of rapidity distributions on the target mass number A_T is rather strong in the target fragmentation and in the central regions of rapidity, while it is not significant in the projectile fragmentation region.

Fig. 2 shows the dependence $\langle y \rangle$ on A_T
a/ for "peripheral" and "central" collisions /selection based on the presence of projectile fragments/
b/ for high $n > 2$ and low $n \leq 2$ multiplicity events
c/ for negative pions with transverse momenta $p_T < 200$ MeV/c and $p_T > 400$ MeV/c.

The presented data may form a basis for testing the validity of various theoretical approaches to the problem of nucleus-nucleus interactions.

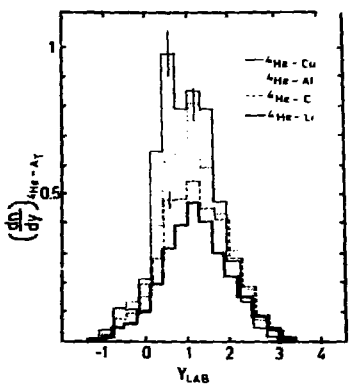


Fig.1

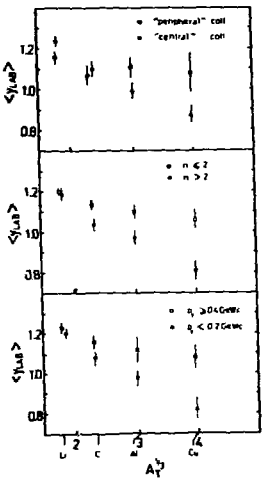


Fig.2

PRE-EQUILIBRIUM PARTICLE EMISSION IN HEAVY-ION REACTIONS (~10 MeV/U)

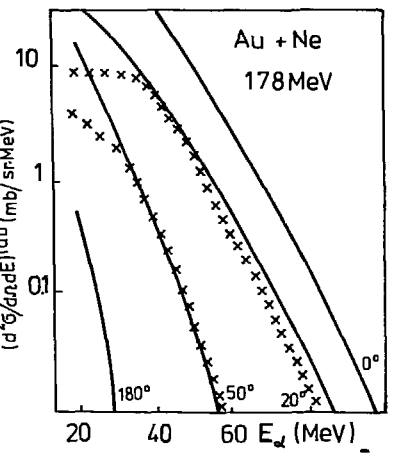
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In recent years there has been a growth of interest in study of pre-equilibrium light particle emission in heavy-ion reaction. It is hoped that these studies will provide the information on the nature of the relaxation processes in nuclei.

Here, we suggest the model for describing pre-equilibrium particle emission in nearly central collisions at ~10 MeV/u. We suppose that in the initial stage of interaction the excitation energy and the momentum transferred are localized in a small volume of the composite-system. The motion of this hot region in a beam direction is accompanied by increasing of number of nucleons A(t) and decreasing temperature T(t) and the velocity up to formation the compound-system. The momentum distribution of nucleons in the continuum $N(\bar{Q})$, corresponding to these assumptions:

$$N(\bar{Q})d^3Q \sim A(t)\sqrt{1+\frac{P_F^2}{Q^2}}\exp\left(-\frac{Q^2}{2mT(t)}\right)d^3Q$$



where $\bar{Q}$ is the external momentum, related with the momentum $\bar{P}$ of the nucleon in the nucleus by the relation $\bar{P}^2 = \bar{Q}^2 + P_F^2$. The nucleon in the continuum form the emitted α-particles. Using the α-particle wave function, we can get the corresponding distribution of α-particles

$$N_\alpha(E,\Omega)dEd\Omega \sim \left(1+\frac{2m_\alpha R_\alpha^2 T(t)}{\hbar^2}\right)^{-9/2}\left(\frac{A(t)T(t)}{E_F}\right)^4\left(\frac{T(t)}{E}\right)^{1/2}\exp\left(-\frac{E}{T(t)}\right)\frac{dEd\Omega}{E} \qquad (1)$$

where R_α is the mean square radius of α-particle. Using (1) and additional assumptions about the motion of the hot region we have calculated the spectrum of α-particles in the reaction Au + Ne (178 MeV)[1]. It is seen from the figure that the model can describe the slope of the energy spectra and angular anisotropy.

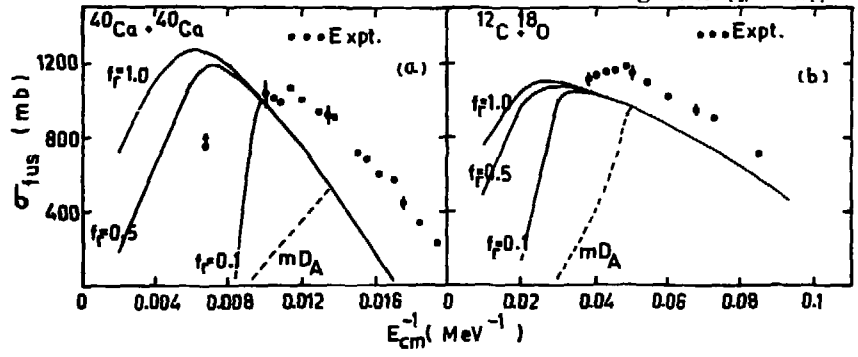
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ENERGY DISSIPATION IN HEAVY ION COLLISIONS DUE TO NUCLEON EXCHANGES

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Nucleon transport has been proposed as one of the basic mechanisms leading to energy loss in relative motion in heavy ion collisions[1]. Analysis of fusion excitation functions for a large number of target-projectile systems with frictional coefficients of Randrup have substantiated this basic mechanism[2]. However, as we show in the figures (a) and (b), the projectile energy at which the fusion crosssection reaches its maximum value is sensitive to the magnitude of the frictional coefficient used and the experimental data seem to be in better agreement with a smaller value of the frictional coefficient than given by Randrup. In the above proximity friction, the effect of Pauli blocking has been neglected, since it was argued by Randrup that such an effect is to be considered only in nucleon exchange but not in energy transfer. However, an alternate formalism of nucleon transport developed by us earlier[3] requires that the Pauli blocking influences both the mass and energy transport, leaving the classical relationship, $k/mD_{AA}=1$, between the mass diffusion coefficient D_{AA} and the frictional coefficient k, intact. We have therefore carried out fusion crosssection calculations with the frictional coefficient given by the above relationship and using the expression for D_{AA} given by Randrup. These results are also shown in the figures. It is seen that the maximum fusion crosssection occures at much lower energy with this value for the frictional coefficient. These calculations have been carried out for lighter target-projectile systems and are being extended to heavier systems wherever fusion crosssection data are available over a large energy range.



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A COMPARISON OF MODELS FOR INCLUSIVE PROTON SPECTRA IN RELATIVISTIC NUCLEAR COLLISIONS

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We present the results of calculations of proton "production" in the forward and backward directions by beams of relativistic protons and nuclei. Several models, each assuming different input, are examined so that the relative importance of different possible reaction mechanisms in different kinematic regions are determined. In particular, we include elastic nucleon-nucleon scattering, inelastic nucleon-nucleon scattering and elastic and inelastic nucleon-light cluster scattering. In analogy to an earlier pion production calculation[1], we have attempted to utilize an invariant parametrization of the elementary subprocess, proper handling of kinematic effects, and a variety of forms for the nucleon momentum distribution within nuclei. Specifically, exponential, gaussian and two component distributions are examined.

We find that the momentum distribution which reproduces "backward protons" is not appropriate for the forward, quasielastic peak. In addition, whereas many models can be adjusted to reproduce the slopes of the data[2], reproducing the absolute normalization is an additional stringent test.

One of the weaknesses in these hard scattering models is the neglect of the many (softer) incoherent scatterings before and after the "hard" one. We discuss also a recent attempt[3] to remove this deficiency.

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CROSS-SECTIONS FOR INELASTIC ^{4}He AND ^{12}C-NUCLEUS COLLISIONS AT 4.5 GeV/c/N INCIDENT MOMENTUM

SKM-200 Collaboration: Alma-Ata - Dubna - Tbilisi - Warsaw

/to be presented by E. Skrzypczak, Inst. of Experimental Physics, University of Warsaw, Poland/

Inelastic interactions of ^{4}He and ^{12}C nuclei were studied in a 2m streamer chamber exposed to beams of relativistic nuclei from the Dubna synchrophasotron. The cross-section values for interactions with pure nuclear targets ranging from Li to Pb were obtained and compared with predictions of some theoretical models. The predictions of models, based on the recent development [4,5,6] of the Glauber approach to the multiple scattering theory for nucleus-nucleus collisions are in a better agreement with experimental data than older approaches [1,2,3] to the problem.

	OUR EXPERIMENT - σ^{inel} [mb]	THEORY
^{4}He-Li	320 ± 15	430[2]
C	450 ± 20	560[1], 550[2], 484[3], 517[4], 454[6]
Ne	615 ± 40	790[2]
Al	720 ± 30	880[2], 793[3], 806[6]
Cu	1150 ± 50	1370[2], 1392[3], 1280[6]
Pb	2400 ±170	2580[1], 2470[2], 2603[3], 2387[6]
^{12}C-C	780 ± 30	950[2], 879[4], 869[5], 764[6]
Ne	1040 ± 60	1280[2]
Si	1130 ± 80	1430[2], 1229[6]
Cu	1700 ± 90	2010[2], 1806[6]
Zr	2025 ±120	2320[1], 2340[2]

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VALIDITY TEST OF THE COHERENT TUBE MODEL (CTM) FOR NUCLEUS - NUCLEUS COLLISIONS IN GEV/NUCLEON ENERGY REGION

SKM-Collaboration: Alma-Ata - Dubna - Tbilisi - Warsaw

/to be presented by E. Skrzypczak, Inst. of Experimental Physics, University of Warsaw, Poland/

Negative pion production in ^{4}He (4.5 GeV/c/N) interactions with pure nuclear targets of Li, C, Al and Cu nuclei was studied in the 2m streamer chamber /4π - geometry detector/. The data /Fig.1/ show that the pion average transverse momentum, $\langle p_T \rangle$, may be decreasing with the target mass number, A_T, and the"degree of centrality" of the collision as derived from the information on the projectile fragments in each collision.

Fig. 2 presents the $\langle p_T \rangle$ dependence on incident momentum p, for nucleon-nucleon collisions [1] . Single data-point corresponding with the results from Fig.1 and plotted at p = 4.5 GeV/c coincide with the $\langle p_T \rangle$ vs p curve for the nucleon-nucleon interactions.

In the framework of the CTM [2] , the pion production in nucleus-nucleus interactions depends on the available energy Q in the cms of the colliding tubes. Due to the increase of the tube dimensions /e.g. "peripheral" ^{4}He - Li,"central" ^{4}He-Cu interactions/ the Q value increases and consequently the $\langle p_T \rangle$ value is expected to grow both with A_T and the "degree of centrality". The observed inconsistency of the CTM predictions and the experimental data reported here /more detailed analysis including tube fragmentation mechanism in CTM,should not remove this inconsistency/ tends to be a strong argument against the CTM approach to the description of the nucleus-nucleus interaction mechanism.

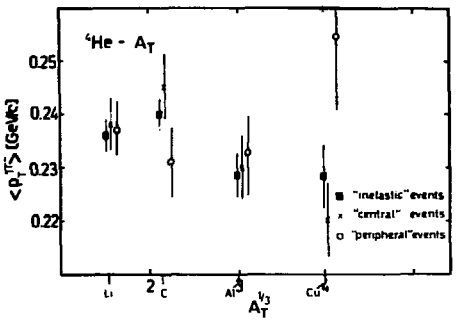


Fig.1

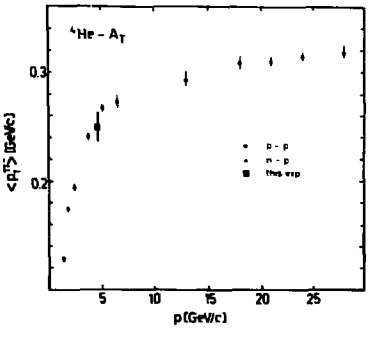


Fig.2

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ON THE SECONDARY INTERACTIONS OF Ar FRAGMENTATION PRODUCTS

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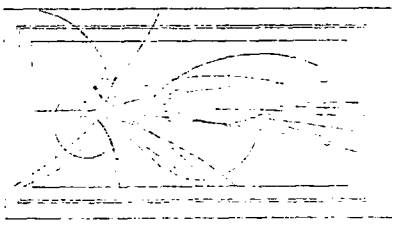
J.W. Harris, J. Brannigan, J.V. Geaga and L.J. Rosenberg
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For a long time there have been sporadic reports in the cosmic ray literature about secondary fragments having two, three or more interactions in a nuclear emulsion stack for which there was a very low probability to occur. More recent studies of ^{16}O and ^{56}Fe fragmentation at 1.8 GeV/A have accumulated a larger sample of such events.[1]

The analysis of the data shows discrepancies between the observed interaction probabilities and those calculated using geometrical reaction cross sections. The data are compatible with the existence of a very short mean free path component in the component in the projectile fragmentation cone. Unfortunately there are little experimental data on the reaction cross sections and isotope distributions of secondary fragments making the calculations somewhat uncertain. There are some hypothesis put forward to explain this effect involving the decay of an excited fragment, which is difficult to distinguish from an interaction in the emulsion. A second experimental approach to verify this effect is necessary.

As a by-product of our streamer chamber stuides of high energy Ar interactions[2] we have subset of data with secondary interactions. The trigger configuration consists of an upstream scintillator, a target and downstream scintillator inside the sensitive volumen. The events of most interest for this study are those in which the Ar interacted in the upstream scintillator leaving the target, gas and downstream counter for the fragmentation products to interact. This technique has several disadvantages compared to the emulsion results since there is no charge identification and the spatial resolution is not as good as in the emulsion. Nevertheless there are many advantages; the events are easy to find, their topology can be studied and the decay vs. interaction hypothesis can be tested. If there is a short mean free path component, the use of relative thin targets (3mm and 1 cm) will enhance it from background of normal interactions. These effects and the bombarding energy dependence are being studied for the Ar projectile spectator interactions.



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EVIDENCE FOR THE HOT-SPOT FORMATION IN HEAVY-ION FUSION-LIKE REACTIONS

T. Nomura

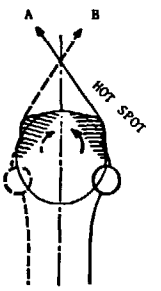
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In heavy-ion collisions light particles (proton, α particle etc.) are often emitted predominantly in the forward direction even at low incident energies(6-8 MeV/amu). Since their energy spectra are well reproduced by the statistical evaporation formula with high nuclear temperature, the above phenomenon has been attributed to evaporation from a locally heated composite (projectile plus target) system[1]). The polarization of such protons has recently been measured to be non-zero and positive in the $^{93}Nb+^{14}N$ reaction at 95 MeV, where most of the protons originate from collisions leading to fusion[2]). The aim of this note is to propose a possible reason for this polarization on the basis of the hot-spot model.

We first point out that if the total angular momenta of a highly excited nucleus are polarized, the intrinsic spin of nucleons emitted during its statistical decay is usually polarized in the same direction. To see this, consider a stretched downward transition by nucleon with kinetic energy E and total and orbital angular momenta j and ℓ respectively, for which the transmission coefficient is denoted by $T_\ell^j(E)$. Then the polarization P of the emitted nucleons is

$$P = f_1 \times \left[\left(T^j_{j-\frac{1}{2}}(E) - \frac{j}{j+1}\, T^j_{j+\frac{1}{2}}(E)\right) \Big/ \left(T^j_{j-\frac{1}{2}}(E) + T^j_{j+\frac{1}{2}}(E)\right)\right], \qquad (1)$$

where f_1 is the initial polarization of the parent nucleus. Since the term within the bracket in eq. (1) is always positive, P has the same sign as f_1. The extension to a general case is straightforward and comes to the similar conclusion since the stretched transitions are usually favored due to the spin dependence of the state density. The extensive statistical calculation carried out for the above reaction, in which level-density parameters are adjusted to simulate preequilibrium emission, yields $P=(0.2\text{-}0.3)\times f_1$.



Let us now consider a projectile captured by a target in a nearly peripheral collision (see a solid-line trajectory). While local heating occurs around the contact region, the composite system starts to rotate due to the transfer of the relative angular momenta. Affected by the rotational motion, the nucleon-emission from this hot spot takes place in the direction A on the average, which is close to the tangential direction. Such nucleons must be polarized in the same direction as the rotational motion. A hot spot created by a projectile reaching the opposite side of the target surface (a dashed-line trajectory) emits nucleons on the opposite side (B) with respect to the beam direction, as far as the hot-spot emission occurs quickly, e.g., within half a period of the rotation[1]). The sign of the polarization is expected to be positive, corresponding to negative-angle emission which is reasonable because the initial kinetic energy is well relaxed within the hot spot as indicated from the observed energy spectra[1]). It is clear that there will be no polarization if the whole surface of the composite system is heated and contributes to nucleon evaporation equally. The measured non-zero polarization is thus considered to be clear evidence for the hot-spot formation.

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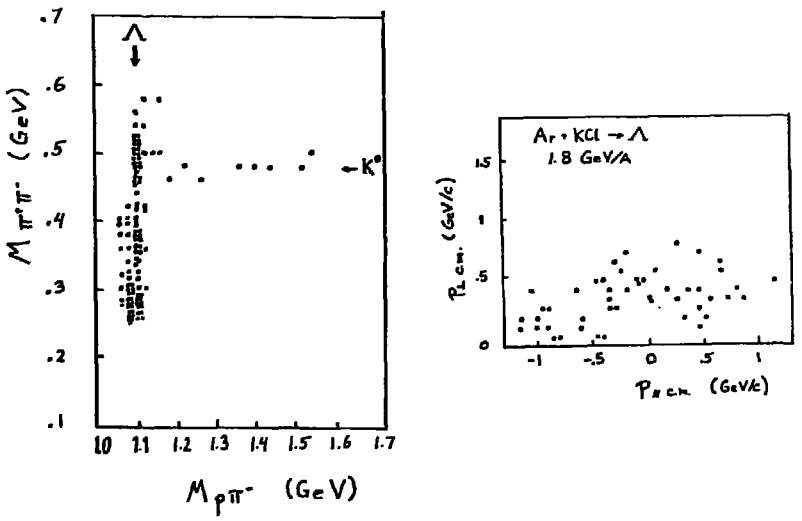
STRANGE PARTICLE PRODUCTION IN CENTRAL COLLISIONS OF Ar ON KCl AT 1.8 GeV/A

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The strange particle production is a unique probe in the study of high energy nucleus-nucleus interactions. The high production threshold due to associated production (Λ+K) and (Σ+K) leads at Bevalac energies to their production most probably only in the first stage of the collision, before a large energy degradation has set in. In contrast to pions and isobars, they cannot be reabsorbed, due to strangenes conservation, making them a more primordial probe. Their production in free NN interactions involves the strange quark-antiquark production from the vacuum. It is conceivable that this vertex is modified in a high density high temperature nuclear medium, making it very interesting to compare their production cross sections in different systems.

In our streamer chamber study of central collisions[1] we should see the strange particle production at the higher bombarding energies. The charged kaons and sigmas, although detected, can not at present be identified from protons and pions. The neutral K^0s and Λs can be readily identified if they decay by charged particles. ($K^0 \to \pi^+\pi^-$ with 68%, $\Lambda \to p\pi^-$ with 64% probability). Most of the identified neutral strange particle decays correspond to the invariant mass of a Λ. An independent particle model predicts a forward-backward c.m. Λ distribution but an almost isotropic kaon distribution.



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EVIDENCE FOR NON THERMAL PION PRODUCTION IN THE CENTRAL INTERACTIONS OF Ar ON KCl AT 1.8 GeV/A

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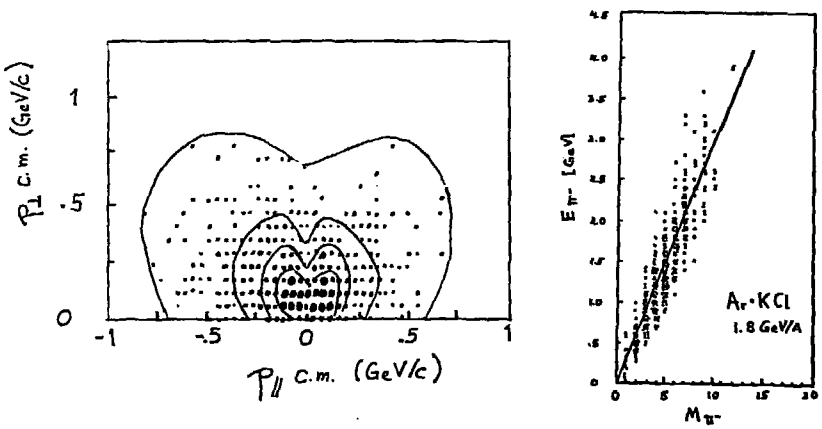
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In the participant-spectator model the pions, among all the reaction products, have an unambiguous origin, namely the participants. The reaction dynamics is sensitive to the number and energies of the produced pions, which can significantly reduce the total aviable energy. It is necessary for models that predict single particle inclusive nucleon spectra to describe the pion production correctly. In the fireball-like models the pions arise from thermal pion production and the decay of isobars in thermal and chemical equilibrium with pions, nucleons and nuclear fragments giving an isotropic and thermal distribution in the center of mass for an equal projectile and target mass system.

As part of our streamer chamber study of the energy dependence of multipion production[1] we have measured and reconstructed the π^-'s produced in the central interactions of Ar on KCl at 1.8 GeV/A.

Preliminary results show a non thermal distribution, with forward-backward peaking in the c.m., reminiscent of the $\Delta(3,3)$ decay pattern. The total c.m. energy flux in π^- shows a linear relationship with the π^- multiplicity with a slope of 300 MeV/π^-.



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MASSIVE TRANSFER: A MECHANISM FOR EMISSION OF NON-EQUILIBRIUM PARTICLES IN HEAVY-ION REACTIONS†

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Inclusive spectra of charged particles such as protons and alphas that are emitted in reactions induced by heavy ions exhibit energies far exceeding those expected from evaporation and angular distributions peaked in the forward direction. Recently experimental studies of particle-gamma coincidence spectra have been made[1]) for a variety of projectile-target combinations in which the discrete gamma rays could be associated with specific transitions in a particular residual nucleus. Thus not only could the exit channel be uniquely identified for a particle of a particular energy and emission angle but also the angular momentum transfer could be inferred from the γ-ray spectrum.

Experimental data have been obtained for targets in the mass range 100-180, for projectiles ^{6}Li through ^{20}Ne, and for bombarding energies ranging from 6 to 13 MeV/u. Particles observed include p, d, t, and α. Intensity patterns of γ rays in coincidence with particles of energy well above their Coulomb energy show little sidefeeding for lower spin states. This indicates localized entry into states of higher spins in the deexcitation process. The average multiplicity of γ rays in coincidence with fast particles and with discrete γ-ray transitions[2]) is consistent with the view that the initial interaction occurred at an impact parameter corresponding to the critical value for fusion.

Angular distributions of the fast particles in coincidence with γ rays are bell shaped, the maximum occurring at small forward angles[1]). This property is characteristic of transfer processes observed in heavy-ion reactions. In the case of α particles, the energy spectrum for the most probable exit channel is peaked at the beam velocity.

These experimental results are consistent with a mechanism in which the projectile is broken up into a light particle (p, d, t, α, etc.) and a massive residue. The massive fragment is then transferred to the target nucleus over a narrow range of impact parameters corresponding to the critical radius for fusion of fragment and target nucleus. Subsequently a (fragment,xn) process occurs and the deexcitation γ rays are observed. The light particle is scattered in the forward direction. In view of this mechanism, "massive transfer" appears to be an apt description of this reaction.

†This work was supported in part by the U.S. Department of Energy and The Robert A. Welch Foundation.

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PARTICLE EXCHANGE IN ^{16}O-^{16}O ELASTIC SCATTERING

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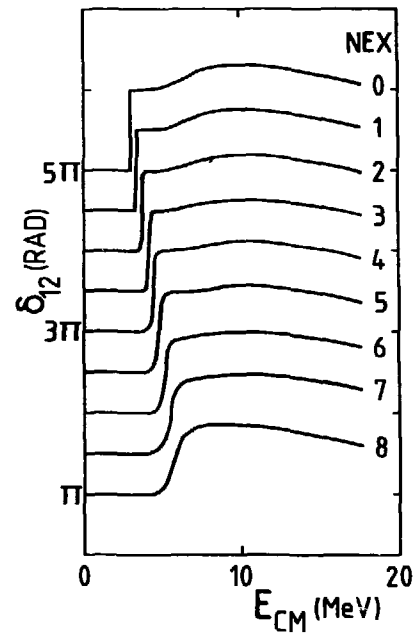
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The phase shifts for ^{16}O-^{16}O elastic scattering have been calculated using the technique[1]) involving the generator-coordinate and natural boundary condition methods for composite particle scattering. The effect on the phase shifts of approximations with respect to the number of nucleons exchanged between the two clusters has been studied.

In the calculations, a two-body Volkov force 2 was used and for simplicity all Coulomb interactions were neglected. For convenience the ^{16}O ground state was taken to be the closed shell $(1s)^4(1p)^{12}$ configuration and the nucleon states were assumed to be harmonic oscillator orbitals which allows the centre-of-mass motion to be separated out.

In particular, the terms arising from one-, two- and multi-nucleon exchange have been identified in a consistent manner by including exchange terms up to a given number (NEX) of nucleons in *both* state vectors of the matrix elements. As a result, the various exchange approximations (NEX=0, 1,2,....,8) modify the calculated phase shifts in a monotonic manner contrary to the results of ref.[2]). It should be noted that NEX=1 implies that up to one-particle exchange *and* up to one-hole (15-particle) exchange terms are included so that the case NEX=8 corresponds to a fully antisymmetrized calculation.

The figure shows a typical set of results for the L=12 partial wave. It is seen that as NEX increases, the phases are modified in a monotonic and approximately linear manner. Thus, in this case, all the exchange contributions are equally important. It should be noted that in the figure, the phase shifts have been separated by $\frac{1}{3}\pi$ for clarity.



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ENERGY SPECTRA AND PARTICLE EMISSION IN THE ^{14}N (10 MeV/n) + ^{27}AL SYSTEM

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The reaction $^{14}N + ^{27}AL$ at 150 MeV incident energy is studied. A mass and charge identification is perfomed and allows the separation of emitted isotopes up to A = 30. The experimental set up includes a time of flight, start and stop are given by channel-plates devices. The obtained resolution (on the elastic pic) is 150ps which allows a flight path of 30 cm only.

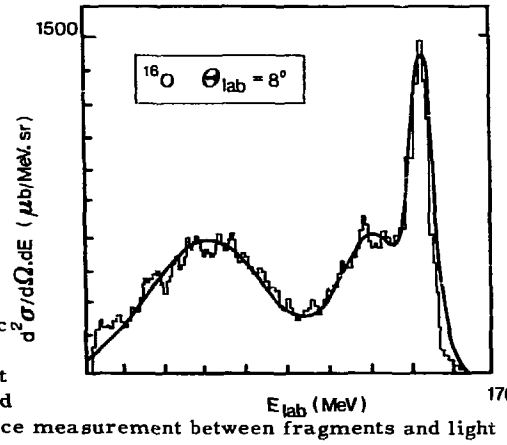
Three components can be observed in the energy spectra of each isotopes. As seen in figure 1, it is possible to analyse the spectra using three gaussien-shapes. This feature is observed for each emitted isotope (from A = 10 to A = 20) however the less excited component is present only for $\Delta A \leq 2$ nucleons.

The mean value and width (in excitation energy scale) for the whole range of isotopes are respectively:

$\bar{E}_{Mev}(16^{+}_{-}3,\ 37^{+}_{-}5,\ 85^{+}_{-}5)$

$E_{Mev}(10^{+}_{-}2,\ 30^{+}_{-}2,\ 40^{+}_{-}2)$

Moreover the angular distributions of the three components are quite different : from very forward peaked for the more quasi-elastic component to nearly symetric for the more damped one.



It seems that different interaction times are involved in the reaction. By coincidence measurement between fragments and light particles (p, α and n), we expect to show a connection between the different mechanisms and the particles emission.

SCATTERING AND REACTIONS OF $^{14}C+^{14}C$

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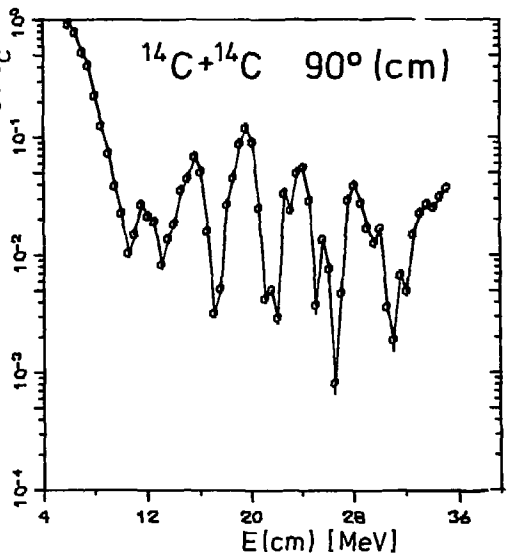
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Through the development of a ^{14}C beam[1] at our MP tandem accelerator and of a ^{14}C target (75 µg/cm²; 80% ^{14}C, 20% ^{12}C) by Maier et al.[2] it became possible to study the interaction of $^{14}C+^{14}C$. The particular interest for this system results from its similarity with the $^{16}O+^{16}O$ system and from the prediction [3] that it is one of the best candidates to observe molecular resonances.

We have measured the elastic and inelastic scattering and several reactions from $^{14}C+^{14}C$ between 6 and 35 MeV (cm). The reaction products were identified through kinematical coincidences between a position sensitive detector and one of 5 large-size rectangular detectors[4].

The experimental results show regular, strongly pronounced resonance - like structures with peak-to-valley ratios of partly more than one order-of-magnitude. The strongest channels are elastic and inelastic scattering and the exit channels $^{13}C+^{15}C$ and $^{10}Be+^{18}O$. The analysis of the data, not completed at present, is expected to reveal the strongest support to date for molecular structures.

The elastic scattering at 90° (s. Fig.) exhibits features reminiscent of $^{16}O+^{16}O$ scattering. Five prominent structures with widths of ∿1.6 MeV (cm) are observed; angular distributions measured on resonance indicate spins of ℓ=10, 12, 14, 16 and 18 ħ (at 28 MeV), which fit well into a rotational band in an energy-vs. - ℓ(ℓ+1) plot.



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4) J. G. Cramer et al., Nucl. Instr. Meth. 111 (1973) 425

EFFECTS OF QUANTUM DIFFRACTION IN DEEP INELASTIC HEAVY ION REACTIONS

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In a forthcoming publication [1] we treat quantum diffraction effetcs in the form of a correction of classical statistical theories. The correction is obtained by applying semi-classical approximations to the summation over orbital angular momenta in each micro-channel and by subsequently averaging over final channels which are not distinguished experimentally. The quantum correction has the form of an analytical functional of the average classical deflection function. We treat two types of quantum corrections : (i) the Fresnel diffraction due to absorption into fusion channels at angular momenta $\ell<\Lambda_1$ and (ii) the Airy-diffraction due to an interference of rays in the vicinity of a rainbow angle. We present results of the correction (i) for the system $^{86}_{36}Kr$ on $^{120}_{50}Sn$ at 514 MeV(LAB). The classical distribution function is calculated within the model of ref. 2.

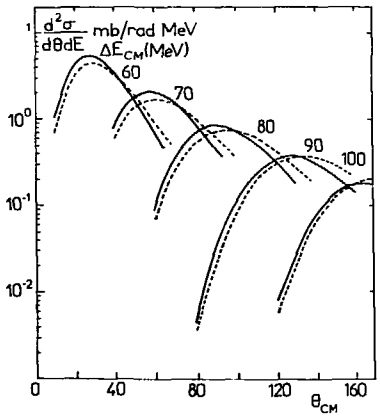


Fig.1 : Classical deflection functions $\bar{\theta}(\ell,\Delta E_{CM})$ for various energy losses ΔE_{CM}. Dashed curve: Average over all energy losses.

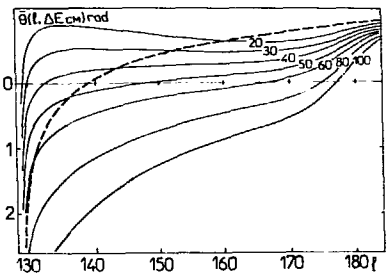


Fig.2 : Angular distribution of outgoing $^{86}_{36}Kr$ for several energy losses ΔE_{CM} (MeV) : dashed curves : purely classical result, full curves: Lower cut-off at $\Lambda_1 = 129\hbar$.

*Supported by the DFG

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ALPHA EMISSION WITH 10 MeV/A ^{14}N PROJECTILES

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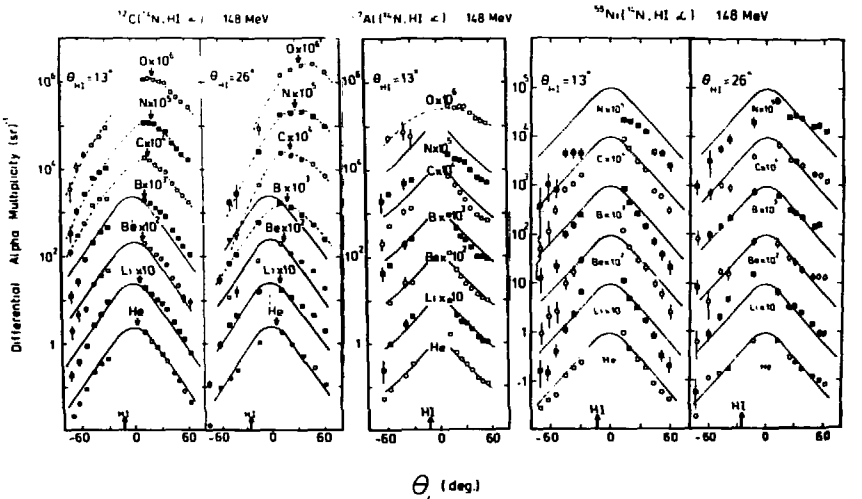
Alpha-heavy ion correlations have been measured on ^{12}C, ^{27}Al and ^{58}Ni targets with a 148 MeV ^{14}N beam. Heavy ejectiles (Z = 3-8) were detected at $\theta_{HI} = 13^{o}$, the grazing angle for ^{14}N + ^{58}Ni and at $\theta_{HI} = 26^{o}$. Coincident α particles were detected in coplanar geometry in the range $\theta_{\alpha} = \pm 70^{o}$. Singles energy and angular distributions and out-of-plane correlations have also been measured. The differential α multiplicities, obtained by dividing the coinci-dence by the singles deep-inelastic cross sections, are shown in Fig.1.

For $Z < 6$ ejectiles from the ^{58}Ni target the correlation data may be factorised[1] as a product of singles α and HI cross sections:

$$d^4\sigma(E_{HI}, E_{\alpha}, \theta_{HI}, \theta_{\alpha}) \propto d^2\sigma(E_{HI}, \theta_{HI}) \cdot d^2\sigma(E_{\alpha}, \theta_{\alpha})$$

Angle-integrated α multiplicities are estimated in the range 0.4 - 0.8. The observed correlations indicate that the α particles are emitted, at an early stage, prior to the formation of the deep-inelastic fragments.

The data from ^{12}C and ^{27}Al targets shows many of the same features. Integral α multiplicities from ^{12}C and ^{27}Al are in the range 1.0 - 2.0 and 0.6 - 1.0, respectively. Factorisation gives a reasonable description of the energy correlations, but the angular correlations show a systematic shift away from the HI direction for $Z \geq 6$. The solid curves (Fig.1) are singles α angular distributions (interpolated at forward angles). Such a backward shift has also been found with ^{11}B on ^{58}Ni, raising the question to what extent it is a general feature of α-HI correlation data for heavy ejectiles.



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DETERMINATION OF NUCLEAR RESPONSE TIME FROM DEEP INELASTIC COLLISION OF NUCLEI

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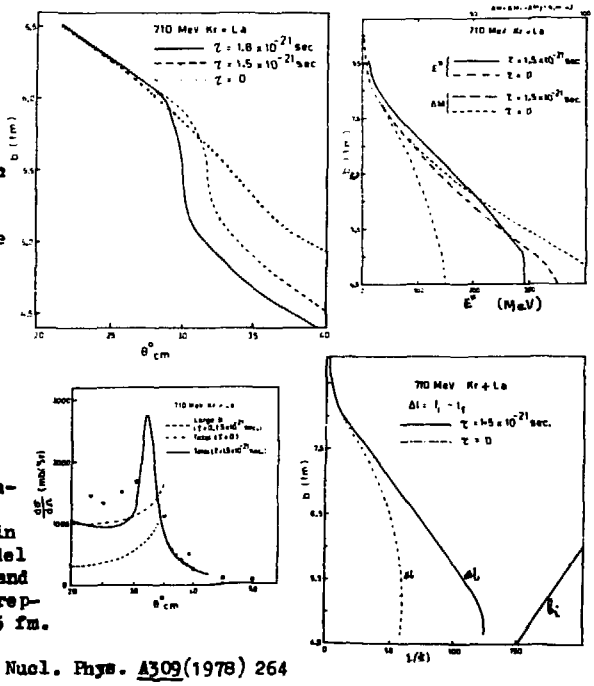
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The energy dissipation in deep inelastic collision of heavy ions has been understood satisfactorily in terms of nucleon exchanges between nuclei while in contact during transit[1]. As the response time of a nucleus is small of the order of transit time, the study of DIC is expected to provide information about nuclear response time (τ). We calculate the energy dissipation, angular momentum transfer and angular distribution for the DIC of 505 to 710 MeV ^{86}Kr with ^{139}La in the nucleon exchange model as a function of τ. The average velocity of the transfered nucleons at any point of the trajectory is:

$$\vec{V}_{average}(\tau) = \frac{\vec{K}(\tau)}{A_1} - \frac{R_1}{\cos\theta_1}\vec{\omega}_{1R}(\tau)$$

Here the first term is the nucleon velocity due to the c.m. motion of nucleus 1, while the second term is the normal component of velocity due to the spin of nucleus 1. At any point on the trajectory the nucleus in our picture does not remember the history of events during the previous period of time τ. For the potential between the two nuclei we used an attractive Saxon Woods form and a shorter range repulsion. The position of the repulsive potential is also determined from the angular distribution of DIC data. The trajectories for various impact parameters, b response time τ, and position of repulsive potential have been evaluated by numerical solution of equation of motion.

As seen in fig.1 there is a kink in the deflection function (b vs. θ_{cm}). The kink and hence the peak[2] in the angular distribution uniquely determines the average τ of the nucleus for the desired relative energy. Response time ($\tau = 1.5.10^{-21}$ sec. for 710 MeV case) is larger than the transit time ($0.5.10^{-21}$ sec). τ has been found to increase with energy. As seen in figs. 2,3,4 the whole a angular distribution, the energy transfer and the angular momentum transfer in DIC of heavy ions can be understood in our nucleon exchange model using $\tau = 1.5.10^{-21}$ sec and an inward shift of the repulsive potential of 2.75 fm.



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A COMPOSITE ABSORPTIVE POTENTIAL FOR $^{16}O + ^{28}Si$ ELASTIC SCATTERING†

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The $^{16}O + ^{28}Si$ system has attracted much attention as a test case for the applicability of the optical model to heavy-ion elastic scattering[1]. In the past we succeeded in accurately fitting angular distributions between $E_{lab}(^{16}O)$ = 45 and 63 MeV and the 180° excitation function. A parity-dependent and surface-transparent optical potential was used which varied smoothly with energy[2]. We have now included the complete angular distribution[3] at 41.23 MeV in the fitting procedure (Fig. 1). We find that - to achieve a fit to all the data - we need a "composite" imaginary part, i. e. a fairly strong volume absorption (W_V) of W-S shape which is confined to the nuclear interior and a small surface term (W_D) of W-S derivative shape which increases steeply with energy. The real potential was kept the same as, and the shape and the magnitude of the composite potential $W = W_V + W_D$ at radii $R \gtrsim 7$ fm were found to be similar to those of ref. 2. As before, a small parity-dependent term is essential for a fit to the 180° excitation function. We are now investigating the connection between W_D and the coupling of the elastic and inelastic channels.

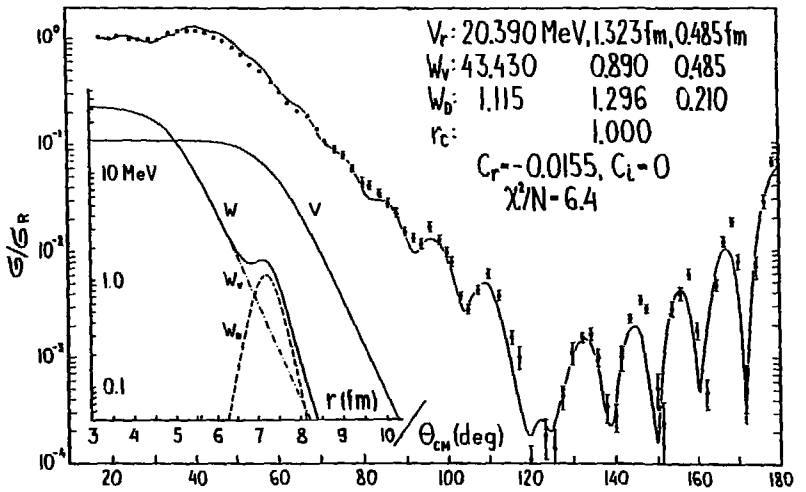


Fig. 1. σ/σ_R and the potential at E_{lab} = 41.23 MeV

† This work was supported in part by the Nuclear Science Division of the U. S. Department of Energy.

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Nuclear Surface Studies Via Coulomb-nuclear Interference*

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Heavy-ion collisions can be categorized as (a) those restricted to the asymptotic region where charge and matter distributions do not overlap and Coulomb interactions dominate, (b) those occuring in an intermediate region where surface distributions overlap somewhat causing a sensitive interplay between Coulomb and nuclear interactions, and (c) those resulting in significant overlap where nuclear interactions dominate. The second region is a rich source of information on the tail of the nuclear interaction potential.

We have conducted an experimental and theoretical study of the effects of exciting deformed nuclei with heavy ions at energies near the Coulomb barrier. The primary tools have been particle-γ-ray spectroscopy techniques and a prescription which exploits radial and angular localization in such collisions under the framework of the classical limit S-matrix formalism to deduce ion-ion interaction potentials.[1-2]

We have found that excitation probabilities for particular spin states in the ground state rotational band of the target nucleus are extremely sensitive to radial and angular details of the nuclear surface potential. Because of the localization effects, the potentials deduced are less sensitive to particular parameterizations or model assumptions. Preliminary results for $^{40}Ar + {}^{160}Gd$ are contained in Ref. 1).

Recently we have included the effect of an adiabatic excitation of giant dipole and quadrupole resonances[3] in the calculation of the interaction potentials. Also, we have made the parameterization of the potential less biased. This new approach will be applied to several other systems over a wider energy range.

*Work supported by U. S. Department of Energy.
**Operated by Union Carbide Corp. under U.S.D.O.E. contract W-7405-eng-26.
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3. J. O. Rasmussen, P. Möller, M. W. Guidry, and R. E. Neese, to be published in Nucl. Phys. A.

SYSTEMATICS OF C + C FUSION-EVAPORATION SYSTEMS

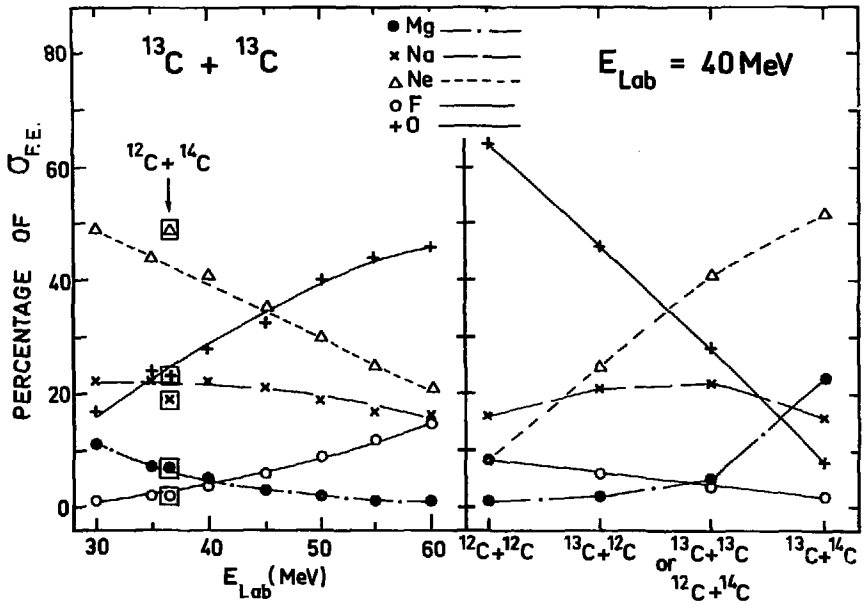
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The Carbon + Carbon fusion evaporation residues have been studied in two series of measurements using a time of flight technique including Z identification :

i - The system $^{13}C + ^{13}C$ has been studied for laboratory-bombarding energies between 30 and 60 MeV in 5 MeV steps. Angular distributions for all residual nuclei have been measured. On the left hand side of the figure are presented the cross sections summed for each element over the corresponding isotopes. The $^{12}C + ^{14}C$ study at $E_{lab}(^{12}C) = 40$ MeV is included, corrected to the same excitation energy of the compound nucleus ^{26}Mg. The agreement with the $^{13}C + ^{13}C$ data demonstrates that, within the experimental errors of 5 %, the results are independent of the way in which the compound nucleus is formed.

ii - The systems $^{12}C + ^{12}C$, $^{13}C + ^{12}C$, $^{13}C + ^{13}C$ and $^{13}C + ^{14}C$ have been studied at $E_{lab} = 40$ MeV. This energy corresponds approximatively to the maxima of the fusion evaporation cross-sections for these systems. The corresponding data are presented on the right hand side of the figure. The additional neutrons strongly affect only the αxn and $2\alpha xn$ channels (Ne and O isotopes, respectively). However the trends are opposite for increasing excitation energy and for increasing neutron number.



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ISOBAR PRODUCTION AND COHERENCE IN PERIPHERAL HEAVY-ION COLLISIONS

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A theoretical estimate for the total cross-section of isobar production in a relativistic ^{16}O heavy-ion at 2.1 GeV/N colliding peripherally with a ^{12}C target nucleus which is also excited to a spin giant resonance is presented. A possible mechanism for the production of pions in the forward direction might be the formation and decay of nucleon isobars in the projectile. Following the approach of ref. [1], the summed nuclear field of the target nucleons on a projectile nucleon is replaced by an average potential which is obtained by folding the spin-spin part of the nucleon-nucleon potential with the target density. This average potential is then transformed into a virtual phonon field carrying energy and momentum to a projectile nucleon. The frequency spectrum for the production of the $\Delta(3,3)$ isobar and spin excitation of the target is given by time-dependent harmonic perturbation theory as

$$F(\omega) = \frac{1}{2\pi}\int dt\, e^{i\omega t} \langle \Psi_\beta \Theta_\mu \phi_m u | V | \Psi_\alpha \Theta_\lambda \phi_\ell u \rangle, \quad (1)$$

where Ψ is the projectile state, Θ the target state, u the motion of the centers of mass in the longitudinal direction and ϕ is the motion of the impact parameter. In the same spirit as Coulomb excitation, a classical straight line trajectory $u^2 = \delta(z-vt)$ is assumed in the longitudinal direction since the loss of energy to excite an isobar is small compared to the overall energy of the projectile. The nucleon-isobar transition potential is given by

$$V = \sum_{p,t} \vec{S}_p \cdot \bar{\sigma}_t\, v_{pt}(\zeta, b), \quad (2)$$

where $\vec{S}_p$ is the transition spin of the $p^{\underline{th}}$ projectile nucleon producing an isobar and $\bar{\sigma}_t$ is the ordinary spin of the $t^{\underline{th}}$ target nucleon. The strength and range parameters in the nucleon-isobar gaussian factor v_{pt} are adjusted to agree with the high-energy nucleon-nucleon average data used in ref. [1]. The longitudinal and transverse separation distances between target and projectile nucleons are ζ and b. The tensor term is neglected for the sake of obtaining a simple order of magnitude estimate. The collective operator used to generate the spin-flip giant resonance is the total spin operator leading to an isoscalar 1^+ state in ^{12}C. The total cross-section then contains a projectile coherence factor A_p^2/A_T where the formation of a target spin giant resonance introduces the "penalty" factor of $1/A_T$ due to normalization. If an isobar spin giant resonance state is generated in the projectile ion in analogy to the target giant resonance, then the total cross-section contains a further "penalty" factor of $1/A_p$. The rough estimates for these total cross-sections are approximately 60mb and 4mb, which is of course considered to be an overestimate. If absorption of pions after the decay of the isobar were included, then these values would be lower. From ref. [1], the cross-sections might be a factor of 10 smaller with inclusion of absorption.

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CONSERVATIVE AND DISSIPATIVE FORCES IN THE FUSION OF VERY HEAVY IONS[†]

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It is well known that the cross sections for fission-like fragments produced in heavy ion reactions on heavy targets may exceed considerably the fusion cross section limits expected from the rotating liquid-drop model[1]). These results suggest the existence of long-lived intermediate composite systems trapped with high angular momenta in the inter-nuclear potential. These trapped systems, although ultimately unstable, have interaction times sufficiently long to allow considerable relaxation of even slowly equilibrating degrees of freedom, such as the mass asymmetry. Because of the long interaction times, the fragments resulting from these trapped systems exhibit a $1/\sin\theta_{cm}$ angular distribution and have masses and kinetic energies essentially consistent with a fusion-fission reaction process. In the case of relatively asymmetric systems, these fusion-fission products are distinguishable from fragments produced in a damped reaction where, on the average, the initial fragmentation is preserved.

Classical trajectory calculations, where the fusion cross section corresponds to all trajectories which are trapped behind an inter-nuclear potential barrier, show that the fusion excitation functions for very heavy systems are sensitive to the conservative and dissipative forces. Therefore, a program has been initiated to investigate the fusion properties and excitation functions for very heavy systems. Measurements have been completed on the ^{165}Ho + ^{56}Fe reaction at ^{56}Fe beam energies up to E_{Lab} = 510 MeV. The measured angular distributions of fission-like fragments are consistent with a $1/\sin\theta_{cm}$ function. For such an angular distribution the intermediate trapped system must have a lifetime long enough to accomplish at least one complete revolution. Hence, the lifetime for trajectories in the ℓ window between the liquid drop limit and ℓ_f for fusion-fission is of the order of 10^{-20} sec. This lifetime is long enough for some particle evaporation to occur from the intermediate system prior to decay.

The cross sections for fission-like fragments exceed considerably the values predicted by the rotating liquid-drop model[2]). In order to reproduce the experimental fusion-fission excitation function in the trajectory calculations, it is necessary to modify the sudden-interaction proximity potential[3]) at close distances. This derived effective potential, when used in connection with the proximity dissipation function, also gives a good fit to the experimentally deduced deflection function for the damped reaction products from the same reaction.

[†]Work supported by the U.S. Department of Energy.

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FRAGMENT CORRELATIONS IN RELATIVISTIC NUCLEAR COLLISIONS[†]

A. Baden, M. S. Freedman, H. Gutbrod, D. J. Henderson,
V. Karadjev, S. B. Kaufman, M. Maier, V. Manko,
J. Petér, W. G. Meyer, H. G. Ritter,
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The masses, kinetic energies, and angular correlation of coincident heavy ($A \geq 12$) fragments emitted in the reactions of 4.9-GeV protons and 40-GeV ^{20}Ne with ^{197}Au have been measured. Masses are determined by a time-of-flight measurement, and the fragments are detected in two arrays of surface-barrier Si detectors. A 12-detector array is centered at 90° to the beam direction and covers an angular range of 15°, while a moveable 16-detector array, covering an angular range of 25°, is on the opposite side of the scatter chamber. The total range of correlation angles between detector pairs is 140°-195° in the reaction plane and 0°-15° out of plane. An array of 80 plastic scintillators outside the scatter chamber gives information on the multiplicity of light, energetic charged particles emitted in each event.

Preliminary results for both projectiles, based on a sample size of about 2000 events, are: (1) The sum of the observed fragment masses, $M = M_1 + M_2$, varies in individual events from $M \sim 25$ up to the target mass. There is a peak at $M \sim 175$ due to fission of near-target residues and a nearly flat distribution below that. (2) The angular correlation of fission events shows a fairly sharp peak centered at a correlation angle of ~177°, indicating little momentum transfer from the projectile to the target. A broader distribution is observed for fragment pairs with $100 < M < 160$, centered at ~175°, while the distribution for $M < 100$ is flat between 140° and 195°. (3) The mean observed multiplicity in the plastic scintillators increases with decreasing M for ^{20}Ne projectiles and is 2-4 times larger than that observed for protons, which is nearly independent of M over the mass range 25-160.

[†]Work performed under the auspices of the Office of Basic Energy Sciences, Division of Nuclear Sciences, U. S. Department of Energy, and the Bundesministerium für Forschung und Technologie, West Germany.

INCOMPLETE FUSION CROSS SECTION IN $^{14}N(100) + ^{27}Al$: EVIDENCE FOR A PREEQUILIBRIUM COMPONENT

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Experimental results have been described in another publication [1]. Angular distributions (θ and φ) and energy spectra for H and He nuclei measured in coincidence with evaporation residues have been obtained.

A multistep Monte-Carlo simulation (evaporation + kinematics) was performed using a program written by J. Cole [2]. Different pieces of information to be compared with experimental data are listed below :

a) yield distribution for the different elements
+ H and He particles multiplicities

b) in plane distribution for particles and evaporation residues
+ out of plane distribution for particle emission

c) energy spectra for H and He particles as well as for the evaporation residues.

Such comparison must be very fruitful for the understanding of the equilibrium as well as the preequilibrium components in E.R. cross section.

Analysis of the angular correlations between He, H and E.R. shows a overall agreement. In opposite when loocking to the φ distribution of He spectrum at forward angle in coincidence with E.R. the interpretation was not so good.

A preequilibrium analysis [3] modified for complex configuration has been shown to be useful to fit the data. We have here, and more effectively at higher incident energies, an unique situation to test the validity of the pre-emission of light particles from complex configuration. Such possibility have to be taken into account in the fast dissipative mode during the collisions of heavy ions. In the same way it has to be considered in the fusion cross section predictions. The full analysis (table I) leads to the presence of 17 ± 4 % of incomplete fusion in coincidence with fast He within the E.R.

Table 1

Evaporation Residues : 830 ± 80 en mb		
He in coinc. with E.R.	1030 ± 300	140 ± 30
H in coinc. with E.R.	1420 ± 200	< 20
	Evaporative	"Direct"

1 R. Billerey et al., Z. Physik, A 292, (1979), 293
2 J. Cole, Rapport Interne, I.S.N. Grenoble, No 7914
3 M. Blann, Nucl. Phys., A 213, (1973), 570

INCLUSIVE NEUTRON PRODUCTION BY RELATIVISTIC HEAVY IONS ON URANIUM*

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We measured inclusive double-differential cross sections for neutron production by ∿ 400 MeV/A heavy ions on uranium. Neutrons were detected with energies between ∿ 15 and ∿ 600 MeV. For incident neon, measurements were made at laboratory angles of 30^{o}, 45^{o}, 60^{o}, and 90^{o}. Data for incident helium and carbon ions were obtained at 0^{o}, 10^{o}, 30^{o}, 45^{o}, and 135^{o}. These data were not corrected by an experimental measurement of the target-dependent background (shadow bar); however, the use of a different beam stop, with a larger aperture, was used to reduce this background to where it contributes an estimated systematic uncertainty of less than 20%. The results are consistent with an isotropic target-evaporation component at low neutron energies; above ∿ 30 MeV, the angular distributions become forward peaked with increasing neutron energy. The lighter projectiles show similar features at low and high neutron energies, but the cross sections for incident helium are a factor of ∿ 2 lower than those for incident neon at neutron energies between ∿ 50 and ∿ 150 MeV. The data are compared to predictions of a thermal model.

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MUTUAL EXCITATION FOR TWO COLLIDING NUCLEI

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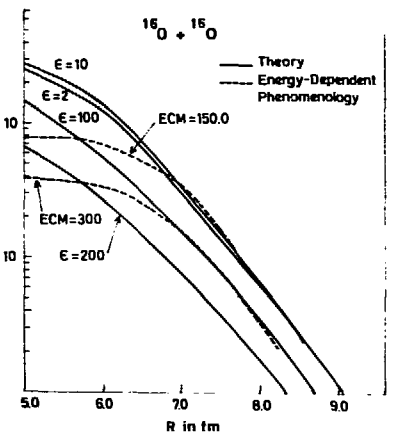
For two colliding nuclei at medium energy (10-100 MeV/A) the second order term has been evaluated when 1p-1h states are excited in each of the two nuclei. Microscopically, the physical situation corresponds to two-body excitations, initiated by collisions between target and projectile nucleons. Assuming typical intermediate states of a constant energy, the second-order term has been computed using a suitable "closure" approximation[1]. The two-body force has both the central and the tensor compound as prescribed by Bertsch et al[2]. The theoretical prediction for the imaginary potential seems to agree rather well with the energy dependent "shallow" phenomenological potentials for $^{16}O + ^{16}O$ elastic scattering, fig.1. The polarization term can be non negligible around the touching radius.

An approximate proximity type of expression has been derived for the imaginary potential given by

$$W = C_a(K)\frac{R_1R_2}{R}\left[\epsilon_0(s_0) + \frac{1}{2}\frac{R_1+R_2}{R_1R_2}\epsilon_1(s_0)\right]$$

where $\epsilon_n(s_0)$ is an universal of the separation distance $S_0 = R - R_1 - R_2$

a, the range parameter for the Gaussian two-body interaction $v_0 e^{-ar^2}$. In the entrance phase, the damping coefficient for deep inelastic scattering between two nuclei has been estimated using the above mentioned proximity function—interestingly enough, the two-body proximity collision function agree remarkably well with the microscopic proximity function described above.



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LIGHT PARTICLE HEAVY ION ANGULAR CORRELATIONS OBSERVED IN THE $^{40}Ca+^{40}Ca$ REACTION AT 400 MeV

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Recently, evidence was presented[1]) for the observation of structures at high excitation energies in the energy spectra of fragments emitted in the $^{40}Ca+^{40}Ca$ reaction. To get a deeper insight into the excitation process of these structures, we measured light charged particles in coincidence with fragments from the same reaction. The experiment was performed with the 400 MeV ^{40}Ca beam from the ALICE accelerator at Orsay. Heavy fragments were identified at $\theta_{lab}=10°$ close to the grazing angle in a standard E.ΔE solid state telescope. Coincident light charged particles -LCP- (protons, deuterons, tritons and alphas) were detected in the angular range of $-60°<\theta_{LCP}<+60°$ in the two large area position sensitive detectors subtending 10° in the reaction plane. Fig.1 shows the energy spectrum for the Ca fragments measured in coincidence with protons detected at $\theta_{LPC}\simeq -11°$ where the negative sign is used to indicate angles on the opposite side of the beam from the heavy ion. The first striking result is the selective population of the structures when observed in coincidence with protons. Apart from protons, no other light charged particle contribution is observed in coincidence with the incompletely relaxed part of the spectrum. The angular correlation for an energy range of $20\leq|Q|\leq 50$ MeV exhibits a strong focusing at small negative angles. The width of the correlation is $\Delta\theta_{FWHM}\sim 30°$. The proton energy spectra exhibits a component with a velocity comparable to that of the beam. These features provide evidence for a very fast mechanism, whereas the contribution of light particle evaporation is very small. In addition, the fact that such a fast component is also observed in the deep inelastic channel suggests an emission of protons at a very early stage in the collision.

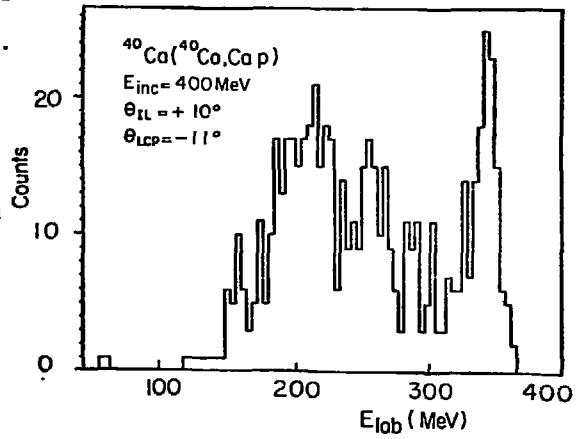


Fig.1. Energy spectrum of Ca fragments in coincidence with protons.

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[1]) N.Frascaria et al., Z. Physik A924 (1980) 167.

QUARK STRUCTURE OF HADRONS AND THE INCLUSIVE SPECTRA IN HIGH ENERGY HEAVY-ION SCATTERING

Bikash Sinha

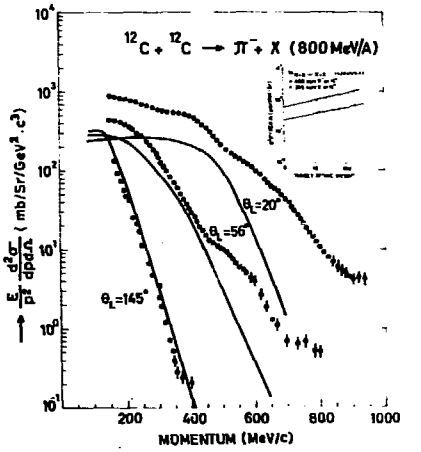
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As per contemporary wisdom, the static properties of hadrons can be conveniently described in terms of quasi-free, spatially discrete, non-relativistic constituent quarks. The inclusive spectra of pions[1,2] for high-energy heavy ion scattering is analysed by using a simple geometrical model where only the non interacting constituent quarks pick up an antiquark from the sea to form a pion at a specified value of the universal scaling variable x. For two colliding nuclei, the probabilities that one, two or three constituent quarks of a nucleon in the projectile (say A_1) interact inelastically with the target nucleus(say A_2) are calculated in terms of the integrals over the impact parameters

$$V_n^{A_1}(A_2) = \binom{3}{n} \left(\sigma_{qp}^{A_1A_2}\right) \int d\vec{b}\, e^{-(3-n)\sigma_q \tilde{T}(b)} \left[1 - e^{-\sigma_q \tilde{T}(b)}\right]^n$$

where n = 1,2,3 correspond to the number of interacting or absorbed quarks and the cross-section $\sigma_{qp}^{A_1A_2}$ can be obtained from the normalisation condition; the quark nucleon cross-section σ_q is assumed to be one third of the total inelastic N-N cross-section, whereas $\tilde{T}(b)$ is the usual profile function.

The inclusive cross-section for pi production is



scaled in terms of proton nucleus data using the above mentioned probability functions.

The forward angle high energy data was not reproduced too well in this analysis, (fig.1) but for the backward angle, the spectra was predicted reasonably accurately. Nuclear effects such as Fermi motion, rescattering etc, not included in this model are important for forward scattering data. The $A^{1/3}$dependence predicted in this model agrees with the Princeton data. Universal functional forms for the inclusive spectra in terms of A_1 and A_2 are also derived.

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HIGH EXCITATION ENERGY STRUCTURES OBSERVED IN THE ASYMMETRIC SYSTEMS $^{36}Ar + ^{58}Ni$ AND $^{36}Ar + ^{208}Pb$ AT 10 MeV/A

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Two interpretations were proposed for the observation of structures in the energy spectra of several heavy ion collisions with symmetric entrance channels[1] : either the excitation of collective modes such as giant resonances or effects resulting from statistical decay processes. The excitation energy dependence of these structures for different reactions would help to clarify the experimental situation.

The experiment was performed with 1.5 MeV overall energy resolution by bombarding ^{58}Ni and ^{208}Pb targets with the ^{36}Ar beam from the VICKSI cyclotron of the HMI at Berlin. The mass identification was achieved by a time of flight measurement associated with E . ΔE telescope. Data were taken with that system at angles close to the grazing angle ($\theta_{lab} = 9^0$ and $\theta_{lab} = 20^0$ for Ni and Pb targets respectively) and simultaneously with a standard E.ΔE solide state telescope for a larger angular range.

The observed spectra (see fig. 1) exhibit pronounced structures in the continuum region. These structures are only observed for the inelastic and the few nucleons transfer channels. Therefore these preliminary results indicate that structures are also observed in very asymmetric reactions.

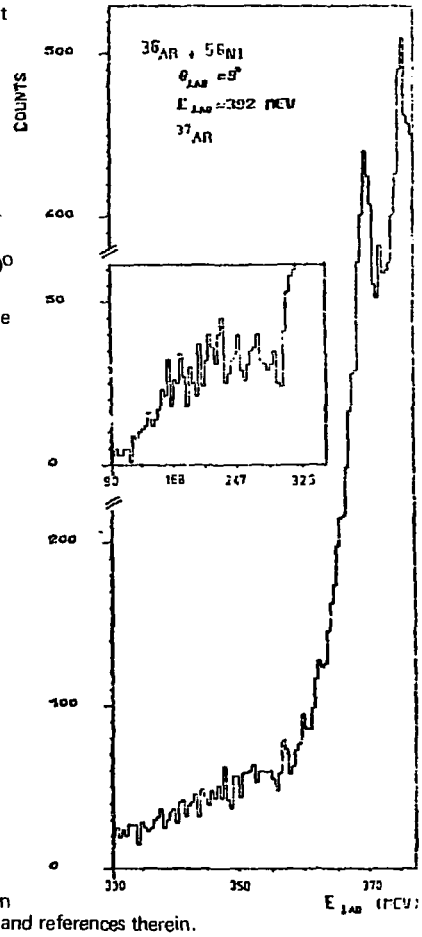


Fig. 1 : Lab energy spectrum for ^{37}Ar produced at $\theta_{lab} = 9^0$ in the $^{36}_{18}Ar + ^{58}_{28}Ni$ reaction at 392 MeV. The inset represents the deep inelastic region of the spectrum while the main figure displays the quasi elastic region of the same spectrum .

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1) N. Frascaria et al., Z. Physik A294 (1980) 167 and references therein.

A DESCRIPTION OF HEAVY-ION COLLISIONS FROM FEYNMAN PATH INTEGRAL METHOD

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Suppose, the relative and intrinsic motions are represented by Q(t) and q(t) respectively, and the coupling between them is $\hat{V}(Q,P,q)$, P is the conjugate momentum of Q. The intrinsic state $\chi_f(q_t)$ can be related to the initial state $\chi(q_0)$ in the following form, by applying the propagator resulted from the Feynman path integral (FPI).

$$\chi_f(q_t)=\int\{\int exp\frac{i}{\hbar}[S(q)-\int_0^t\hat{V}(Q,P,q)\,dt]\,\mathcal{D}q(t)\}\,\chi(q_0)\,dq_0 \qquad (1)$$

Where $S(q)$ is the intrinsic action. Following [1], we calculate $\langle\hat{V}\rangle=\int\chi_f^*(q_t)\hat{V}(Q,P,q)\chi(q_0)dq_0$ under weak coupling assumption. Thus, from the exchange of energy between Q(t) and q(t), we obtain the friction coefficient:

$$\gamma_{kl}=-\sum_{\mu\nu}\sum_{ij}\rho_{ii}\,\nabla_{Q_k}(\hat{V}_\mu)_{ij}\,\nabla_{Q_l}(\hat{V}_\nu)_{ji}\,B(t_2,t_1) \qquad (2)$$

Where ρ_{ii} is the initial density matrix, $B(t_2,t_1)$ is time integral, and μ, ν, k and l represent the cartesian coordinates.

Following [1], using FPI method we obtain Schrodinger-eq. in Q. Suppose $\psi=exp(R+iS)$ from Schrodinger-eq. we obtain two eqs. One of them is interpreted as the Hamilton-Jacobi eq. for action $S=\hbar\bar{S}$. Taking its derivative with respect to Q. the eq. of motion of Q can be written by

$$M\frac{d^2Q_k}{dt^2}=-\nabla_{Q_k}\hat{U}(Q)+\sum_l\gamma_{kl}\dot{Q}_l-\hat{\delta}_k(Q)-\hat{\lambda}_k(Q)+\sum_l\Gamma_{kl}\dot{P}_l+\frac{1}{2}\nabla_{Q_k}\sum_{\mu\nu}M_{\mu\nu}\mu_\nu \qquad (3)$$

The first term is the external force, the second is the friction force, the third and fourth are forces resulted from the coupling, and they depend on the intrinsic transition $i\to i$ and $i\to f$ respectively, the fifth results from the P dependence of the coupling, and so on.

Taking $\rho=\psi^*\psi$, from another eq. we obtain a smoluchowski-like eq.

$$\frac{\partial\rho}{\partial t}=D\sum_k\frac{\partial^2}{\partial Q_k^2}\rho-\sum_k\frac{\partial}{\partial Q_k}[U_k\rho]-\sum_k\frac{\partial}{\partial Q_k}[B_k\rho]+\sum_k\frac{\partial}{\partial Q_k}[\lambda_k\rho]$$
$$+\sum_l\frac{\partial}{\partial Q_k}[R_l\rho]-\sum_{kl}\frac{\partial}{\partial Q_k}[\Gamma_{kl}\dot{Q}_l\rho]-\sum_{kl}\frac{\partial}{\partial Q_k}[\gamma_{kl}\dot{P}\rho] \qquad (4)$$

The first term is the diffusion of the system Q, the second to the fourth are the drift resulted from the coupling, they in turn depend on the intrinsic transition $o\to o$, $i\to i$ and $i\to f$, the sixth is the drift of the energy dissipation, the last term results from the P dependence of the coupling.

In this work, we show that the FPI is a very useful method for describing the heavy-ion collisions.

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NONEQUILIBRIUM NEUTRON EMISSION IN ^{12}C AND ^{13}C INDUCED FUSION REACTIONS*

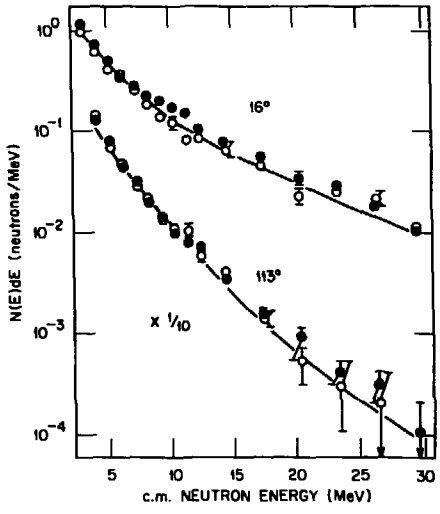
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Nonequilibrium neutron emission has been observed in ^{12}C induced fusion reactions on ^{158}Gd at 152 MeV.[1] The existence of energetic neutrons in this reaction coincides with the depletion of high gamma multiplicities, indicating the peripheral nature of this emission. The purpose of this experiment is to determine the effect of the neutron binding energy in the projectile on the number of nonequilibrium neutrons emitted. Neutron spectra obtained in coincidence with fusion fragments for 150-MeV ^{12}C fusion (circles) and 160-MeV ^{13}C fusion (full points) leading to the same ^{170}Yb compound nucleus are presented in Fig. 1. Two angles of neutron detection are shown - 16° and 113°. There is no significant difference between the neutron spectra for the two projectiles. The full line is the result of a chi-square minimization fit to the spectra at four angles assuming two sources: (1) an evaporation (Maxwellian) spectrum moving with the C.N. velocity; (2) an additional component emitting a Maxwellian-shaped spectrum isotropically from a moving source with a temperature and velocity determined by minimizing chi-square. A good fit is obtained if we assume that, in addition to the evaporation spectrum (T = 1.6 MeV), 20% of the neutrons are emitted isotropically from a source moving at 1.6 cm/nsec (∿ 1/3 of the beam velocity) with a temperature of 4 MeV. The overall good quality of the fit suggests neutron emission while the projectile is decelerating although the binding energy of the neutron in the projectile does not play any role at this energy.



*This work is supported by the Division of High Energy and Nuclear Physics, Office of Energy Research, U. S. Department of Energy, under contract W-7405-eng-26, with the Union Carbide Corporation.

[1] L. Westerberg et al., Phys. Rev. C 18, (1978) 796.

HEAVY ION-ALPHA CORRELATIONS IN DEEPLY INELASTIC COLLISIONS OF 204-MeV ^{16}O WITH ^{93}Nb*

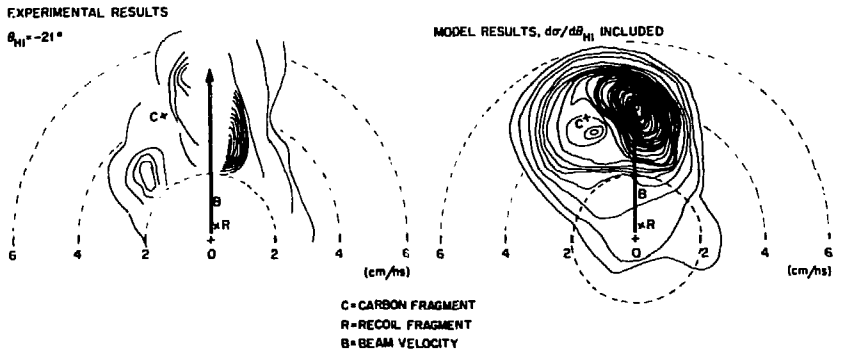
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Measurements of correlations between projectile-like fragments (PLF) and alphas emitted in deeply inelastic collisions (DIC) at bombarding energies of 6-20 MeV/nucleon exhibit angular correlations that are strongly forward-peaked and not symmetric around the direction of either of the DIC fragments. Most of these correlations have been interpreted as arising from nonequilibrium α-emission. We have measured alpha particles coincident with PLF from DIC of 204-MeV ^{16}O with ^{93}Nb. On the basis of earlier results, nonequilibrium α-emission was expected to account for a large fraction of all observed alphas.

Heavy ions were detected in gas ionization ΔE-E telescopes at -12° and -21°, and coincident alpha particles were detected in silicon surface barrier telescopes positioned at several angles in and out of the reaction plane. The results, for carbon-α coincidences at $\theta_{HI} = -21°$, integrated over the energy of the deeply inelastic 'bump,', are presented on the left side of Fig. 1 in terms of a Galilean invariant multiplicity $dM_\alpha/dv^3d\Omega_{HI}$. A strong clustering of strength near the beam axis is seen, with a much weaker clustering near $\theta = -45°$, as was noted in previous works. The right side of Fig. 1 presents results of a Monte Carlo simulation of α evaporation from excited ^{16}O and ^{93}Nb nuclei. Included in the simulation were (1) average n, p and α energy spectra and multiplicities determined with a Monte Carlo evaporation code, and (2) TKE, mass and angular distributions of PLF determined from a singles measurement. From Fig. 1, it follows that the calculations reproduce the main features of the experimental spectra. This indicates that it is not necessary to include nonequilibrium α-emission to account for the present results.



*This work supported by the Division of High Energy and Nuclear Physics, Office of Energy Research, U. S. Department of Energy, for the Union Carbide Corporation.

DOUBLE-FOLDING MODEL FOR LI + LI SCATTERING†

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Optical-model potentials calculated from the double-folding model can reproduce the observed elastic scattering for a large number of systems. However, the potential that reproduces ^{6}Li scattering from heavier nuclei is only about 60% as deep as the folded potential. Satchler and Love[1]) have surmised that the discrepancy is caused by the breakup ^{6}Li → α + d. The work described below confirms this surmise.

Elastic-scattering angular distributions for ^{6}Li + ^{6}Li and ^{7}Li + ^{7}Li were measured for E_b = 2.0 to 5.5 MeV. The folded potential provides a good fit to the data for ^{7}Li + ^{7}Li for the entire energy range and for ^{6}Li + ^{6}Li for energies low enough so that the breakup can not occur (E_b = 2.94 MeV). At higher energies, the real part of the potential falls off rapidly with energy so that by 5.5 MeV, the potential is only 36% as deep as is predicted by the folding model. By using the same nucleus for both the beam and target, the peculiarities caused by Li are enhanced. The ^{7}Li + ^{7}Li system shows that the folding model works well even at these low energies.

The folding model predicts the real part of the potential with no arbitrary parameters. The depth of the potential at the center is 70 MeV for ^{6}Li + ^{6}Li and about 90 MeV for ^{7}Li + ^{7}Li. The imaginary part of the potential was assumed to have the same shape but was multiplied by an overall scale factor. The calculation of the folded potential was made faster and more accurate by evaluating the various integrals analytically rather than numerically[2]).

The Li + Li potentials show discrete ambiguities. Real potentials both larger and smaller than the folded potentials can be found that fit the data. Above E_b = 3.0 MeV, ^{6}Li + ^{6}Li is exceptional in that really good fits can not be obtained for deeper potentials although moderately good fits can be obtained for almost any real potential if the shape and magnitude of the imaginary part of the potential is suitably chosen.

The ^{6}Li + ^{6}Li potential was tested in a DWBA calculation for the 2 ^{6}Li → 3 α reaction that was previously[3]) found to be particularly sensitive to the elastic-scattering potential. The folded potential gave an excellent fit to available data[4]) at 2.0 MeV, while other potentials that provided equally good fits to the elastic scattering data gave poorer fits to the reaction data.

†This work was supported in part by the U. S. Department of Energy.

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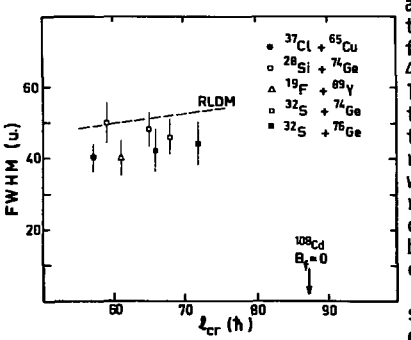
FISSION-LIKE PROCESSES AROUND $A_{CN} = 100$

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Studies of fission-like fragments resulting from decay of composite systems with mass around 100 u are scarce. Recent measurements [1] have shown a strong change from asymmetry to symmetry in the mass distributions of the relaxed fragments from systems with $91 \leq A_{CN} \leq 121$. Entrance channel effects have also been observed [2] in the decay of ^{102}Pd formed in the ^{28}Si + ^{74}Ge and ^{37}Cl + ^{65}Cu reactions. These results imply that the compound nucleus formation is questionable. We have further investigated the dependencies of entrance channel, excitation energy E* of the fused system, and angular momentum brought by the projectile for the ^{108}Cd composite nucleus. It was formed at various critical angular momenta ℓ_{cr} and divers E* in the two reactions ^{19}F + ^{89}Y (E_{inc} = 140 MeV) and ^{32}S + ^{76}Ge (E_{inc} = 158 and 178 MeV). The fragments were detected with a time of flight set-up and the results have been compared to those relating to the ^{102}Pd and ^{106}Cd composite systems [2,1].

The data present the following characteristics, in agreement with the fission picture : the $d^2\sigma/d\theta dA$ versus A distributions measured at various angles show no angular dependence in the c.m. Their FWHM presented in the figure are on the average equal to 45 ± 5 u in accordance with the rotating liquid drop model predictions (RLDM) ; they increase slowly with the ℓ_{cr} of the fused system and its nuclear temperature. The TKE of the fragments agree with the Coulomb repulsion between 2 rotating spherical nuclei. The fission cross sections are correctly reproduced by Hauser-Feshbach statistical decay calculations like GROGI-F.



However, conflicting with the fission deexcitation picture, the shapes of the $d^2\sigma/d\theta dA$ show for a given system a dependence on the entrance channel.

D.I.C. contributions have been examined and mass diffusion calculations [3], including shell and pairing effects, and variable drift coefficients with the number of transferred nucleons, have been performed leading to satisfactory agreement with experimental results. A mechanism [4] intermediate in time between D.I.C. and fission can be considered although the systems under study have $\ell_{cr} < \ell_{B_f} = 0$.

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FURTHER EVIDENCE FOR EQUILIBRIUM IN DEEPLY INELASTIC HEAVY ION COLLISIONS†

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Measurements of angular momentum transfer as a function of Q-value can be shown to be consistent with the establishment of equilibrum during deeply inelastic collisions. This is not immediately apparent if one plots the transferred angular momentum versus the initial orbital angular momentum (deduced by a model from the Q-value). The evidence for equilibrium comes, however, by comparing the observed transfer with predictions based on the density of states for a fixed value of kinetic energy loss, as required by experiments.

The density of states is developed from the conservation of energy and angular momentum, and the microscopic densities for the two fragments (1 and 2):

$$\rho(E_i-E_f,\vec{\ell}_i-\vec{\ell}_f,E_1,\vec{J}_1,E_2\vec{J}_2) \propto \delta(E_i-E_f-E_1-E_2)\delta^3(\vec{\ell}_i-\vec{\ell}_f-\vec{J}_1-\vec{J}_2)\rho(E_1,\vec{J}_1)\rho(E_2,\vec{J}_2).$$

We have used Fermi gas forms for the individual fragment densities:

$$\rho(E_i,\vec{J}_i) \propto \exp(2(a_i(E_i-\frac{\hbar^2}{2I_i}J_i^2))^{\frac{1}{2}}) \ ,$$

with I_i the momentum of inertial characterizing the Yrast line, and a_i the density constant. With this density we find the expectation value of $\vec{\ell}_i-\vec{\ell}_f$, with energy loss, E_L, fixed, to be:

$$\langle\vec{\ell}_i-\vec{\ell}_f\rangle_{E_L} = \frac{2}{\sqrt{\pi}}\sqrt{\frac{2(I_1+I_2)}{\hbar^2}}\ \frac{E_L^{\frac{1}{4}}}{(a_1+a_2)^{\frac{1}{4}}} \ .$$

The same density used to calculate the expectation value of $\ell_i-\ell_f$ with ℓ_i fixed provides:

$$\langle\ell_i-\ell_f\rangle_{\ell_i} = \left(\frac{I_1+I_2}{I_1+I_2+\mu R_f^2}\right)_{av}\ell_i \ ,$$

where the additional average is over the variable R_f, characterizing the radius from which the fragments separate at the end of the reaction. This is essentially the "sticking" prediction.

The experimental results demand comparison with the predictions for $_2E_L$ fixed. For this, numerical evaluation with $a_i = A/9$ and $I_i = 2/5mA_i^{5/3}(1.4)^2$ leads to excellent agreement with both average γ-multiplicities and standard deviations for the multiplicities, when a reasonable model for the average multipolarity of γ-rays is used. Predictions based on the density of states also gives excellent agreement for the observed J of the heavy fragment in sequential fission experiments as well as for the alignment P_{zz}.

The above agreement may be taken as evidence for the establishment of equilibrium. Furthermore, the approach allows a simple way of understanding the experimental results without need for detailed models.

†This work was supported in part by the U. S. National Science Foundation.

INCOMPLETE FUSION IN $^{14}N+^{159}Tb$ COLLISIONS: LINKS TO ORDINARY ℓ-MATCHED BINARY REACTIONS.

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Our previous study of incomplete fusion reactions in the $^{12}C+^{160}Gd$ system lead us to interpretation of these reactions in terms of a generalized concept of critical angular momentum[1]. A model based on this concept predicts localization of different incomplete fusion channels in a sequence of "ℓ-windows" above the critical angular momentum for complete fusion. Such interpretation of the incomplete fusion reactions makes no essential difference between the incomplete fusion reactions (called also "massive transfer reactions") and a wider class of those binary reactions which satisfy approximately the ℓ-matching condition.

We perfomed an experiment aimed to measure absolute cross sections for many binary reaction channels in collisions of ^{159}Tb with ^{140}MeV ^{14}N ions. The binary reactions were selected by taking coincidences between specific γ-rays from the target residue nuclei and the complementary light products detected and identified with a solide-state detector ΔE-E telescope. To obtain an over view of all the processes involved the γ-particle coincidence measurements were combined with inclusive detection of charged particles, γ-multiplicity measurements (in coincidence with charged particles) and particle-particle coincidence measurements[2].

The absolute cross sections were obtained for the following reactions: $^{159}Tb(^{14}N,\alpha)Yb$, $^{159}Tb(^{14}N,^{6}He)Yb$, $^{159}Tb(^{14}N,2\alpha)Er$, $^{159}Tb(^{14}N,^{9}Be)Er$, $^{159}Tb(^{14}N,^{10}Be)Er$, $^{159}Tb(^{14}N,^{10}B)Ho$, $^{159}Tb(^{14}N,^{11}B)Ho$, $^{159}Tb(^{14}N,^{12}B)Ho$, $^{159}Tb(^{14}N,^{12}C)Dy$, $^{159}Tb(^{14}N,3\alpha)Dy$, $^{159}Tb(^{14}N,^{13}C)Dy$, $^{159}Tb(^{14}N,^{14}C)Dy$ and $^{159}Tb(^{14}N,^{15,16}O)Gd$. The data were analized in terms of a "sum-rule" model which is an extension of the model of ref. 1. It is assumed in this model that reaction probabilities are scaled by the available phase space. (The Qgg-dependence of the reaction probabilities was assumed for all reactions proceeding via stage of the partially equilibrated di-nuclear system.) Additionally, angular momentum limitations of ref. 1 are supposed to constrain the reaction probabilities. With these assumptions a sum rule for reaction probabilities enables one to calculate absolute cross sections for complete fusion and all the incomplete fusion channels, as well as to predict localization of all these reactions in the ℓ-space. A good agreement between the model predictions and the experimental data was obtained.

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SEQUENTIAL BREAK-UP VS. FRAGMENTATION IN $^{14}N+^{159}Tb$ COLLISIONS AT 10 MeV/NUCLEON

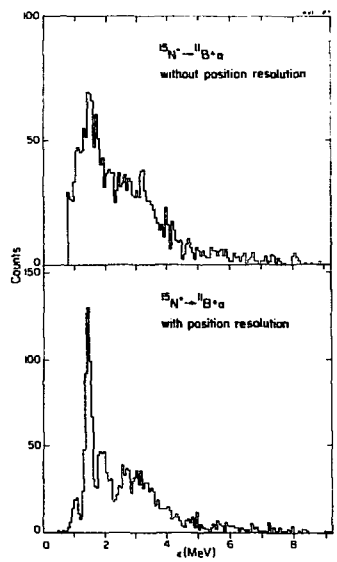
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The mechanism of the break-up of heavy ions in energetic nucleus-nucleus collisions is a subject of much current interest. An open question is what intermediate states are involved mostly in the break-up reactions. One of the possibilities is that the break-up proceeds via inelastic scattering or transfer to unbound states which subsequently decay by particle emission. Such a sequential break-up can be studied by accurately measuring the energies and relative emission angles of the two fragments.

The experiment was performed using a 140 MeV $^{14}N^{4+}$ beam from the KVI variable energy cyclotron. A 3 mg/cm^2 thick foil of metallic ^{159}Tb was used as target. Charged particles over the range $2 \leq Z \leq 7$ were detected and identified with two identical position-sensitive telescopes consisting of three solid-state detectors : 50 µm, 500 µm and 1500 µm thick, respectively. Depending on the range of a particle, the middle (position sensitive) detector could be used either as a ΔE-detector (together with the front one) or as an E-detector (together with the rear one).

As an example, the relative energy spectrum ($\varepsilon = E_x - Q$ (threshold)) for $^{11}B+\alpha$ coincidences ($\bar{\theta}_1 = 20^o$, $\bar{\theta}_2 = 30.5^o$) is shown on the lower part of the figure. Several α-decaying states in $^{15}N^*$ have been identified in this spectrum. The upper part of the figure illustrates the importance of a good angular resolution : the same coincidence data are plotted with the position of information ignored ($\beta = \bar{\theta}_2 - \bar{\theta}_1$).



In order to estimate relative contributions of the sequential break-up and other (uncorrelated) fragmentation processes particle-particle coincidences were measured for various angular configurations. For large relative angles the coincidence data are properly described by the "factorization prescription" suggested in ref. 1. On the other hand, for close angular configurations the sequential break-up dominates. Estimates of the angle-integrated cross sections show that 19±8 % of the total inclusive cross section for production of Lim Be and B isotopes can be attributed to sequential break-up processes, and 26±6 % comes from uncorrelated fragmentation events. The remaining part of the total inclusive cross section must be related to binary reactions which were studied seperately for the same $^{14}N+^{159}Tb$ system by using γ-particle coincidence technique[2].

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CORRELATED CHARGE AND MASS DISTRIBUTIONS IN THE EVAPORATION RESIDUE REGION FROM THE $^{20}Ne + ^{27}Al$ REACTION

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We have measured the energy and angular distributions of the products resulting from the reaction Ne + Al at 167 MeV and 118 MeV. The mass and charge of each product was determined by time-of-flight and by ΔE-E techniques. Even in the evaporation residue region, each isotope is well resolved for this system.

The results of our measurements are then compared with a modified version of the evaporation program[1] (JULIAN), which uses Monte-Carlo techniques to produce energy and angular distributions as well as total cross sections for each isotope. A comparison of our experiment data with the results of the calculations is shown in Fig. 1 for E (lab) = 118 MeV and in Fig. 2 for 167 MeV. In both cases we show Z- and A-distributions which have been integrated over energy, angle and summed over A in the upper part of the figures and over Z in the lower part.

As may be seen, the program underestimates the yield for larger Z and A values, particularly at the lower energy; however, the overall agreement is satisfactory considering the fact that no parameters were varied from the averages appropriate for this region and only evaporation from the compound system is considered. Other reaction channels such as deep inelastic scattering and incomplete fusion must be considered in addition to the evaporation process in order to obtain a complete picture of the reaction mechanism. In particular, the discrepancy between experiment and calculation for low values of Z and A at 167 MeV may be explained by incomplete fusion.[2]

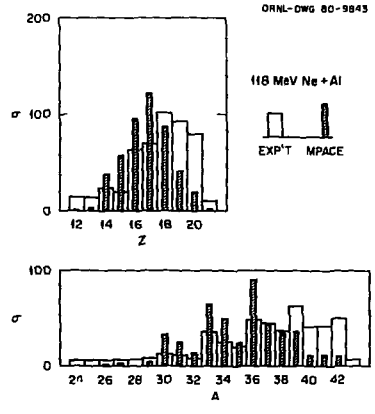


Fig. 1

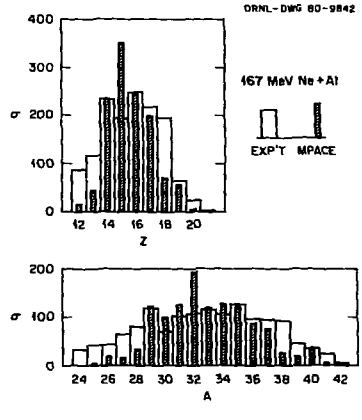


Fig. 2

*This work is supported by the Division of High Energy and Nuclear Physics, Office of Energy Research, U. S. Department of Energy, under contract W-7405-eng-26, with the Union Carbide Corporation.

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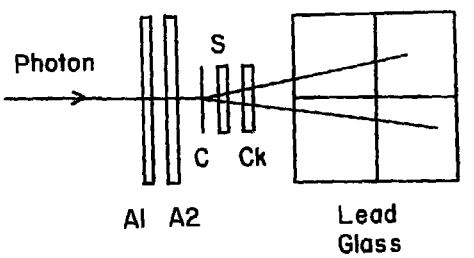
EMISSION OF HIGH-ENERGY GAMMA-RAYS FROM 1.8 GeV/amu ^{40}Ar + ^{208}Pb[†]

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There are several possible sources of high-energy (E > 10 MeV) gamma-rays from relativistic, heavy-ion collisions; very little is known about their relative production rates. We are particularly interested in the following sources: 1) Bremsstrahlung. Our calculations indicate that the amount of bremsstrahlung emitted is a sensitive function of the dynamics of the collision. 2) Photons from π^o decay. This is the main source of photons in the energy range of interest. 3) $\Delta(1236)$ decay. This resonance decays via Nγ about 0.6% of the time. The resulting photons, peaked around 260 MeV, may be visible above the background produced by π^o decays.

A schematic diagram of our detector is shown. By using state-of-the-art phototubes with high quantum efficiency and excellent light collection, we expect to achieve good energy resolution. Tests using cosmic-ray muons suggest that a photon energy resolution of ~20% (FWHM) at 100 MeV is possible. The problem of neutron rejection was given special consideration in the design. A photon from a collision first passes through A1 and A2, which are anti-coincidence scintillator paddles to reject charged particles. The photon then interacts in converter C, a thin lead sheet, to produce an electron-positron pair. The electron and positron produce signals in S, a scintillator, and Ck, a plastic Cerenkov detector, and then deposit their energy in approximately 13 radiation lengths of lead glass. Neutron rejection is provided by analyzing the signals in S and Ck: in order to accept an event we require signals in these detectors that correspond to two relativistic, singly-charged particles. Analysis of the shower development in the lead-glass blocks may provide further neutron rejection. Not shown are the target, and two detectors in the beam path that form a central-collision trigger.



The experiment is scheduled to run at the Lawrence Berkeley Laboratory Bevalac facility around June. We will be measuring gamma-ray energy spectra at various angles, as well as performing a number of background checks. We expect to present preliminary results at the conference.

[†]This work is supported by the Nuclear Science Division of the U.S. Department of Energy.

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CHARGE AND MASS EXCHANGE IN ^{56}Fe-INDUCED REACTIONS*

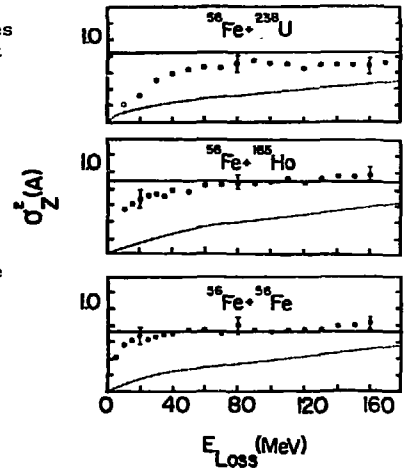
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Projectile-like fragments have been measured with discrete A and Z resolution as a function of energy loss (E_{LOSS}) for both symmetric and asymmetric systems with varying A/Z ratios. Monoisotopic targets of ^{56}Fe, ^{165}Ho, ^{209}Bi and ^{238}U were bombarded with 465 MeV ^{56}Fe ions from the LBL Super-HILAC accelerator. The measured energies were transformed into primary yields and center-of-mass energies by an iterative event-by-event procedure. Inclusive charge and mass distributions show that, for the asymmetric systems, a drift in the $\bar{Z}$ towards smaller atomic numbers can be attributed to a charge equilibration process in which protons are preferentially transferred from the Fe-like fragments to the heavy partner.[1] $\bar{A}/\bar{Z}$ increases smoothly with E_{LOSS} over a range of more than 100 MeV towards the A/Z value of the combined system. The variances of the charge and mass distributions indicate that the relationship between σ_A^2 and σ_Z^2 is intermediate between correlated and uncorrelated neutron-proton exchange for the partially damped events. However, with increasing E_{LOSS} all systems evolve toward correlated exchange.

The variances of charge distributions for fixed mass asymmetry have recieved much attention recently.[2-4] Data for all our systems indicate that the σ_Z^2 vs E_{LOSS} curves are remarkably similar for all individual A. Averaged values for $\bar{A} \simeq 52$ to 57 (not corrected for particle emission) are shown in the figure for the ^{56}Fe + ^{56}Fe, ^{165}Ho, and ^{238}U reactions. All systems achieve a saturation value of $\sigma_Z^2 \simeq 0.8$. The transition region of increasing σ_Z^2 ranges from ~ 20 MeV in E_{LOSS} for the ^{56}Fe target to ~ 50 MeV for the ^{238}U target, which corresponds to ~ 10 MeV of excitation energy in the projectile like fragments for all systems. For comparison, the figure includes curves from calculations for statistical fluctuations[2], $\sigma_Z^2 = T/C$ (dashed-dotted lines), and for quantal fluctuations[2,4], $\sigma_Z^2 = \hbar\omega/2C$ (full lines), with $\hbar\omega$ of the isovector GDR, T the nuclear temperature, and C the stiffness coefficient from the liquid drop model.



*This work was supported in part by the National Science Foundation and the Department of Energy.

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STRUCTURE IN THE ^{56}Fe + ^{56}Fe REACTION*

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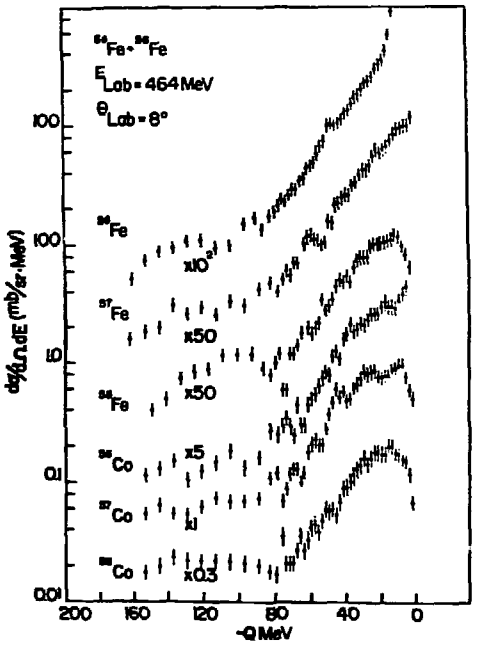
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The discovery of structure in the energy spectra of specific final fragments formed in damped collisions between symmetric target-projectile pairs has stimulated speculation concerning their origin.[1] We have studied the ^{56}Fe + ^{56}Fe reaction at 8.3 MeV/u at the Lawrence Berkeley Laboratory Super-HILAC. The figure shows the excitation energy spectra for the dominant reaction products with A ≥ 56 and Z ≥ 26, taken at 8° to the beam. Four peaks are clearly visible in the ^{57}Co spectrum, corresponding to total excitation energies of 10,22,44 and 58 MeV, prior to corrections for particle evaporation. Structure is also observed in other reaction channels, although not as prominant. It is difficult to obtain any systematic description of the structure in terms of Q values. However, the persistance of structure to excitation energies of ~60 MeV is an important feature.

In order to help explain the origin of this structure, we have examined the role of statistical evaporation processes following the production of the primary fragments, assuming their origin in nucleon-exchange processes.

Similar calculations of the ^{41}Ca energy spectrum in the ^{40}Ca + ^{40}Ca reaction have shown that it is possible to generate structure due to statistical processes.[2] However, it is difficult to reproduce the energy spectra of ^{57}Co and ^{58}Co with a consistent set of initial conditions. Moreover, calculations show that the opening of an increasing number of reaction channels with increasing excitation energy rapidly smooths out any structure due to individual decay channels, making it difficult to account for a peak at ~60 MeV of excitation with this mechanism.



*Research supported by the U. S. Department of Energy.
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††On leave from the Hahn-Meitner Institut, Berlin, West Germany.

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FUSION CROSS SECTIONS DERIVED FROM OPTICAL POTENTIALS+

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In recent years detailed studies of heavy ion elastic scattering and also fusion excitation functions have appeared in the literature. One interesting question which these data allow us to investigate is whether or not the optical potentials obtained from fits to elastic scattering are also capable of reproducing the measured σ_f values. In an attempt to answer this question, existing data have been utilized from the following systems: $^{16}O+^{12}C$, ^{27}Al, ^{28}Si, ^{40}Ca and $^{12}C + ^{28}Si$. The elastic data in each case have been fit with an optical potential having either a Woods-Saxon (WS) or a proximity form for the real part coupled with a WS imaginary part. A typical fit to high energy data for the $^{16}O+^{28}Si$ system is shown in fig. 1. For the systems studied, it is found that potentials which provide a good fit to the high energy data set predict about the same values for the position and height of the ℓ=0 fusion barrier, and that the data show sensitivity to the potential into separation distances well inside this radius. Thus, the high energy elastic scattering data are in fact measuring the interaction potential in just the radial region to which the fusion data are expected to be sensitive.

Fusion cross sections have been calculated with various friction-free models. The first involves a simple sharp cutoff (SCO) calculation in which $\sigma_f(E)=\pi\lambda^2(\ell_{cr}+1)^2$, where ℓ_{cr} is the highest partial wave for which the maximum in the real potential (nuclear + Coulomb + centrifugal) is below energy E. In addition, calculations including barrier penetrability have been performed using the Hill-Wheeler (HW) expression for passage through a parabolic barrier. For both calculations the barrier heights and positions were obtained from the appropriate optical potential. Shown in fig. 2 are the results of fusion calculations for the $^{16}O+^{28}Si$ system using the same WS potential as in fig. 1. Comparable results are obtained for the $^{16}O+^{27}Al$ and $^{16}O+^{40}Ca$ systems, but the results for the systems involving ^{12}C are less satisfactory.

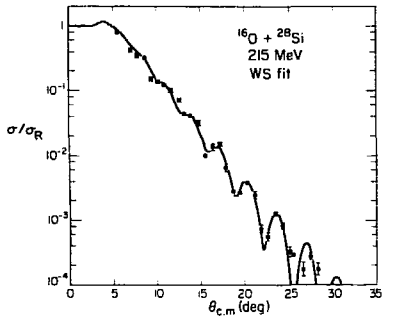


Fig. 1

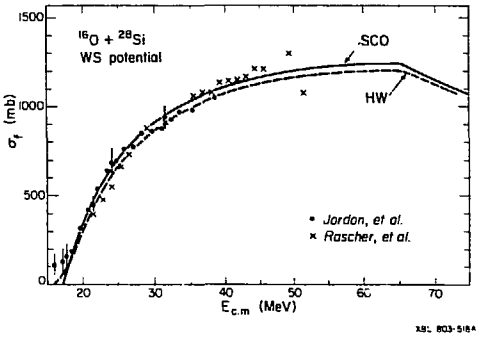


Fig. 2

+This work was supported by the Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Dept. of Energy.

SUB-BARRIER FUSION OF $^{58}Ni + {}^{58}Ni$, $^{58}Ni + {}^{64}Ni$ AND $^{64}Ni + {}^{64}Ni$[†]

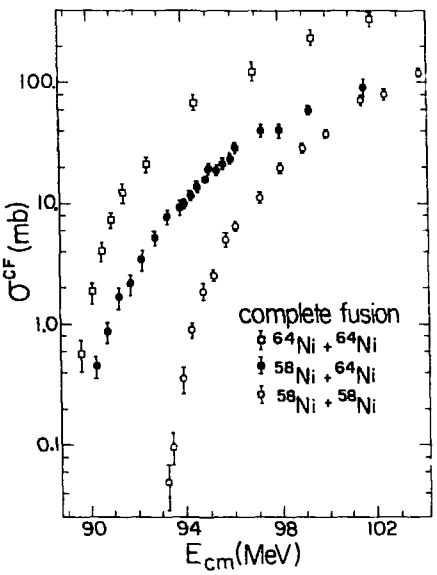
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In this work we determined $^{58}Ni + {}^{58}Ni$, $^{58}Ni + {}^{64}Ni$ and $^{64}Ni + {}^{64}Ni$ complete fusion excitation functions over a range of energies from just above to well below the fusion barrier. These Ni systems comprise a triad of massive, nearly closed-shell symmetric target-projectile combinations; the Ni isotopes have similar quadrupole deformation parameters and nuclear stiffnesses, and our objective in doing these measurements was to investigate the possible influence of valence neutrons upon the fusion process in general and upon barrier penetration in particular.

To determine the excitation functions we measured evaporation residue differential cross sections over angular ranges from 0 to 6° (lab) with high precision using the MIT-BNL velocity selector system together with a gas ΔE-E telescope. The fusion measurements were preceded by detailed calibrations of the detection system using elastically scattered ^{127}I ions of energies similar to those of the evaporation residues. The results are displayed in the figure with error bars which incorporate both systematic and statistical uncertainties; in most instances the statistical errors are comparable to or smaller than the squares and circles.

We find that there are substantially larger variations in shape and magnitude of the excitation functions than expected from either coulomb barrier considerations or liquid drop predictions. Perhaps the most interesting feature of these data is that the fusion barrier for $^{58}Ni + {}^{64}Ni$ appears to be more penetrable than that for $^{64}Ni + {}^{64}Ni$ or $^{58}Ni + {}^{58}Ni$ while the fusion of $^{58}Ni + {}^{64}Ni$ seems to be somewhat inhibited at higher energies. We interpret these data as providing evidence of a dynamic role in the fusion process of valence neutrons.



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COMPOSITE PARTICLE EMISSION IN HIGH ENERGY HEAVY ION COLLISIONS[†]

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H. Steiner, and I. Tanihata[†††]

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In collisions of C + C, Ne + NaF, Ar + KCl, C + Pb, Ne + Pb, and Ar + Pb at 400, 800, and 2100 MeV/nucleon incident energies, composite nuclear fragments (d, t, and ^{3}He) have been measured at laboratory angles from 10° to 145° for fragment energies up to 1.3 GeV/nucleon. Examples of inclusive spectra are shown in Fig. 1 where deuteron spectra observed in 800 MeV/nucleon Ar + KCl collisions are displayed by black circles. Open squares and diamonds shown in Fig. 1 are the spectra calculated by squaring the observed proton spectra in the same reaction. An excellent agreement between the deuteron and proton-squared spectra is observed.

In all the collisions studied, we observe that the following relation[1]) holds very well over a wide range of fragment momentum and angle:

$$E_A(d^3\sigma_A(P_A)/d^3P_A) = C\,(E_p d^3\sigma_p/d^3p_p)^A \qquad \text{with } P_A = A\,p_p\,, \qquad (1)$$

where A is the nucleon number of the composite particle (A = 2 for d and 3 for t and ^{3}He). The coefficient C is a constant which depends only on the beam energy, projectile mass, target mass, and the fragment type. The observed features of C are as follows:

1. C is almost independent of beam energies once projectile and target masses are fixed.
2. C is smaller for heavier mass system.
3. C is almost the same for t and ^{3}He.

According to Mekjian[2]) the coefficient C can be related to the volume of the participant piece through the relation, $C \propto (1/(\text{volume}))$. Under the assumption that the participant piece has a spherical shape, the radius R was evaluated from the observed valued of C. As shown in Fig. 2, the radius R is larger for heavier-mass system. The observed value of R = 3-4 fm is also comparable to that obtained in a pion interferrometry experiment[3]).

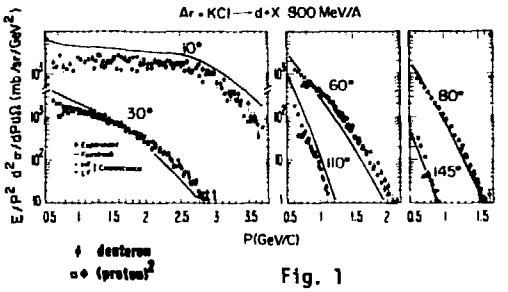


Fig. 1

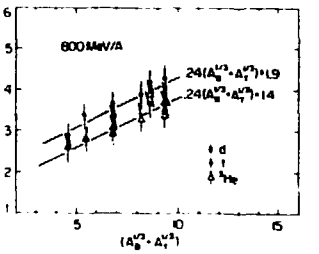


Fig. 2

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[†]Work supported by the Nuclear Science Division of the U.S. Department of Energy, the Yamada Foundation, and the INS-LBL Collaboration Program.

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CORRELATIONS BETWEEN LIGHT FRAGMENTS IN HIGH-ENERGY HEAVY-ION COLLISIONS†

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Two-particle correlations and the light-fragment spectra for high-multiplicity events (HME) have been measued in heavy-ion collisions at incident energies of 400 & 800 MeV/nucleon. A magnetic spectrometer was used to determine the Z, m, p, and angle of one particle, while the other particle(s) from the same event were detected by a set of 9 plastic counter telescopes placed at 40° with respect to the beam and arranged symmetrically in azimuth.

A. Two-Particle Correlations: We measured a) the in-plane coincidence between the spectrometer at $(\theta,\phi) = (\theta_S, 0°)$ and the telescope at (40°, 180°), and b) the out-of-plane coincidence between the spectrometer and the telescope at (40°, 90°) or (40°, 270°). Examples of in-plane to out-of-plane coincidence ratios are plotted in Fig. 1. A strong peak due to pp quasi-elastic scattering is observed in the ratio, which demonstrates the importance of the nucleon-nucleon clean-knock-out process in heavy ion collisions. From the study of peak heights for C + C, Ne + NaF, and Ar + KCl we evaluated that about 50% of protons emitted to the kinematical region around the peak are from the clean knock-out process. For heavier-mass targets no peaks due to pp QES are observed. Instead, the nuclear shadowing effect is observed.

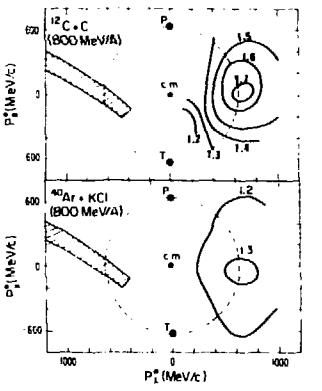


Fig. 1

B. Light-Fragment Spectra from HME: HME were detected from an M-fold coincidence of counter telescopes where M was typically more than 4 or 5. In Fig. 2 proton angular distributions for both HME and inclusive events are plotted. In the c.m. frame of the participant piece an almost isotropic angular distribution is observed for HME, while forward and backward peaking is observed for inclusive events. For Ar + Pb the forward emission observed in inclusive events is highly suppressed in HME. These facts suggest that particles emitted in HME are mainly from multiple nucleon-nucleon collisions. In the case of 800 MeV/nucleon Ar + KCl we studied systematically the relative importance of clean knock-out and multiple cascade components from the comparison between inclusive events and HME. The results are that a) large-p_T fragments are mainly from the cascade process, b) forward and backward emission is mainly from the clean knock-out process, and c) for protons with $E_{c.m.}$ = 200 MeV both processes are highly intermingled. The last result is consistent with the result obtained in the two-proton correlation data described above.

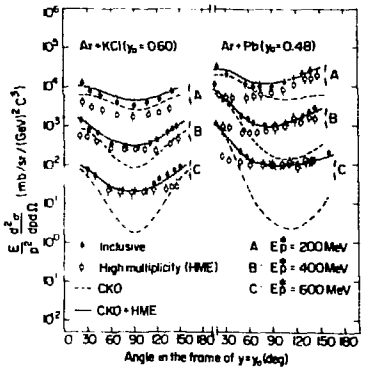


Fig. 2

†Work supported by the Nuclear Science Division of the U.S. Department of Energy, the Yamada Foundation, and the INS-LBL Collaboration Program.
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†††On leave from INS, University of Tokyo, Tanashi-shi, Japan.

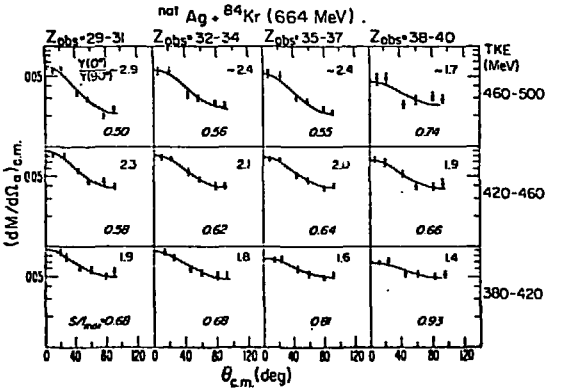
LIGHT PARTICLE EMISSION AS A PROBE OF THE ROTATIONAL DEGREES OF FREEDOM IN DEEP-INELASTIC REACTIONS

L.G. Sobotka, G.J. Wozniak, C.C. Hsu, G.U. Rattazzi,
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We have used the technique of sequential light particle emission[1] to investigate the transfer of orbital angular momentum into intrinsic spins of the deep-inelastic fragments for the system 664-MeV $^{84}Kr+^{nat}Ag$. The experimental configuration involved a ΔE-E solid-state telescope to detect the projectile-like fragment and to define the reaction plane. On the opposite side of the beam axis an out-of-plane arc containing 4 light-particle telescopes was employed to measure the out-of-plane correlation of α-particles emitted from the target-like fragment. In addition, an array of 7 NaI detectors was positioned above the reaction plane to simultaneously measure the gamma ray multiplicity.

Out-of-plane α-particle angular distributions in the center-of mass of the target-like fragment were obtained as functions of the number of coincident γ-rays, TKE and charge asymmetry. In the figure the dependence of the angular distributions on TKE and charge asymmetry is shown. The TKE bins span only the deep-inelastic region. The angular distributions become more focused in-plane, as TKE or charge asymmetry is increased, (indicating a higher degree of alignment or increased spin of the emitting fragment). The trend with TKE is possibly the result of increased fluctuation of the emitting fragment's spin with increasing energy loss due to the excitation of angular momentum bearing modes in the deep-inelastic process. The change in the angular distributions with charge asymmetry could reflect rigid rotation of the deep-inelastic complex.



*This work was supported by the Nuclear Physics Division of the Dept. of Energy under contract no. 7405-eng-48.

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NEUTRON PRODUCTION BY RELATIVISTIC NEON IONS ON CARBON, ALUMINUM, COPPER, AND URANIUM

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We measured inclusive double-differential cross sections at angles of 30°, 45°, 60° and 90° for the production of neutrons above about 15 MeV by relativistic neon ions bombarding targets of C, Al, Cu and U. The bombarding energy at the center of the production targets was about 337 MeV/A. Three different energy regions can be distinguished in the neutron spectra: (1) a low-energy "evaporation" region, (2) a high-energy exponential tail reflecting the internal momentum distribution of the nucleons, and (3) an intermediate energy region reflecting quasi-free and pre-equilibrium processes. The intermediate-energy region becomes less pronounced with increasing angle and is almost non-existent at 90°. This behavior is consistent with the interpretation that the intermediate-energy region consists mainly of scattering processes with a few impulsive direct collisions. The intermediate-energy region is relatively flat at the forward angles and merges into an exponential fall-off at wide angles. The 30-degree spectrum from the carbon target shows a broad peak around 150 MeV, which we interpret as a signature of quasi-free nucleon-nucleon collisions. It is reasonable to expect this signature from the lighter system because the smaller number of participating particles is less likely to wash out the kinematic relationships for a quasi-free nucleon-nucleon collision. Although the neutron detection threshold does not permit us to see the evaporation peaks, we do see evidence of the evaporation tails. The evaporation yields apparent in our spectra increase with the mass number of the target.

The cross sections integrated in energy above 25 MeV fall off exponentially with angle. The total integrated cross section above 25 MeV is proportional to the fifth power of the sum of the radii of the target and the projectile. This representation implies that the average multiplicity of neutrons above 25 MeV, taken as the ratio of the measured cross section to the geometric cross section, is proportional to a geometric interaction volume of $\frac{4}{3}\pi r_o^3 (A_p^{1/3} + A_T^{1/3})^3$, where A_p and A_T are the mass numbers of the projectile and the target, respectively. The average multiplicities for neutrons above 25 MeV are 1.9, 2.4, 4.2 and 8.2 for C, Al, Cu and U targets, respectively.

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**Supported in part by the Office of Health and Environmental Research of the U.S. Department of Energy and by the National Aeronautics and Space Administration.

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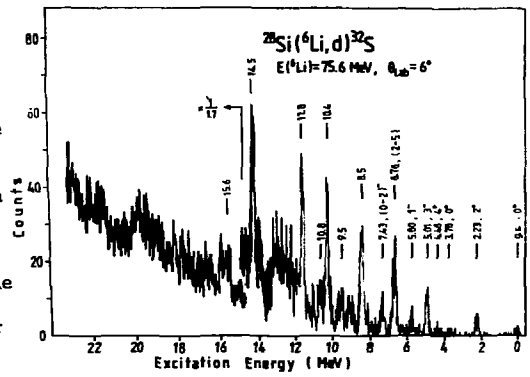
STUDY OF THE $^{28}Si(^{6}Li,d)^{32}S$ REACTION AT 75 MeV

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The $(^{6}Li,d)$ α-transfer reaction on ^{28}Si was investigated at 75.6 MeV bombarding energy. The $^{6}Li^{3+}$ beam of about 100 nA was obtained from the INS SF cyclotron. A self-supporting natural Si foil made by etching of a single-crystal Si was used as a target. Deuteron spectra were measured with a magnetic spectrograph.

Typical deuteron spectrum is shown in the figure. Some levels in ^{32}S are populated more selectively than are observed with the $(^{6}Li,d)$ reaction at lower bombarding energies[1]). Relative α-particle spectroscopic factors were extracted from the comparison of exact finite-range DWBA[2]) calculations with the experimental angular distributions. The calculations were made assuming a cluster transfer mechanism by using ^{6}Li optical potential parameters obtained from the fits to the data for the elastic scattering of ^{6}Li on ^{28}Si measured at the same time (V=176.5 MeV, r_R=1.3 fm, a_R=0.7 fm, W_{vol}=32.9 MeV, r_I=1.7 fm, a_I=0.9 fm) and average deuteron parameters[3]). Results are compared with the corresponding numbers from other α-transfer reactions[4]) on ^{28}Si in the table. It can be seen that there is reasonable agreement among these results as regards the ratio of the S-factors for the low-lying states in ^{32}S. The angular distributions for the strongly populated levels at 6.7, 8.5, 10.4, 11.8, 14.5 and 15.6 MeV appear to be consistent with L=4, 5 or 6 orbital angular momentum transfer. These states seem to have strong α-cluster components.



E_x(MeV)	J^π	$(^{16}O,^{12}C)$ S_α/S_α^{gs}	$(^{18}O,^{14}C)$ S_α/S_α^{gs}	$(^{6}Li,d)$, present S_α/S_α^{gs}	present σ/σ^{gs} (6°-55°)
0.0	0^+	1	1	1	1
2.24	2^+	.38	.47	.46	2.3
3.78	0^+	.51	-	.17	.39
4.46	4^+	.22	.02	.18	1.4
5.01	3^-	.38	.20	.21	5.6
5.80	1^-		.09	.19	2.4
6.7					11
7.4					6.8
8.5					13
10.4					17
11.8					18
14.5					23
15.6					28

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KAON PRODUCTION IN RELATIVISTIC HEAVY ION COLLISIONS†

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M.-C. Lemaire,[2] R. Lombard,[3] E. Moeller,[4] and S. Nagamiya

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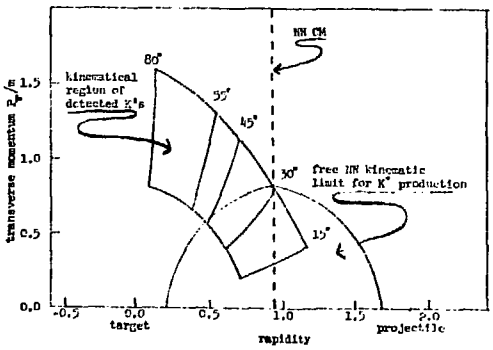
We have measured the inclusive differential cross section, $d^2\sigma/d\Omega dp$, for production of K^+-mesons in the following reactions: Ne(2.1 GeV/N) + (C, NaF, KCl, CU, and Pb) and d(2.1 GeV/N) + (NaF and Pb). The laboratory angles covered were 15°, 35°, 45°, 55°, and 80°, and the laboratory momenta of the detected kaons ranged from 350 MeV/c to 750 MeV/c. The figure shows this kinematical region on a plot of kaon transverse momentum versus kaon rapidity. Also shown are the kinematical limits for K^+ production in free NN collisions.

The K^+-meson has a relatively small cross section, ~10 mb, for scattering on nucleons. In addition, because of its + strangeness it is not readily absorbed. Thus we expect the observed kaon spectra to more directly reflect the initial stages of the interaction than comparable measurements made with pions or protons.

More specificially, our analysis is directed toward obtaining information about

(1) The momentum and angular spectra of the produced kaons for various projectiles and targets,
(2) The projectile and target mass dependences,
(3) The comparison between kaon and pion production.

Preliminary analysis has shown K^+ production in regions considerably beyond the free NN kinematical limits shown in the figure. We are studying how well this result can be explained by the various models. For example, we are interested in learning whether or not the data can be fit adequately with a model based on independent NN collisions using conventional internal momentum distributions.



†Work supported by the Nuclear Science Division, U.S. Department of Energy and the INS-LBL collaboration.
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PREEQUILIBRIUM NEUTRONS FROM DEEP INELASTIC COLLISIONS (DIC)†

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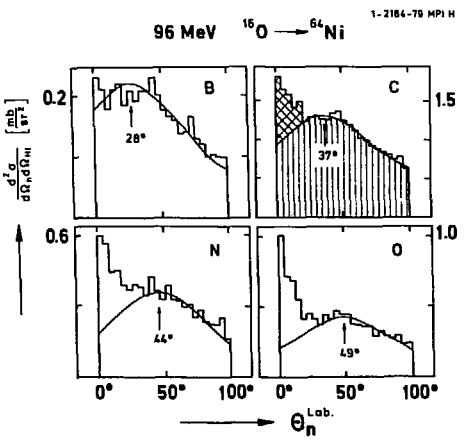
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So far only equilibrium emission of neutrons is known in DIC. We measured the neutron emission for 6 - 9 MeV/amu ^{16}O on 1 mg/cm2 $^{58,64}Ni$ (at the Heidelberg MP-Tandem with postaccelerator) in coincidence with projectile-like fragments. One aim of these experiments was to find a preequilibrium component in n-emission during DIC. For in-plane correlations a 1 m long position sensitive movable neutroncounter (position resolution ~5 cm) was used at a distance of 82 cm (140 msr or a horizontal acceptance of 56°). Additional a standard NE213 neutron counter 5" Ø x 2" was mounted at 101° out of plane at a flight path of 71 cm (25 msr). The coincident projectile-like fragments were detected near the grazing angle (~29°) at 35° with a position sensitive (x,y) ionization chamber (12 msr).

The three-body event by event analysis of the measured n-fragment correlations show three physically different mechanisms:

1) A quasilelastic component which is due to a quasifree (knock out) process from the target nuclei $^{16}O + ^{58,64}Ni \rightarrow ^{16}O + n + ^{57,63}Ni$ and can be clearly seperated for the further data evaluation.

2) Isotropic evaporation from the heavy target-like fragments gives rise to a bell shaped angular correlation (hatched area in the figure) peaked at the recoil angle (arrows). The measured energy distributions correspond to temperatures around 1 MeV in agreement with evaporation calculations. The n-multiplicities ~0.2 and ~1.0 for ^{58}Ni and ^{64}Ni respectively are low because of the high n-binding energies. The out of plane anisotropies of ~0.1 and ~0.2 correspond to J = 13 $\hbar$ in both cases which is in agreement with earlier findings for charged particles[1]).



3) After subtraction of the isotropic equilibrium spectra and the quasielastic part a fast preequilibrium-like component (cross hatched area) shows up, which falls off exponentially (in the lab-system) with increasing angle beginning from the beam direction. The maximum temperature at 0° is about 2.9 MeV. The shape of the angular correlations seems to contradict to the known hot spot predictions[2]). From ^{58}Ni to ^{64}Ni the production cross section of fast neutrons increase by a factor 2.7 which proves the target as the source of these neutrons and points also to a knock out process as the underlying reaction mechanism at the very beginning of the DIC.

†Supported by the Federal Ministry for Research and Technology (BMFT), FRG.
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DIRECT REACTIONS WITH ∿10-20 MeV/amu ^{16}O

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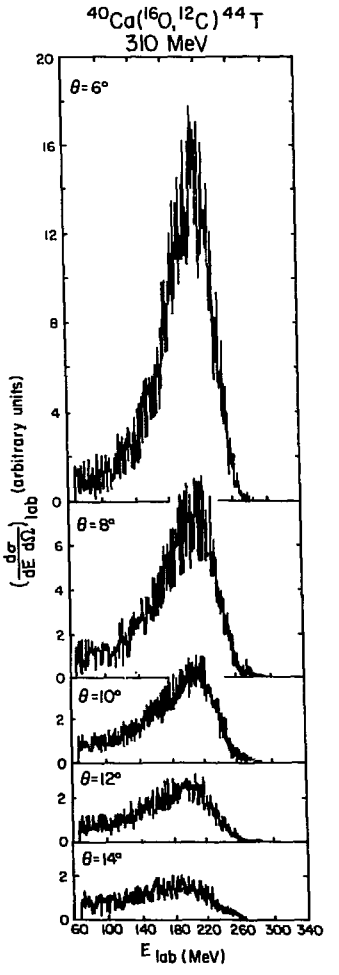
and

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One of the most intriguing problems in heavy-ion physics is to understand the reaction mechanism in terms of the colliding energy. For instance, when the colliding energy is changed from low to high, the mechanism is expected to evolve from the compound to the preequilibrium process and end in fragmentation. In recent years, special attention has been focused on the features associated with reactions from 10 MeV/amu to relativistic energies, and a number of arguments, most of which are qualitative, such as phase transition, have been made.

Here we present a study of the mechanism at ∿10-20 MeV/amu. Special emphasis is placed on theoretical analyses applied to various reactions[1,2]. Using ^{16}O beams from 140 to 310 MeV, inclusive spectra of many outgoing channels were obtained. An example is shown in the figure, where the spectra of the $^{40}Ca(^{16}O,^{12}C)$ reaction are displayed at various angles. The shapes of these spectra change with angle; strong peaking, which is seen in the high energy region at forward angles, diminishes at larger angles. This change is also clearly demonstrated in the angular distribution, as the high energy component falls off rapidly at forward angles, then falls off more gradually at larger angles. At lower incident energies, the high energy peak is less prominent. This feature is quite similar to that which we observed in the reaction $^{40}Ca(^{20}Ne,^{16}O)$, for which successful theoretical analyses were made in terms of the breakup and direct transfer process[2,3]. Therefore, by applying the same treatment, we can consistently understand the reaction mechanism in a quantitative fashion.



*Supported in part by the National Science Foundation.

**Supported in part by the Department of Energy.

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PROJECTILE BREAKUP PROCESS $^{40}Ca(^{20}Ne,^{16}O\alpha)$

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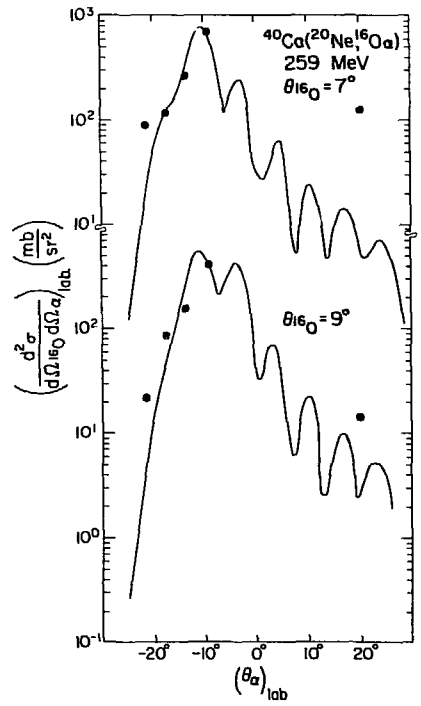
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Studying the continuum spectra of heavy-ion induced alpha-transfer reactions, it was found that the $(^{20}Ne,^{16}O)$ reaction has a component in the high energy region at very forward angles, for which a projectile breakup process was proposed[1,2]. The model assumes inelastic excitation of the ^{20}Ne projectile into ^{16}O-α scattering states.

In order to examine this process, ^{16}O-α correlation measurements were carried out at 259 MeV incident energy. In the figure, correlation cross sections are plotted versus α angle, where negative angles correspond to opposite sides of the beam axis. The points at $\theta_\alpha = \pm 20°$ indicate only upper limits, since the spectra do not show the peak characteristic of this type of breakup, but may, instead, indicate the background from other processes, such as transfer. The solid curves show theoretical results normalized to the experimental cross section. The shapes of the angular correlations and other features observed are nicely explained by the model, but the theoretical analysis overestimates the strength of the coincidence cross sections relative to the inclusive data. This missing strength in the correlation measurements must represent a re-scattering effect of the breakup α with the target nucleus. In fact, including such an absorption effect significantly reduces the outgoing ^{16}O-α strength and can explain the observed result.



*Supported in part by the National Science Foundation.

**Supported in part by the U.S. Department of Energy.

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ROLE OF GIANT QUADRUPOLE INTERMEDIATES IN RELATIVISTIC GRAZING HEAVY ION REACTIONS

X. J. Qiu* and J.O. Rasmussen**

In BEVALAC studies with 2.1 GeV/n ^{16}O beams the formation cross section for ^{12}C is abnormally large compared to neighboring products[1], and the dispersion and shift in $p_{\parallel}$, longitudinal momentum, are abnormally small.[2] We believe that these special features are a consequence of excitation of ^{16}O to giant quadrupole (GQR) states (~11-20 MeV) which largely break-up into ^{12}C plus ^{4}He. To explain the small dispersion in $p_{\parallel}$ the break-up must be anisotropic, favoring 90°.

Using time-dependent perturbation theory and constant-velocity trajectories, we calculate theoretically an integrated cross section of 0.26 barns for excitation of the ^{16}O GQR strength on a Pb target. The experimental ^{12}C formation cross section [1] is 0.126b. Since the GQ states decay by other modes in addition to alpha decay, the agreement is satisfactory. Excitation is mainly due to the Woods-Saxon nuclear potential, taken as $|V|$=130 MeV, d=0.6 Fm, ro=1.2 Fm, but is partly electromagnetic. We also calculated other target-projectile combinations and energies.

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SEARCH FOR OPTIMUM CONDITIONS FOR MULTINUCLEON TRANSFER IN DEEP INELASTIC COLLISIONS*

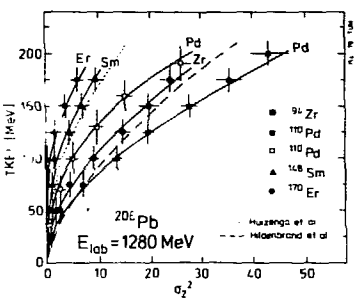
H.C. Britt**, G. Beier, H. Essel, K. Hartel, H. Hopf, P. Kienle, H.J. Körner, W. Mayer, K.E. Rehm, P. Sperr, and W. Wagner

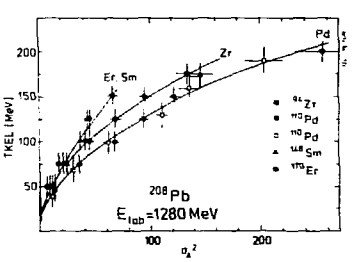
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The entrance channel dependence of mass and charge transfer in collisions of ^{208}Pb ions with various target nuclei was investigated at bombarding energies close to the Coulomb barrier. Fig. 1 shows the relation between the energy transfer and the variances of the charge and mass distributions for various systems. We observe:

i) The number of exchanged nucleons is largest for a mass asymmetry of about 2 : 1 in the entrance channel. This might indicate the importance of radial boundary matching for the wave functions of the transferred nucleons.

ii) The system ^{208}Pb + ^{110}Pd shows the largest widths of both mass and charge distributions. The variances σ_Z^2 are even larger than those of ^{238}U + ^{238}U. This effect can be related to the strong polarizability of ^{110}Pd, which is also evidenced by a very large deformation, $\varepsilon \sim 0.7$, found for the nuclei of the exit channel.





iii) At incident energies closest to the barrier less protons but correspondingly more neutrons are transferred, which leads to a neutron-rich nucleon flow, especially during the initial phase of the reaction (open and closed symbols refer to 1180 and 1280 MeV incident energy respectively). The suppression of the proton transfer can be explained as a barrier effect, whereas the enhancement of the neutron flow at the lower bombarding energy may point at the influence of pair correlations at small energy transfer.

iv) Additional measurements with ^{112}Sn and ^{124}Sn as targets show larger variances of both mass and charge exchange for the neutron rich ^{124}Sn.

Thus reactions between two heavy neutron-rich nuclei with a mass ratio of about 2 : 1 and high polarizabilities and bombarding energies close to the Coulomb barrier seem to be most favourable for the synthesis of very heavy nuclei in deep inelastic collisions.

*Supported by the BMFT, Bonn.

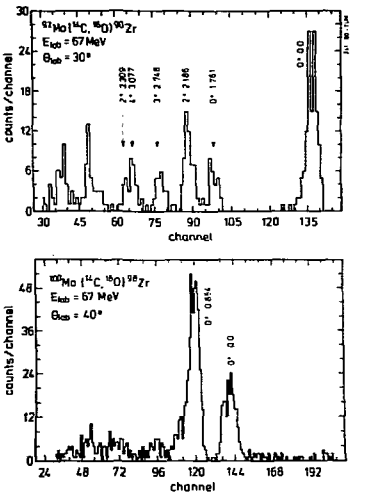
**Humboldt awardee, LASL, Los Alamos.

STRUCTURE INFORMATION FROM (^{14}C,^{16}O) AND (^{16}O,^{14}C) REACTIONS ON MEDIUM WEIGHT NUCLEI*

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The investigation of collective proton states via the (^{3}He,n) reactions is severely complicated by the poor energy resolution obtained in neutron time-of-flight measurements. We have therefore employed the heavy ion (^{16}O,^{14}C) and (^{14}C,^{16}O) reactions in order to study excited 0^+ states in the even Zr and Sn nuclei. The emerging particles were analyzed in the Q3D magnetic spectrograph. With a solid angle of 11 msr and a target thickness of 200 $\mu g/cm^2$ we achieved an energy resolution of < 100 keV for the (^{16}O,^{14}C), and 150 keV for the (^{14}C,^{16}O) reaction,respectively.

Fig. 1 shows two energy spectra for the reactions $^{92}Mo(^{14}C,^{16}O)^{90}Zr$ and $^{100}Mo(^{14}C,^{16}O)^{98}Zr$ at 67 MeV incident energy. Many levels in ^{90}Zr are populated in the two proton pickup reaction on ^{92}Mo including the first excited 0^+ state at 1.76 MeV. Contrary to this behaviour we observe a predominant population of the ground state and the first excited 0^+ state in ^{98}Zr from the reaction on the neutron rich ^{100}Mo nucleus. A similar selectivity is observed in the $^{114}Cd(^{16}O,^{14}C)^{116}Sn$ reaction, where the two lowest 0^+ states are excited with equal strength, while the transition to the first excited 2^+ state is strongly suppressed. These experiments demonstrate that structure information can be obtained from heavy ion transfer reactions which cannot be extracted from light ion studies.



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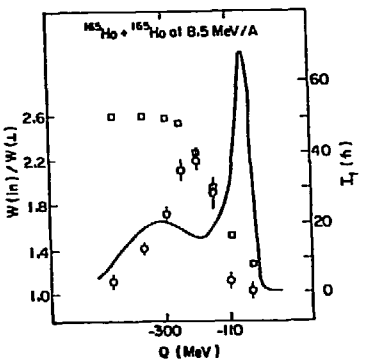
FRAGMENT SPIN ORIENTATION IN THE DEEP-INELASTIC REACTION ^{165}Ho+^{165}Ho FROM ANISOTROPY MEASUREMENTS OF CONTINUUM GAMMA-RAYS

R.J. McDonald. D.J. Morrissey, A.J. Pacheco, G.U. Rattazzi, C. Schuck, S. Shih, G.J. Wozniak, R.M. Diamond, C.C. Hsu, H. Kluge, L.G. Moretto, L.G. Sobotka, and F. S. Stephens

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The anisotropy (ratio of in-plane to out-of-plane yield) of continuum γ-rays emitted in the reaction ^{165}Ho+^{165}Ho at 8.5 MeV/A was measured to determine the alignment of fragment spin as a function of Q-value. Simple friction models predict that the transferred spin should be aligned perpendicular to the reaction plane. One therefore expects to observe a large anisotropy for rotational nuclei which decay predominantly by stretched E2 transitions. Symmetry in the entrance channel allows us to study this effect over all Q-values.

The solid line in the Figure shows the particle spectrum taken at 27°in the lab. The spectrum clearly shows a broad elastic and quasi-elastic peak at ≈110 MeV and the deep-inelastic peak at ≈300 MeV. Two redundant systems, each consisting of a Si particle detector and two NaI detectors (in-plane/out-of-plane)were used to measure multiplicities and anisotropy.



The ratio of efficiency-corrected coincident γ's to particle singles was used to determine multipilicity and therefore angular momentum per fragment (corrected for neutron emission and W(θ). As seen in the figure (squares), the angular momentum per fragment (I) rises with increasing energy loss to a maximum and remains there through the DI region. The anisotropy (circles) reaches a maximum of about 2.2, before the multiplicity peaks, and decreases rapidly across the DI region. The function W(θ) depends both on the fraction of dipoles emitted per reaction and the ratio σ^2/I^2, where σ^2 is a measure of the random fluctuations in angular momentum. Assuming reasonable % dipoles (from compound nuclear work) we may extract an experimental σ^2. We explain the observed σ^2 in terms of thermal excitation of angular momentum bearing modes according to the model of Moretto and Schmitt.[1]

*This was supported by the Division of Nuclear Physics of the U.S. Dept. of Energy under contract no. 7405-eng-48.

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TWO-PARTICLE CORRELATIONS IN HIGH ENERGY NUCLEAR COLLISIONS

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We discuss the correlations of two particles (proton-proton, proton-pion) in high energy nuclear reactions by means of the linear-cascade model (rows on rows).[1,2] It describes the observed cross sections in terms of contributions arising from dynamically independent groups of interacting nucleons. In addition to a correlated part where both observed particles arise from the same group, there is also a significant background contribution from the particles originating from two independent groups. The construction of the one and two particle spectral functions by means of a Monte Carlo simulation method allows the inclusion of various dynamical effects, such as the production of delta isobars or precritical scattering.

The presently available data[3] express the amount of correlation by a ratio R of the in-plane to out-of-plane coincidence cross sections registered in a tag counter and a spectrometer. Our initial studies indicate that not only the height of the quasi-elastic peak, but also its position in momentum space may be sensitive to the background term and to correlations arising from the sharing of energy and momentum among more than two particles. Its shape reflects the width of the Fermi momentum distribution and the windows set for the tag counter.

Footnotes and References

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SPECTROSCOPY OF THE (fp)-SHELL NUCLEI WITH MULTINUCLEON TRANSFER REACTIONS*

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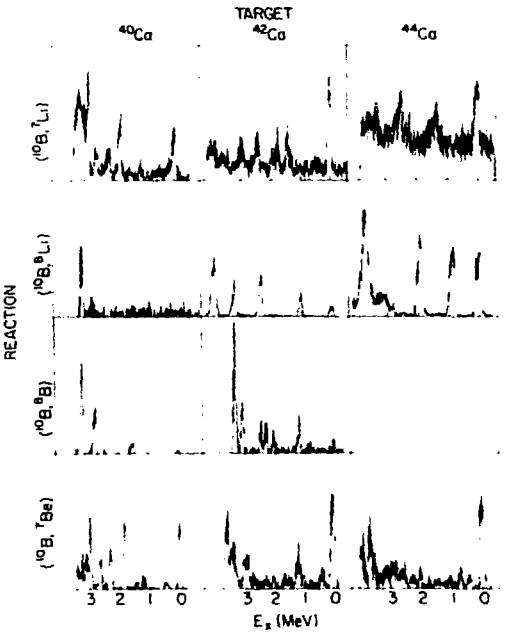
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The use of multinucleon transfer processes induced by ~10 MeV/amu heavy ions has proved to be quite useful in selectively studying high-spin particle hole states[1,2]. Such studies, however, have been made extensively only in the light nuclei region. We have performed a number of experiments which extend these studies into the beginning of the (fp) shell nuclei. The figure shows a collection of experimental spectra of various 2- and 3-nucleon transfer reactions induced by a 70 MeV ^{10}B beam on $^{40,42,44}Ca$ targets using the Brookhaven tandem, together with a QDDD spectrograph. Strong selective populations are clearly seen, due to 1) the reaction dynamical effect and 2) the structure effect. An understanding of the reaction dynamics is necessary if structure information is to be extracted. This is being attempted theoretically by analyzing the data with DWBA and by performing several other experiments using different projectiles at different energies. A systematic survey is also very helpful in finding the structural information. For instance, the combined information of 2- and 3-nucleon transfer, together with a weak coupling scheme, can provide a simple picture of the configurations.



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PROJECTILE FRAGMENTATION*

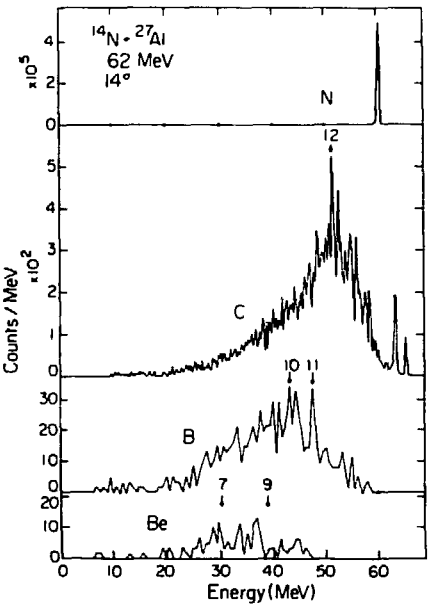
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The continuum spectra of particles lighter than the projectile have been investigated for beams of 36 MeV ^{6}Li and ^{7}Li, 63 MeV ^{12}C, 62 MeV ^{14}N and 70 MeV ^{18}O on targets of ^{12}C, ^{27}Al, ^{45}Sc, and ^{63}Cu. A gas-ionization counter-Si surface barrier detector telescope and a conventional telescope were used for Z identification.

Examples of the spectra obtained are shown in the figure for an ^{14}N beam. The energies corresponding to the same energy per nucleon as that of the beam are shown by arrows for various final masses as indicated. The C, B, and Be spectra form broad peaks centered near these energies, which are appropriate for particles traveling with beam velocity. In general the forward angle spectra of particles lighter than the projectile appear to peak at the beam velocity, a signature of projectile fragmentation. This is similar to what has been observed for light-ion projectiles[1),2)].

Further work is in progress to characterize the production of these fragments as a function of beam energy, detection angle, target mass, and binding energy. Coincidence measurements are planned. Preliminary calculations using a simple breakup model[3)] roughly reproduce the shapes of the energy spectra and angular distributions.



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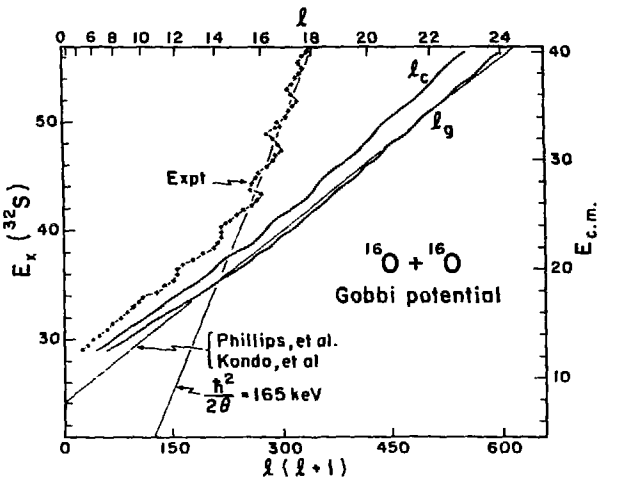
FUSION CROSS SECTIONS FOR SYMMETRIC LIGHT SYSTEMS +

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The limiting angular momentum for fusion in the $^{12}C + ^{12}C$ and $^{16}O + ^{16}O$ systems displays some interesting phenomena which are not easily explained on the basis of current understanding of the ion-ion potential. In particular, the "trajectory" of L_c, the experimental critical angular momentum, shows discontinuities in slope at successive even values of ℓ, as is appropriate for systems of identical bosons, but the transitions are much more abrupt than predicted on the basis of optical-model calculations using the best potentials available in the literature. Secondly, at high energies the trajectory of L_c appears, on the average, to display quasi-rotational behavior with superposed oscillatory structures similar to those described above. The low-energy extension of this line passes through the origin of the plot, i.e., the J = 0 ground state of the compound system, and has a moment-of-inertia parameter appropriate to the ground state band. Finally, the transition between the low-energy and high-energy regimes is also astonishingly abrupt, and correlated with characteristic "resonances" in some of the direct reaction channels.

All of the features discussed above appear in the figure, which shows the experimental L_c for the $^{16}O + ^{16}O$ system, compared to optical-model calculations using the Gobbi potential[1]). The curve labeled ℓg is the grazing angular momentum for this potential and ℓc is the critical angular momentum for the predicted total reaction cross section. The straight line passing through the data at high-energy extrapolates to the origin of the plot and has a slope parameter of 165 keV, which may be compared to the value of 180 keV obtained from a shell model calculation of the high-spin states of ^{32}S due to B.H. Wildenthal.



+ This work supported in part by the U.S. National Science Foundation.

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ENERGY DISSIPATION IN RELATIVISTIC NUCLEAR COLLISIONS

H. H. Gutbrod, W. G. Meyer, A. M. Poskanzer, A. Sandoval, R. Stock,
C. H. King, G. King, Nguyen Van Sen, and K. L. Wolf

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In central collisions the disintegration of a large target nucleus by a light projectile should yield information on the energy dissipation from the incoming projectile to the target. If there is no transverse momentum transfer from the participants to the spectator a hole is punched into the target nucleus and little or no change in the decay pattern of the target spectator will be found as function of the projectile energy. However, a change will be seen with increase of the projectile size. On the other hand, if there is a strong and fast dissipation of the projectile's kinetic energy as it gets stopped in the target nucleus, the whole target nucleus will share the incident kinetic energy.

Uranium was bombarded with various projectiles from protons to ^{40}Ar at energies from 250 MeV/n to 2.1 GeV/n. A surprising result is observed in Fig. 1 where the associated multiplicity for protons of 40 to 200 MeV at 90° lab (cf. Ref. 1) is plotted vs the total kinetic energy of the projectile. A smooth, nearly linear relationship between the mean associated multiplicity and the total kinetic energy is observed, regardless of the geometrical size of the projectile, or whether the incident energy is at the pion-threshold or way above it. In fact not only the means but also the observed multiplicity distributions are nearly the same as is shown for two projectiles with 42 GeV kinetic energy in Fig. 2.

These observations support models where a high density is reached early in the diving stage. Then, in the expansion phase, the energy is spread over most of the nucleus. Transparency is therefore highly unlikely up to incident energies of 2.1 GeV/n.

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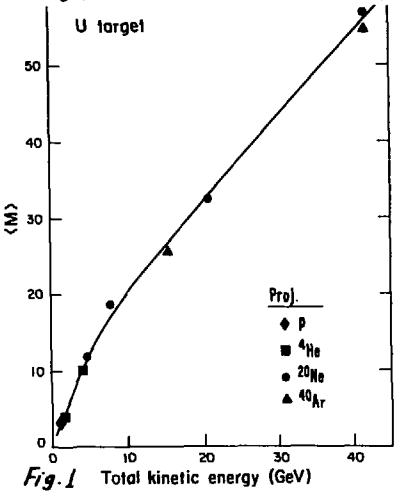


Fig. 1 Total kinetic energy (GeV)

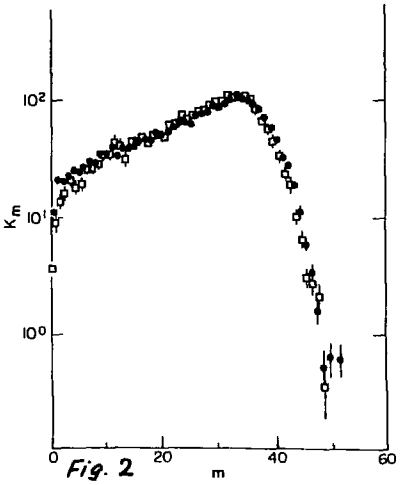


Fig. 2

COULOMB EFFECTS ON LOW Z FRAGMENT PRODUCTION IN CENTRAL RELATIVISTIC NUCLEAR COLLISIONS

A. Baden, M. Freedman, H. H. Gutbrod, D. J. Henderson, S. Kauffmann, K. Karadjev, M. R. Maier, V. Manko, W. G. Meyer, J. Péter, H. G. Ritter, E. P. Steinberg, H. Stelzer, A. I. Warwick, F. Weik, H. Wieman, and B. D. Wilkins

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Using TOF telescopes and an array of plastic scintillator detectors, in several experiments at the Bevalac, we have measured the multiplicities of fast charged particles associated with low Z target fragments from relativistic heavy ion collisions. We find that fragments of mass approximately equal to that of carbon originate in violent high multiplicity events ($\langle m \rangle = 15$). The energy spectra of these fragments ($6 \leq Z \leq 12$) at 90° exhibit a peak which increases in energy with increasing fragment charge and which indicates a Coulomb barrier much lower than that of the undeformed composite system of target and projectile.

The measured multiplicities of fast charged particles allows an estimate to be made of the charge removed from the composite system. We find that this mechanism is inadequate to fully explain the reduction of the Coulomb barrier. Using the measured peak energies of the fragments and the slope of the spectra for the apparent temperature, the apparent second body for carbon emission has an atomic number of about 42 and a reduced Coulomb radius of $r_0 = 2.0$ fm. $Z = 42$ is small compared to the upper limit of $Z = 65$ which is given by $Z_{projectile} + Z_{target} - Z_{carbon} - \langle m \rangle$. The large apparent Coulomb radius indicates a highly deformed emitting system.

The observed violence of these collisions and the drastic reduction of the Coulomb barrier, together with separate evidence[1]) for a coupling of the 'fast' and 'slow' processes, points away from a slow evaporation picture towards an emission mechanism which may depend upon the fast stage of the collision and in which the Coulomb force plays a more complicated role.

Further measurements are being analyzed in which a second fragment is looked for in coincidence with the low Z fragment, as a function of angle. These data will elucidate the relative importance of deformation and charge removal in determining the effective Coulomb barrier, and reveal any angular dependence of the Coulomb effects. In addition, a more elaborate multiplicity array, consisting of a TOF wall of scintillators downstream of the target, will yield information on the momenta of the fast charged particles.

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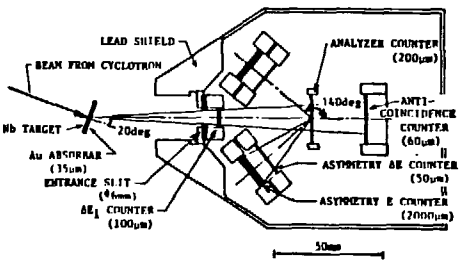
POLARIZATION OF PREEQUILIBRIUM PROTON EMISSION IN THE $^{93}Nb+^{14}N$ REACTION

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Protons emitted in heavy-ion reactions often exhibit a forward-peaked angular distribution and a continuous energy spectrum enhanced at the high-energy part when compared with that expected in compound reactions. In order to study the reaction mechanism involved, we have measured the polarization of such protons for the first time by the double-scattering method using a Si detector as the analyzer.

The figure shows a schematic view of the present polarimeter, which is similar to the one studied by Martin et al.[1]), except that the asymmetry detectors consist of ΔE-E Si-counter telescopes. This is necessary to eliminate possible backgrounds such as γ rays, electrons and neutrons which otherwise cannot be discriminated from protons having a continuous energy distribution. The ΔE_1 Si counter works for another particle identification when the sum of signals from the other detectors is treated as an E signal, making it possible to distinguish elastic from inelastic scatterings occurring in the analyzer detector. The experimental analyzing powers of Si reported in ref. [1]) are used to calculate those of the present assembly as a function of incident proton energy. The analyzing powers thus obtained are always positive in the energy region of present interest (6-14 MeV), though they vary from 0.1 to 0.5 in this range.



A 9 mg/cm^2 thick Nb foil with a 35 μm Au backing was bombarded with 95 MeV ^{14}N ions from the IPCR cyclotron. The polarization measurement was performed at 20° with respect to the beam, where the emitted protons have a spectrum peaked around 7 MeV with a slow exponential fall toward the higher energy characteristic of the preequilibrium (PE) emission[2]). The backing is thick enough to stop the beam, thus protecting the ΔE_1 counter from strong elastic scattering. The proton yield from the backing was negligible. The left-right asymmetry deduced in the usual manner was found to be 4.2±2.1, 3.3±1.8 and 4.0±2.3 % for 6-8, 8-10 and 10-14 MeV protons, respectively, definitely indicating positive polarization (we follow the Madison convention for the sign) in all cases. The averaged polarization of protons in the range of 6-14 MeV was estimated to be 13±4 %.

The p-γ coincidence measurement performed in the same reaction has shown that most of protons in question originate from collisions leading to fusion, suggesting that the relevant emission is due to the PE decay of a composite (projectile plus target) system as proposed in ref. [2]). It can be shown[3]) that if the total angular momenta of an excited nucleus are polarized, protons emitted during its statistical decay are also polarized by 20-30 % of the initial polarization in most cases. The present result therefore indicates strong positive polarization of the composite system mentioned above.

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PROJECTILE FRAGMENTATION ACCOMPANIED BY INCOMPLETE FUSION*

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A model calculation based on projectile fragmentation, pre-equilibrium emission and evaporation emission is formulated to describe the particle-particle angular correlations and particle-gamma correlations in complex projectile induced reactions. The reaction is assumed to take place in two steps. The projectile breaks up in the first step producing a fast ejectile, while the remainder of the projectile fuses with the target. In the second step, the composite nucleus decays via particle and γ emission. The laboratory differential cross section for fragment x and decay particle y in coincidence is given by

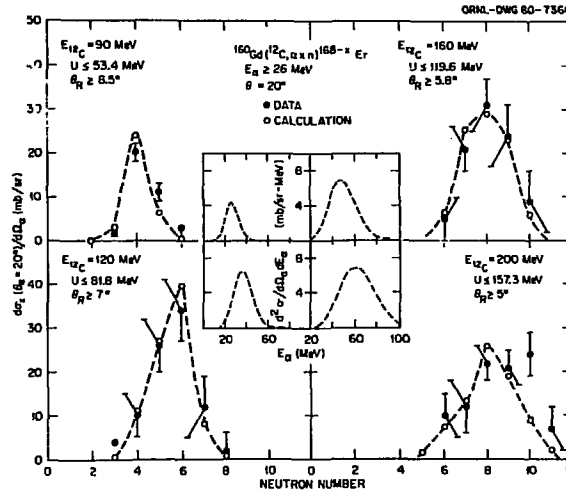
$$\frac{d^4\sigma}{d\Omega_x d\Omega_y dE_x dE_y} = \frac{d^2\sigma}{d\Omega_x dE_x} \frac{d^2P(U,\vec{q})}{d\Omega_y dE_y} \delta(\vec{P}_p - \vec{P}_x - \vec{q}) \quad \delta(E_p - E_x - E_R - U - Q)$$

$$= N_x P_x m_x \left| \phi(\vec{P}_x - \frac{m_x}{m_p}\vec{P}_p) \right|^2 \sigma_R(U) \frac{d^2P(U,\vec{q})}{d\Omega_y dE_y}$$

$$\delta(\vec{P}_p - \vec{P}_x - \vec{q})\delta(E_p - E_x - E_R - U - Q)$$

$$\left| \phi(\vec{p}) \right|^2 = \left| \phi(\vec{P}_x - \frac{m_x}{m_p}\vec{P}_p) \right|^2 = \left(\frac{1}{\sqrt{2\pi}\sigma} \right)^3 \exp\left(-\frac{p^2}{2\sigma^2}\right) .$$

The model gives a good description of the production of fast projectile-like α particles accompanied by incomplete fusion for $^{160}Gd(^{12}C,\alpha xn)^{168-x}Er$ reactions at four energies (see figure).



*This work was supported by U.S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corp.

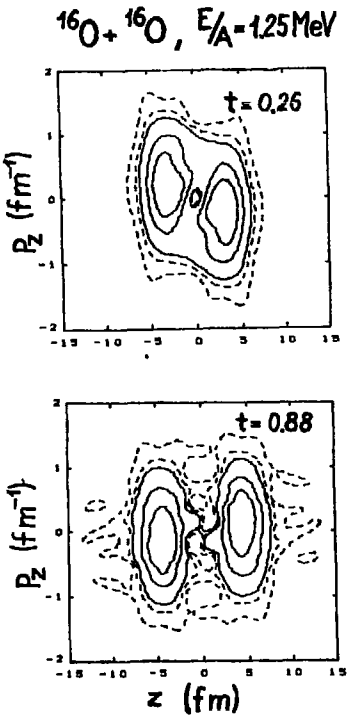
PHASE SPACE DISTRIBUTIONS OF TDHF COLLISIONS

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We have calculated the Wigner transform[1], of 3 dimensional (2-d,head on) TDHF solutions, for the ^{16}O-^{16}O reaction at 1.25 MeV per nucleon, c.m. energy. Numerical integrations of the TDHF equations were done with a time step of $\Delta t = 5 \times 10^{-24}$sec and space step of $\Delta r_\perp = \Delta z = 0.4$ fm in a mesh of size 7.6 fm x 21.6 fm. As a function of time t, we study the Wigner function $f(\vec{r},\vec{p},t) \equiv f(z, D_\perp, p_z, p_\perp)$, where $\vec{D}_\perp$ and $\vec{p}_\perp$ are the coordinate vectors perpendicular to the z and p_z axes respectively.

In the figure, we show contour plots of $f(z,p_z)$ for neutrons, where the perpendicular components of space and momentum have been integrated out. Time is in units of 10^{-21}sec. The contour values for the solid lines are 0.2-1.0(0.4), and for the dashed lines 0.02-0.10(0.08). The corresponding plots for protons are very similar. These plots clearly show the spilling over of nucleons from one nucleus to the other. While we do not observe the fast emission of nucleons at earlier times (PEPs), there are some indications of nucleon emission into the continuum at later times. Rapid changes of the distribution function in the neck region are also seen at later times. During the interaction time, the momentum distributions of nucleons in the $z \gtrless 0$ space (space integrated f's), differ considerably from a thermalized distribution. In this contribution we shall also present results of f, with other interesting combinations of variables throwing light on the time development of the quantum phase space distribution function, and compare them with one dimensional results[2,3].



Further investigations at 5 and 10 MeV per nucleon c.m. energy are in progress with a less coarse mesh.

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MOLECULAR SINGLE-PARTICLE EFFECTS IN THE $^{16}O+^{25}Mg$ AND $^{17}O+^{24}Mg$ REACTIONS†

Jae Y. Park†† and Werner Scheid

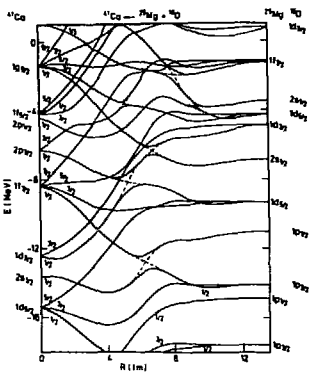
Institut für Theoretische Physik der Justus-Liebig-Universität, Giessen, West-Germany

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In order to examine the possible effects of the nuclear Landau-Zener mechanism, namely the promotion of nucleons at level crossings[1], we have calculated the two-center single-particle neutron level diagrams for the $^{16}O+^{25}Mg$ and $^{17}O+^{24}Mg$ reactions using the asymmetric two-center shell model (ATCSM). The parameters in the ATCSM are determined by fitting the experimental single-particle levels near the Fermi surface, and using the Nilsson model for the deformed nucleus ^{25}Mg.

The neutron level structure of the ATCSM for the reaction $^{16}O+^{25}Mg \rightarrow ^{41}Ca$ is shown in the figure. It is seen that the 1d5/2(Ω=1/2) level in ^{25}Mg which is initially occupied by the valence neutron has an avoided crossing with the 2s1/2 level of ^{25}Mg near 5-6 fm. Furthermore the later level has a second avoided crossing with the 1d3/2(Ω=1/2) level of ^{25}Mg near 6.5-7.0 fm, thus enhancing the inelastic excitation of neutron. The avoided crossing of the 1d3/2(Ω=1/2) level of ^{25}Mg with the 1d5/2(Ω=1/2) level of ^{16}O near 5 fm gives rise to the neutron transfer, $^{16}O+^{25}Mg \rightarrow ^{17}O+^{24}Mg$. The avoided crossing of the 1d5/2 (Ω=3/2) level of ^{25}Mg with the 1d3/2(Ω=3/2) level of ^{25}Mg near 3.5 fm can also enhance the neutron inelastic excitation of ^{25}Mg. The rotational coupling between the 1d5/2 (Ω=1/2) level of ^{25}Mg and the 1d3/2(Ω=3/2) level of ^{25}Mg near 4-5 fm can play a role in the inelastic excitation process and the rotational coupling between the later level and the 1d5/2(Ω=5/2) level of ^{16}O near 5-6 fm can induce the neutron transfer.



It is hoped that the measurement of excitation functions for inelastic scattering and neutron transfer reactions for the $^{16}O+^{25}Mg$ and $^{17}O+^{24}Mg$ systems will give an experimental proof for molecular single-particle orbitals.

† This work was supported by DFG, GSI and BMFT.

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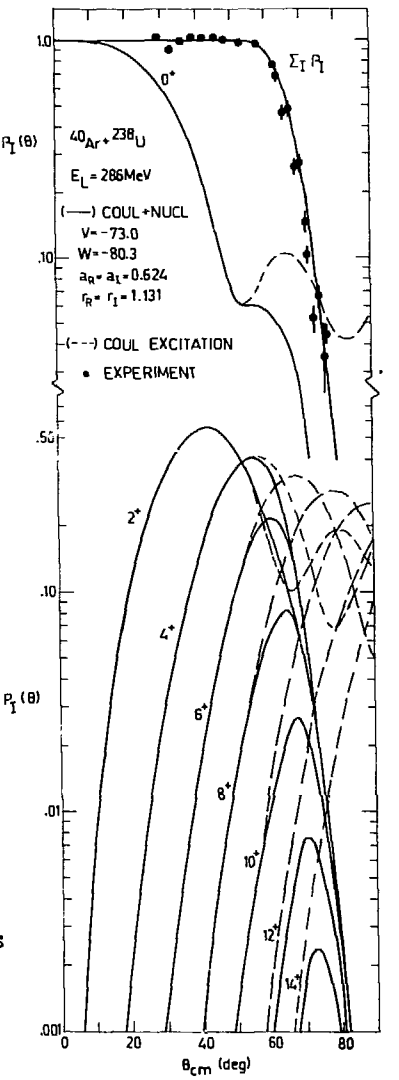
SOLVING COUPLED EQUATIONS BY ITERATION FOR HEAVY ION COLLISIONS

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The quantum mechanical description of inelastic scattering processes with multiple excitation needs the solution of a set of coupled linear second-order differential equations. This set can be rewritten as an equivalent set of coupled integral equations. In a recent study [1] of heavy ion multiple Coulomb excitation of ^{238}U by Kr up to a state with $I=24\hbar$, use has been made of Airy functions as piecewise analytic reference solutions. This makes it possible to evaluate analytically the integrals that arise in the set of integral equations. In case the dimension of the set becomes very large, the differential equations can only be solved efficiently by iterating the integral equations. Two iteration schemes, an inward-outward and a perturbative or sequential one, were investigated.

To include also nuclear excitations the optical model potential over a radial interval has to be approximated by a complex linear reference potential, yielding Airy and modified Hankel functions with complex arguments as piecewise analytic reference solutions. This procedure has been applied to a test case dealing with multiple excitation of ^{238}U by 286 MeV Ar up to a state with $I=14\hbar$. A calculation with Kr as a projectile is in preparation. It turns out that the inward-outward iteration scheme is an efficient one.

In the figure the quantum mechanical excitation probabilities, calculated in the center-of-mass system, are plotted for the various target states against the scattering angle θ. The optical model parameters mentioned are taken from ref. [2]. The solid curves show the probabilities for Coulomb-nuclear excitation ($\beta_2^N=0.237$, $\beta_4^N=0.067$, $\beta_2^C=0.2121$, $\beta_4^C=0.0667$). The dashed curves represent the result expected for pure Coulomb excitation. The figure shows also the elastic scattering experimental data of ref. [2]. It is remarkable how they disagree with the elastic 0^+ curve, while on the contrary the agreement with the curve of summed probabilities is worth mentioning. Presumably, the experimental data do not represent elastic events only.



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SURPRISAL ANALYSIS OF ENERGY SPECTRA IN HEAVY-ION TRANSFER REACTIONS[†]

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Heavy-ion transfer reactions to highly excited states are examined in terms of surprisal analysis — a constrained phase space approach. The experimentally measured energy spectra were found to be well described (Fig. 1) by a distribution of maximal entropy subject to one or two constraints. The dominant constraint is the mean kinetic energy above the Coulomb barrier, while the second constraint is related to the width of the exciton distribution. A general dynamic analysis implies that the final mean value of the constraint should be linearly dependent on its initial value. We have derived

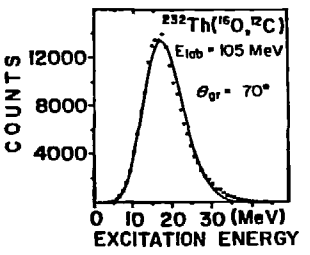
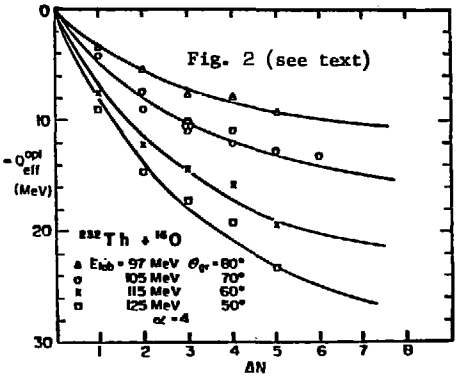


Fig. 1: $d^2\sigma/dE^*d\Omega$ vs. excitation energy E^*: the experimental (dots) and the one constraint (continuous line) distributions



such a sum rule from a simple model assuming momentum matching and tangential friction. The model has only one adjustable parameter α which is independent of the different exit channels and the initial bombarding energy. To verify the validity of this sum rule we have performed a series of measurements for the reactions $^{15}N + ^{232}Th$, ^{181}Ta (at 86, 95, 103 MeV of incident energy), $^{16}O + ^{232}Th$ (at 97, 105, 115, 125 MeV) and $^{35}Cl + ^{181}Ta$ (205 MeV). Some of the results are summarized in Fig. 2, where the predictions of the model (continuous lines) are compared with the observed optimal Q value in the $^{16}O + ^{232}Th$ reaction as a function of the number of transferred nucleons ΔN. The analysis suggests that α/μ_i (μ_i is the incident reduced mass) is independent of the entrance channel. In summary, we have demonstrated that all the energy spectra for different exit channels and bombarding energies can be reconstructed from one common parameter α. The dynamical information needed for such a reconstruction can be extracted from a simple sum rule.

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[††]Chaim Weizmann Postdoctoral Fellow.

COULOMB EFFECTS IN RELATIVISTIC NUCLEAR COLLISIONS†

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Because of their light masses, charged pions produced in relativistic nuclear collisions are strongly influenced by electromagnetic forces. Hence, it is possible that the π^+/π^- ratio is sensitive to the time evolution of the charge density. We investigate this point in a classical model. Let $S(\vec{r},t,b,\vec{p}_i)$ be the probability of creating a pion at the space-time point $(\vec{r},t)$ with momentum $\vec{p}_i$ during a collision with impact parameter b. The inclusive cross section will be

$$E_f \frac{d^3\sigma}{dp_f^3} = \sum_{\vec{p}_i} \int d^3\vec{r} \int dt \int d^2b \; S(\vec{r},t,b,\vec{p}_i) \frac{E_f}{E_i} \left| \frac{d^3p_i}{d^3p_f} \right| \quad ,$$

where $\vec{p}_f$ is the final asymptotic momentum, calculated by integrating the classical equations of motion under the Lorentz force, and the integral is evaluated by Monte-Carlo methods. The Lorentz force corresponds to the charge distributions generated by a "cascade" calculation of the nuclear collision.[1] In the simplest approximation, the distributions are given by three expanding gaussians: one participant-like and two spectator-like parts. The source functions S is localized in $(\vec{r},t)$ near the participants.

The figure shows how the results compare with a measurement[2] of the π^-/π^+ ratio at 0°. The agreement obtained for the peak around the projectile rapidity indicates that the expansion of the spectators is well described. Additional findings are: (1) the value of this ratio at 0° is fairly insensitive to the source S, i.e., the way the pions are produced. (2) the value of this ratio at 0° is related to the expansion of the participants. It is evident that pi-mesic atoms are being formed in such reactions, possibly around exotic spectator fragments.

Additional study of other regions of phase space will lead to information about the source function from inclusive measurements and hence open the possibility of detecting exotic phenomena.

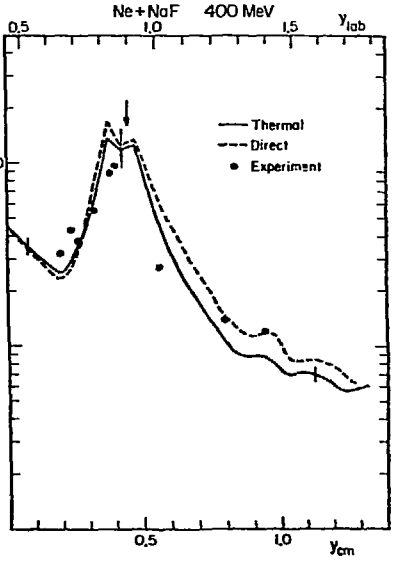


Fig. 1. Ratio of the π^- to π^+ yield at 0° for Ne+NaF at E/A = 400 MeV.

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††† Alfred P. Sloan Foundation Fellow.

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DISSIPATION OF ANGULAR MOMENTUM IN INCOMPLETE DEEP-INELASTIC $^{20}Ne+^{168}Er$ SCATTERING AT 13.5 MEV/N†

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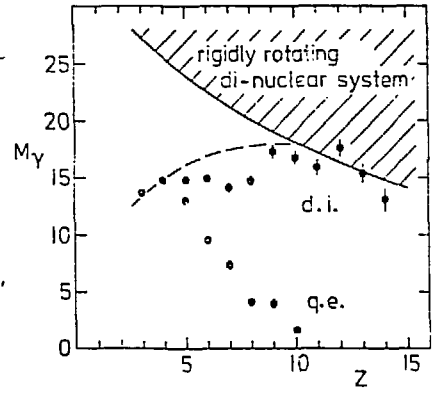
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The multiplicity of γ-rays, M_γ, from the 270-MeV $^{20}Ne+^{168}Er$ reaction has been measured with a 13 cm•13 cm NaI crystal in coincidence with the projectile like fragments detected at 35° which is 15° behind the grazing angle. In the figure we show as a function of the light-fragment Z-number the values of M_γ obtained in the centers of the quasi-elastic (q.e.) and deep-inelastic (d.i.) groups. The heavy-fragment spin is given by $I \cong 2M_\gamma$ in good approximation for $M_\gamma \geq 5$. On the other hand, the γ-ray spectra establish a rather weak radiative strength of the light fragments with $Z<9$.

For q.e. events, the rate at which I increases with the projectile's loss of mass is very small in view of the grazing angular momentum $\ell_{graz}=142\ \hbar$. Probably, fast light particles as observed in a similar system [1] account for the major part of the loss of angular momentum, $\ell_i-\ell_f$.

Our data for d.i. events may serve to localize these events in the vast span in ℓ-space between the critical value for complete fusion [2], $\ell_{crit}=64\ \hbar$, and ℓ_{graz}, which is dominated by the incomplete fusion reactions. Rigid rotation of the di-nuclear systems would result in fragment spins confined to the hatched area in the figure where the lower limit corresponds to $\ell_i=\ell_{crit}$. Our data are in clear contradiction to that assumption: (i) Independent of the fractionation of ℓ_i, the amount of I in the $Z<9$ channels is considerably below the sticking limit although the exit channel energy is centered close to the Coulomb barrier, indicating complete equilibration of the relative motion. (ii) For systems displaying a mass drift towards increasing asymmetry, as observed in the present case, I should increase rapidly with increasing asymmetry in contrast to the slow decrease observed. To explain our data we propose the picture of sticking after break-up. In a simple version, a given light fragment X with mass $M<20$ originates most probably from that partial wave with ℓ_i equal to the critical value [2] $\ell_{crit}(X)$ for the fusion of $X+^{168}Er$ after break-up of the projectile. Sticking of the $X+^{168}Er$ system, rotating with angular momentum $\ell_{crit}(x)\cdot M/20$, results in the dashed curve which agrees reasonably with the data, indicating that equilibrium of the rotational degrees of freedom is reached in the deep-inelastic process after fast-particle emission.



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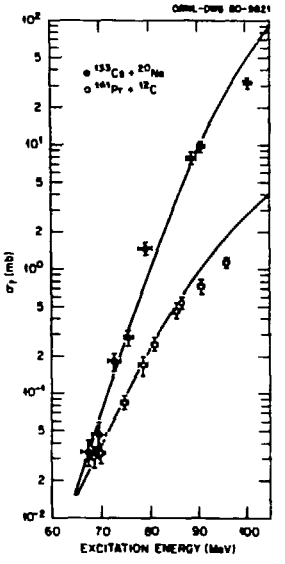
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FISSION BARRIER OF $^{153}Tb^{*+}$

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The increased fissility of systems with high angular momenta makes it possible to deduce fission barriers of relatively light nuclei. To accomplish this for a given case, it is necessary to measure, not only the fission excitation function, but also the excitation function for evaporation residues. The results can be analyzed by means of fits with statistical model calculations in which the variation of fission barriers with angular momentum is given by the rotating liquid drop model.[1] The fission barrier of the non-rotating system, B_f, and the ratio of the level density parameter for fission to that for particle emission, a_f/a_ν, are the two adjustable parameters. Beckerman and Blann have analyzed several systems and have reported values of B_f that ranged from 51% to 65% of the calculated liquid drop values.[2]

We have measured fission cross sections, σ_f, and evaporation residue cross sections, σ_{ER}, for ^{12}C + ^{141}Pr and for ^{20}Ne + ^{133}Cs at several energies. Both reactions lead to the compound nucleus $^{153}Tb^*$. The fission excitation functions are shown in the figure. The measurements extend to much lower σ_f values than those considered in Ref. 2. The value of B_f obtained by means of the statistical model fits was found to be very sensitive to the slope of the fission excitation functions, especially at the lowest energies, and rather insensitive to the absolute values of σ_{ER}. The solid curves in the figure indicate a simultaneous fit with B_f = 28.5 MeV and a_f/a_ν = 1.08. The difference in fissility between the two systems is due to the larger angular momenta involved in the Ne + Cs case. Since both excitation functions are described with the same values of B_f and a_f/a_ν, we conclude that the variation of the fission barrier with angular momentum is adequately described by the rotating liquid drop model.[1] The deduced B_f value of 28.5 ± 1.7 MeV is about 83% of the liquid drop value, in excellent agreement with recent calculations of Möller and Nix.[3] The very low B_f values of Ref. 2 were obtained due to one or more of the following effects: σ_f values have not been determined at sufficiently low energies; ranges of excitation energy are too limited; and (in some cases) deeply inelastic events contributed to the apparent fission cross sections.



+This work is supported by the Division of High Energy and Nuclear Physics, Office of Energy Research, U. S. Department of Energy, under contract W-7405-eng-26, with the Union Carbide Corporation.

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COULOMB FISSION OF $^{238}_{92}U$ AND $^{232}_{90}Th$ BY VERY HEAVY PROJECTILES

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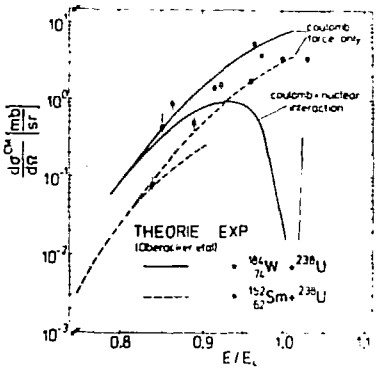
Coulomb fission of actinide nuclei ($^{238}_{92}U$, $^{232}_{90}Th$) by very heavy projectiles ($50 \leq Z_p \leq 92$) is studied within a semiquantal theory. Numerical coupled channels calculations show the following characteristics of the Coulomb fission (CF) process:

a) Prompt fission near the distance of closest approach is found to be negligible. Typical fission times are on the order of $T_{CF} \sim 1.5 \times 10^{-20}$ s.

b) The fragment angular distributions follow roughly a $1/\sin\theta_f$ pattern, but there are deviations at low incident energies.

c) Collective rotations play an important role (lowering of the effective barrier height $E_f(J)$).

d) As a consequence of multiple excitation, the theory predicts a strong dependence of the CF probabilities on the projectile charge number, $p^{CF}(180°) \sim (Z_p)^6$ in the case of ^{238}U at a given incident energy E/E_{Coul}[1]. This result has been confirmed by recent GSI experiments[2] (see figure). For a $^{232}_{90}Th$ target, the increase with Z_p is even steeper.



e) The theoretical excitation functions for $_{62}Sm$, $_{74}W \rightarrow ^{238}_{92}U$ are in good agreement with recent GSI data[2] at $E \leq 0.90\ E_{Coul}$, i.e. in the "pure CF region" where the electric interaction dominates (see figure). Some deviations at higher energies are due to the predominant nuclear force. The nonexistence of a Coulomb-nuclear interference minimum near E_{Coul} is likely to be caused by other fission channels (giant resonances, virtual transfer) which have been neglected in the present theory. Their influence can be described by an imaginary coupling potential; this is under investigation.

*Research sponsored by the Division of Basic Energy Sciences, U.S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation.
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CHARGED PARTICLE EMISSION FROM ^{194}Hg COMPOUND NUCLEI: ENERGY AND SPIN DEPENDENCE OF FISSION-EVAPORATION COMPETITION*

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The interpretation of particle and photon emission data from complex heavy-ion collisions frequently requires knowledge of the statistical and thermodynamic behavior of nuclei at high excitation and spin. Such information can come from systematic studies of reactions that proceed via equilbrated compound systems. We report results from experiments with twelve reactions that produce the compound system ^{194}Hg over the excitation energy range 57-195 MeV. Beams of ^{12}C, ^{19}F, ^{20}Ne, and ^{40}Ar ions in conjunction with appropriate targets have been used to measure H/He, fission, and evaporation residues (ER). Most of the evaporative ^{1}H and ^{4}He seems to be emitted prior to fission or instead of fission, and very little appears to come from the fission fragments. Table I summarizes the cross section data and displays the pattern of cumulative decay fractions (cross sections divided by the fusion cross section) for ^{194}Hg* over a wide range of excitation energy and spin. The probability of H/He evaporation increases dramatically with E^* and decreases slowly with spin, extending to very large spins ($> 60\hbar$) for $E^* \geq 100$ MeV. Fission in competition with evaporation becomes weaker for $E^* > 100$ MeV.

Table I. Experimental Results for ^{194}Hg Compound Nuclei

The Reaction Systems												
Beam	^{12}C	^{12}C	^{20}Ne	^{40}Ar	^{12}C	^{19}F	^{40}Ar	^{12}C	^{19}F	^{40}Ar	^{20}Ne	^{40}Ar
Target	^{182}W	^{182}W	^{174}Yb	^{154}Sm	^{182}W	^{175}Lu	^{154}Sm	^{182}W	^{175}Lu	^{154}Sm	^{174}Yb	^{154}Sm
E_{lab} (MeV)	77	104	125	196	121	135	221	167	184	272	252	340
E* (MeV)	57	82	80	80	98	98	100	142	142	141	194	195
Cross Sections (mb), ^{4}He/^{1}H Ratio, ℓ_{cr} and ℓ_{ER}												
^{1}H	-	204	114	55+	266	214	73.5+	544	490	242	1189	703
^{2}H	-	27	-	2.8+	24	25	6.7	65	87	31.4	189	108
^{3}H	-	9	-	1.09+	11	10	2.9	32	51	15.6	104	66
^{4}He	31	124	73	37	176	152	77	387	354	232	984	624
ER	545	475	291	94	458	351	86	539	312	79	225	124
Fission	23	330	663	~500	607	780	754	861	1066	919	985	1439
Fusion	568	805	954	594	1065	1131	840	1400	1378	998	1210	1563
^{4}He/^{1}H	-	0.61	0.64	0.67	0.66	0.71	1.05	0.71	0.72	0.96	0.83	0.89
ℓ_{cr}	25.5	36	53	66	45	59	83	65	76	101	85	142
ℓ_{ER}	25	27	29	26	29	32	26	37	36	28	36	39
Cumulative Decay Fractions												
^{1}H	-	0.25	0.12	0.093	0.25	0.19	0.087	0.34	0.36	0.24	0.98	0.45
^{2}H	-	0.034	-	0.005	0.02	0.022	0.008	0.04	0.063	0.03	0.16	0.07
^{3}H	-	0.011	-	0.002	0.01	0.009	0.003	0.02	0.037	0.016	0.09	0.04
^{4}He	0.055	0.15	0.076	0.062	0.17	0.13	0.092	0.24	0.26	0.23	0.81	0.40
ER	0.96	0.59	0.305	0.16	0.43	0.31	0.10	0.38	0.23	0.08	0.186	0.08
Fission	0.04	0.41	0.695	0.84	0.57	0.69	0.90	0.62	0.77	0.92	0.81	0.92

+Upper limit.

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GAMMA-RAY MULTIPLICITY FOLLOWING HEAVY-ION INDUCED FISSION[+]

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Gamma-ray multiplicity has been measured for the reactions ^{107}Ag (^{37}Cl, fission) and ^{112}Cd (^{32}S, fission), which have the same compound nucleus ^{144}Gd, for beam energies from 150 to 210 MeV in 10 MeV steps. A principle purpose is to determine the dependence of the saddle-point shape on angular momentum; such a dependence is predicted by the Rotating Liquid-Drop model of Cohen et al.[1]

The gamma rays were measured in an array of 12 3" x 3" NaI (Tl) detectors positioned in a hemispherical stand about the target, in coincidence with both fission fragments, counted in two solid state detectors positioned symmetrically about the beam.

The measured kinetic energy released in fission and the width of the mass spectrum both increase with increasing beam energy. The mean total gamma-ray multiplicity increases from 9.6 to 11.8 with increasing beam energy. The multiplicity decreases with increasing mass asymmetry and with increasing total kinetic energy of the fragments. The gamma-ray anisotropy W(0)/W(90) deviates from 1 as the mass ratio approaches unity. The dependence of the multiplicity and gamma-ray anisotropy on the mass ratio imply that the total spin of the fragment is higher for symmetric fission.

The results of the multiplicity measurements from the two different entrance channels have been used to decouple the angular momentum and the nuclear temperature in the fissioning nuclei, and to calculate the derivative $d\langle \ell \rangle / d\langle J_1 + J_2 \rangle$, which is expected to be proportional to the scission-point moment of inertia. The uncertainties in the results do not allow definitive conclusions about the dependence of this derivative on angular momentum; the averaged results indicate that the scission-point moment of inertia is larger than that of a system of two equal sticking spheres.

[+]This work was supported by the U.S. Department of Energy.

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TOTAL KINETIC ENERGY RELEASE IN THE REACTIONS ^{232}Th(^{4}He,^{4}He'f) AND ^{238}U(^{4}He,^{4}He'f) AND THE SYMMETRIC MASS SPLIT OF ^{232}Th

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The total kinetic energy release in the fission processes ^{232}Th, ^{238}U(^{4}He,^{4}He'f) has been measured at E(^{4}He)=50 and 120 MeV as function of excitations energy E_x with the double energy method. The ^{4}He-particles scattered inelastically were recorded in a counter telescope at 50 MeV bombarding energy and in the QMG/2 magnetic spectrograph at 120 MeV with a resolution of 70 keV. The preneutron emission masses and energies were determined using excitation energy and mass dependent ν_p-values. Fig. 1 displays the $\overline{TKE(E_x)}$ results for ^{232}Th and for ^{238}U [1]. The slopes $d\overline{TKE(E_x)}/dE_x$ for E_x from fission threshold B_f to 8 MeV are + 1.48 ± 0.4 MeV/MeV for ^{232}Th and - 1.1± 0.6 MeV/MeV for ^{238}U at 120 MeV and - 0.8±0.3 MeV/MeV for ^{238}U at 50 MeV [2].

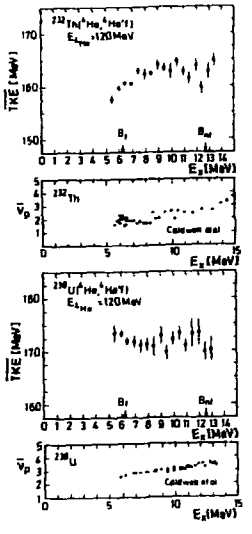


Fig. 1

Insight into the symmetric and asymmetric mass divisions for ^{232}Th as function of excitation energy is given in fig. 2, where the ratio of the symmetric yield (A_H=115-117) to the smooth total mass yield is displayed.

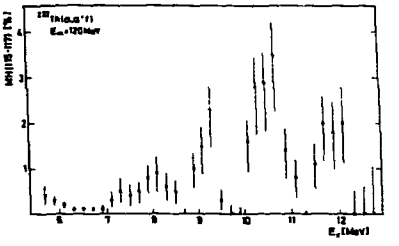


Fig. 2

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SEARCH FOR TIME DELAYS IN THE 1160-MeV $^{136}_{54}Xe$ + $^{208}_{82}Pb$ REACTION*

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We are searching for time delay effects in the deep inelastic reaction 1160-MeV ^{136}Xe + ^{208}Pb. According to Anholt[1]) a variation of the reaction time with total kinetic energy loss[2]) (-Q) would produce a Q-dependence of the K-vacancy production probability P_K in the target-like reaction products. (Zero time delay would give an essentially Q-independent value of P_K.)

Projectile-like particles were selected by a gas ΔE - surface barrier E detector system at 35±4° with respect to the beam. X-rays were detected in a planar Ge detector at 90°, provided with a 0.01" Cu absorber to reduce Xe and lower energy x-rays. For the elastically scattered Xe particles we find P_K=0.14±0.02, in good agreement with calculations of Reinhardt et al.[3]). For the inelastic projectile-like particles we find a dependence of the target-like x-ray production probability P_x on Q. We also measured the total gamma ray intensity I_γ in a Ge(Li) coax detector (low-energy cutoff ~ 300 keV) as a function of Q. We assume that internal conversion of the gamma rays gives a contribution to P_x which is proportional to I_γ, with a proportionality coefficient k independent of Q. Furthermore we assume that at larger -Q values, fission of the target-like reaction products reduces the number of experimentally detected target-like x-rays by a factor f(Q)[4]). Hence we fit the experimental target-like x-ray production probability by the relation $P_x(Q) = [\omega_K P_K(Q) + k\, I_\gamma(Q)]f(Q)$, where ω_K is the K fluorescence yield (≈0.96) and f(Q)≈1 for -Q≲ 100 MeV. The extracted values of f(Q), shown in the table below, appear to be reasonable[4]). At present we can only state that for -Q≈100 MeV the nuclear time delay is shorter than ~ 4×10^{-21} sec. We hope that in a more refined version of this experiment, with an additional detector for the unfissioned target-like particles, a better estimate of time delay effects can be made.

-Q(MeV)	f(Q)
140-260	0.4 ± 0.1
200-320	0.3 ± 0.1
260-380	0.3 ± 0.2
320-440	≤0.2
380-500	≤0.15

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†Recipient of Swiss National Science Foundation Fellowship (1979-80).

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SEARCH FOR COMPOUND-NUCLEUS X-RAYS IN 250-288 MeV Ar+Pb, Th REACTIONS*

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Gugelot[1]) first suggested that it should be possible to detect compound-nucleus (CN) x-rays, i.e. x-rays resulting from the formation of a relatively long-lived CN system in a nuclear reaction. If the particle detector cannot distinguish particles originating from CN and from other inelastic reactions, the expected number N_x is

$$N_x = \omega_K F_c N_p P_{in} \lambda_K \tau_c/(1+\lambda_K \tau_c). \quad (1)$$

Here ω_K is the fluorescence yield, F_c is the (angle dependent) fraction of particles originating from CN reactions, N_p is the total number of particles detected in the selected energy bin and angular opening, P_{in} is the probability of forming a K vacancy in the united atom on the way into the collision, λ_K is the decay probability of this vacancy and τ_c is the mean life of the CN system. CN x-rays have been detected in proton-induced reactions[2,3]). A model calculation by Anholt shows that with heavier projectiles CN x-rays should also be found[4]). A search in 350-MeV ^{84}Kr induced reactions on targets between K and Y indicated that the dominant production of united-atom x-rays is due to internal conversion in evaporation residues[5]). This effect should be avoided in fusion-fission reactions with high-Z targets.

250-288 MeV Ar beams were directed onto 800 $\mu g/cm^2$ Pb and Th targets. Fission-like reaction products were selected by their energy in a Si surface barrier detector placed at 40° or 60° with respect to the beam. X-rays were detected in a planar Ge detector at 90°. In the x-ray energy region of interest (near 150 keV) a continuous pulse height spectrum with an intensity of ~ 0.02 pulses/keV per detected particle was found, which far exceeds the expected intensity of CN x-rays. On the basis of Eq. (1) our results permit at best to set an upper limit of ~ 10^{-18} sec for the product $F_c \tau_c$, if $P_{in} = 0.01$, as reasonable estimates suggest.

*Work supported in part by the National Science Foundation. This experiment was performed at the Superhilac Accelerator of the Lawrence Berkeley Laboratory.

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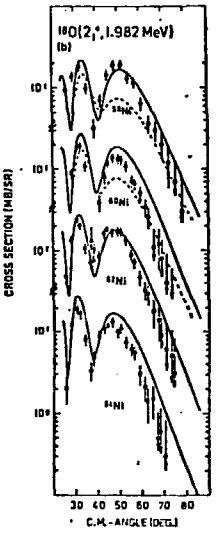
SEMI-MICROSCOPIC DESCRIPTION OF HEAVY-ION SCATTERING[+]

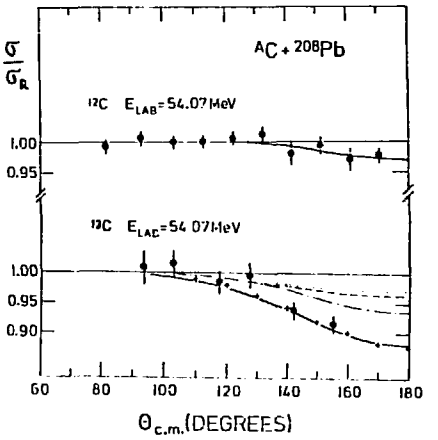
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In the semi-microscopic model of the scattering of nuclei near closed shells we separate the interaction into core and valence terms. The diagonal core term is taken as the empirical optical potential for the closed shell nucleus while the collective model is used to account for core-polarization. Valence matrix elements are computed by folding single-particle states with the empirical (complex) nucleon optical potential. This approach was first used to explain the failure of the collective model for ^{18}O excitation[1]. It has been applied to the elastic and inelastic scattering of $^{17}O + {}^{40}Ca$[2], where single-particle effects dominate but collective contributions are still important. We have further found good agreement in a systematic analysis of $^{17,18}O$ scattering for a range of targets and energies. We propose to analyze sub-Coulomb data to more specifically test the imaginary part of the valence potential[3].

An example from the systematic analysis is shown by the excitation of ^{18}O by various Ni isotopes. The solid curves are CC calculations including reorientation and two-step transfer processes. The dashed curves result if only the core term is used. Some results for sub-Coulomb scattering are also shown[3]. The full valence potential and its imaginary part only give the dashed and dotted curves, respectively. Adding a core potential, chosen to fit the ^{12}C data, results in the dash-dotted curve. The final result includes coupling to the observed transfer channels as two-step processes (solid curve).





+ Supported by a grant of the BMFT, Fed.Rep. of Germany

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4 π MEASUREMENTS OF CHARGED PARTICLES USING A STREAMER CHAMBER

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L.S. Schroeder and K.L. Wolf*
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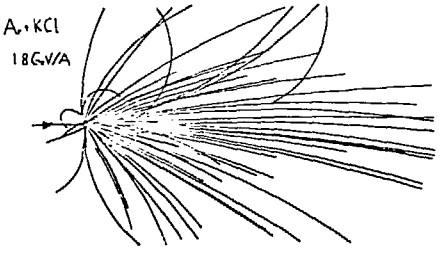
and

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In reactions of heavy ions at relativistic energies, the number of charged particles in the final state often exceeds the total charge of projectile and target eg. up to 60 for Ar+KCl. In order to extract information about the reaction mechanism it is necessary to obtain a measurement as exclusive as possible. A triggered streamer chamber offers the possibility of detecting charged particles with 100% efficiency in a 4π geometry. We have used the Berkeley streamer chamber to study p and Ar induced reactions at energies between 400 MeV/A and 2.1 GeV/A. The chamber, with a sensitive volume of 126x59x40 cm^3 is placed inside a 13.2 Kgauss field. The primary ionization of the reaction products is amplified by a factor of 10^8 by a 10 ns 700 KV pulse applied across the chamber, generating a row of streamers along each track. For each event 3 pictures are taken with high speed 35 mm film. The chamber can be triggered 3 to 4 times per sec. The maximum frequency is given by the film advance mechanism and the charging time of the Marx generator.

The frames are scanned and measured manually. After reconstruction of the tracks in three dimensions, the particles momenta and emission angles are extracted. The streamer chamber has proven to be a very powerful detector, its main characteristics are: 4π solid angle and 100% efficiency for charged particles; lower threshold of less than 1 MeV for protons; vertex position resolution of ∿1 mm; $\Delta P/P$ <5%; angle resolution $\leq 1^{o}$; good efficiency for detection of neutral and charged particle decays, limited charge resolution.

Some of the modifications that have been done or are in progress to improve the image quality, particle identification, speed of reconstruction and flexibility of the detector are: use of ppm of isobutane, stabilization of the Marx generator, use of image intensifiers, setup of external hodoscopes, semiautomatic reconstruction and use of CCD cameras and image digitalization.



*Work supported by the Division of Nuclear Physics of the U.S. Dept. of Energy under contract W-7405-eng-48.
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A GLOW MEMORY CHAMBER FOR USE IN THE MEASUREMENT OF HIGH MULTIPLICITY EVENTS[†]

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It has been proposed[1]) to eliminate the usual x-y correlation ambiguities introduced by multiple tracks in a wire chamber by employing the chamber itself as an information storage device. Hits in the chamber ignite glow discharges at the locations of thi hits. Sequentially perturbing one chamber coordinate and sensing this perturbation transmitted via the glow discharges to the other coordinate allows the reading out of the x-y coordinates of the hits in a correlated way. This method should prove considerably less expensive than other solutions to the multiple track, x-y correlation ambiguity.

Prototypes of such detectors have been constructed by the authors. Studies of the properties of glow discharges and the effects of such properties on detector design will be discussed. The design and performance of a readout system will be described. Plans for future employment of a glow memory chamber as a vertex detector for the HISS spectrometer at the Bevalac will be discussed.

[†]This work was supported by the Nuclear Science Division of the U.S. Department of Energy.

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RESPONSES OF INORGANIC AND ORGANIC SCINTILLATORS, AND CERENKOV RADIATORS TO RELATIVISTIC HEAVY IONS[†]

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Exposure of several types of organic scintillators, an alkali halide (NaI:Tl) scintillator, and a variety of Cerenkov radiators to relativistic Ne, Ar, and Fe ions at LBL's Bevalac has provided detailed response information previously unavailable for these heavy ion detectors. It has been found that NaI:Tl response follows a nearly Z-independent (i.e., only dE/dx dependent) curve already established for e^-, p, and α response[1]). To explain dose distribution insensitivity, as well as relative quenching, a model incorporating migration and interaction of free and self-trapped excitons, free holes and electrons, and trapping sites is presented. Data from a wide variety of organic scintillators is presented, along with empirical response expressions for some widely used commercial plastic scintillators. Determination of a detailed response model for these complex systems is still underway. Cerenkov radiator data for Ne, Ar, and Fe has been used to place limits on classical and QED corrections to a first order, Z^2, Cerenkov emission process[2]). In addition, range-energy data taken during these runs is presented, demonstrating the importance of higher-order corrections to stopping power in this charge-energy regime.

[†]This work was supported by the Nuclear Science Division of the U.S. Department of Energy.

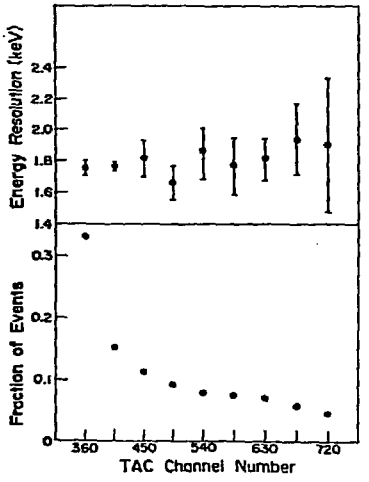
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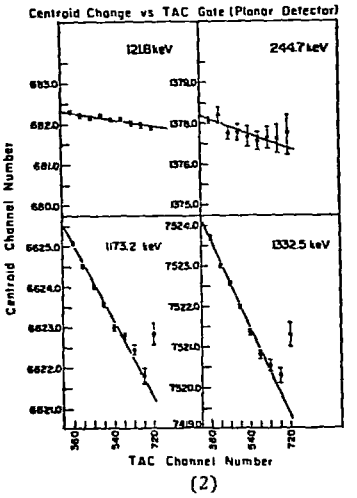
PAINLESS IMPROVEMENT OF Ge DETECTOR ENERGY RESOLUTION*

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An important aim of γ-ray spectroscopy with Ge detectors is to obtain the best possible energy resolution. We have demonstrated that this resolution can be significantly improved by pulse rise time discrimination without any loss of detector efficiency. In the example below we shall discuss our results for a planar, intrinsic Ge detector with an area of 1000 mm^2 and a depth of 1.3 cm. Using standard fast coincidence techniques with branched preamplifer signals we recorded coincident rise time and pulse height information on magnetic tape for off-line analysis. The energy resolution, plotted as a function of the rise time, is shown in figure 1 where the total resolution is 1.84 keV (FWHM at 1332 keV). No significant rise time dependence is apparent in the energy resolution. In figure 2 the centroid shift for various energy γ rays is similarly plotted. Here a striking rise time dependence is seen, particularly at higher γ-ray energies. At 1332 keV a 0.6 keV shift was observed between the fastest and slowest rise time gates. The centroid depends linearly on the rise time so we have developed computer software methods to reconstruct the energy spectrum while removing that shift. After this correction the resolution was improved to 1.77 keV without the loss of any events. Although the improvement is small, we have also found that a large, neutron damaged, coaxial detector with 4.9 keV resolution could be improved to 2.3 keV (FWHM) by the same technique. In that case only the faster rise times were usable because the slow rise time pulses had intrinsically poor resolution. In addition to the resolution improvement we have also demonstrated a substantial increase in the peak-to-background ratio using pulse rise time discrimination techniques.



(1)



(2)

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TRACE PROGRAM COMPILER*

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Recent studies have shown that nuclear phenomena can be partitioned into secular and fluctuation parts[1]. Statistical spectroscopy champions the former; low-order moments of products of operators suffice to determine locally averaged results. For example, traces of H and H^2 determine, respectively, the centroid and width of a spectrum. Traces of products of the type $OH^{\mu}OH^{\nu}$ are required to determine the secular behavior of the strength distribution of an excitation operator O. Moment methods have also been shown to hold promise in effective interaction studies[2].

Although algebraic forms for traces of products of operators can be generated in a straightforward manner, fast numerical calculations require efficient usage of various symmetry relations within and among the operators. We have developed a "compiler" which takes over the tedious process of writing FORTRAN codes for each type of product operator. The compiler is capable of handling configuration traces of products of up to eight angular-momentum coupled operators, each of which may be of particle rank two or less. While numerical evaluations require the defining matrix elements of each basic operator, input to the compiler are algebraic equations produced, for example, by another program[3] that utilizes angular moment recoupling and pattern recognition algorithms to generate the closed diagrams associated with contractions (Wick's theorem) of creation-annihilation operator pairs[4]. The compiler generated codes are optimized to include permutation and exchange symmetries within each operator as well as among equivalent members within a product.

Codes for configuration traces of H^3 and H^4 illustrate practicality of the procedure and allow the open question on the validity of the Gaussian assumption for spectral intensities of partitioned spaces to be addressed.

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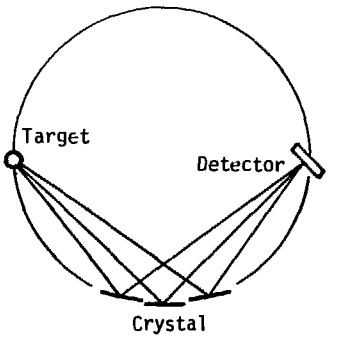
A POINT-FOCUSING GRAPHITE CRYSTAL SPECTROMETER FOR LOW ENERGY PIONIC X RAYS[†]

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A reflection-type point focusing graphite crystal spectrometer has been developed for the purpose of measuring pionic x rays in the 2-12 keV region, such as the 2p-1s transitions in pionic hydrogen and deuterium[1]).

The source (target), the diffraction crystal, and the detector are arranged along a 1.0 m-radius focal circle, as shown in the figure. The crystal assembly consists of an array of 20 graphite single crystal[2]) wafers, 0.1 mm thick, 1.2 cm wide and 10 cm high, each placed with its center on the focal circle. The crystallites are curved for point focusing in a plane through the normal to the focal circle. The lattice distance associated with the (002) reflecting planes is 3.35 Å and the Bragg angle for the 2.43 keV 2p-1s π^- H is 49.6^0. The 20 cm long detector is a position sensitive proportional counter based on pulse rise time differences. Its position resolution is 1.5 mm fwhm. The spectrometer is in a helium confinement.



Tests based on K x rays of S and Cℓ and L x rays of Ru show that the spectrometer is capable of an energy resolution of 25 eV at 2.5 keV in first order reflection. In third order a resolution of 23 eV at 7.5 keV was obtained. The over-all efficiency in first order is about 2×10^{-5}, which is about 10^3 times larger than that of a conventional transmission-type curved quartz crystal spectrometer.

Helpful discussions with A. Hahn, P. Lee, and K.-C. Wang are gratefully acknowledged.

[†] Work supported by DOE.

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2) Monochromator grade graphite was obtained from Union Carbide, Parma, Ohio 44130.

TANDEM ACCELERATOR MASS SPECTROMETRY AT ROCHESTER

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We have used the University of Rochester MP tandem accelerator and beam transport system as an ultrasensitive mass spectrometer to measure isotope ratios in the range 10^{-12} to 10^{-15}. For the long lived radioisotopes studied (see table), the improved sensitivity over decay counting and neutron activation analysis has reduced the amount of natural material required by more than 10^3 and may lead to the development of new million year chronologies. Possible nuclear physics applications include half-life determinations, solar neutrino detection, radiative capture, double beta-decay, and searches for superheavy elements and quarks.

Tandem accelerator mass spectrometry[1,2]) makes use of conventional heavy-ion acceleration and detection techniques. Negative ions are formed from 1 to 10-mg samples in a Cs sputter ion source, momentum analyzed, accelerated to 12 - 80 MeV, mass analyzed with a combination of magnetic and electrostatic deflection, then detected with a gas ionization counter or a time-of-flight detector. Stable isobars are distinguished by multiple energy loss measurements; molecules are eliminated by selecting charge states greater than two. Isotope ratios are determined by alternately changing all magnetic beam elements to select a stable isotope and then reading its current at the detector.

The presentation will include plans for a new high resolution injector and new post-acceleration analyzers, the latest results for the isotopes listed, and progress being made on the detection and measurement of other radioactive and stable isotopes.

Radio-isotope	Half-life	Isobars	Samples studied	Sensitivity[a] × 10^{15}
^{10}Be	1.6 My	^{10}B	Pure Be	7
^{14}C	5730 yr	^{14}N[b])	Woolly Mammoth,[c]) Mummy cloth[c])	0.3
^{26}Al	0.72 My	^{26}Mg[b])	Pure Al	10
^{36}Cl	0.31 My	^{36}S,^{36}Ar[b])	Groundwater,[d]) Meteorites[e])	0.2
^{129}I	16 My	^{129}Xe[b])	Meteorites[e])	300

a) The lowest measured atom ratio in reagent samples.
b) The problem of interference from these isobars is removed by the use of negative ions, an advantage for acceleration with a tandem.
c) With M. Rubin, U.S. Geological Survey, Reston, Virginia.
d) With H. Bentley, University of Arizona.
e) With J.R. Arnold, K. Nishiizumi, M.T. Murrell, R.C. Finkel, University of California at San Diego.

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Work supported by the NSERC of Canada.
† General Ionex Corporation, Newburyport, MA 01950.
†† Work supported by the National Science Foundation, Grant PHY 78-22698.

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THE POSITRON-A LEPTONIC PROBE FOR MATERIALS SCIENCE*

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Nuclear science has continuously been a source of new techniques for the study of other basic sciences. The prediction, discovery, and description of the nature of the positron and its eventual annihilation has motivated chemists and physicists alike to uncover ways in which these properties might be employed in studies at the atomistic and molecular level. The contemporary importance of the positron in materials science derives from its ability to describe the environment in terms of the momentum distribution of the electrons with which it annihilates. This property, coupled with the additional propensity for the positron to become trapped at atomic vacancy defects yields a probe which is both sensitive and specific for vacancy-like structures. Various examples of both defect and electronic structure studies where positrons have been utilized will be described so as to demonstrate the usefulness of the technique.

Studying the positron's interaction in a material involves either measuring the distribution of momenta of positron-electron pairs, or the lifetime of the positron which measures the positron-electron wave-function overlap. The tools for performing such measurements are familiar to nuclear scientists; angular correlation detectors, gamma-ray energy spectrometers, and fast, high resolution, timing techniques. However, the implementation of these methods are far from standard. A description of the special advances made in counting methods which have resulted from positron research may prove of general interest to nuclear scientists. Examples of the types of procedures used to stabilize the pulse-height information obtained in positron experiments, particularly the post acquisition digital techniques, will be described. Because the counting techniques and requirements in positron spectroscopy are often at the edge of instrumental technology, positron annihilation has significantly contributed in its own way to the continued advancement of the very technology which fostered it.

*Work supported by the U.S. Department of Energy.

PHYSICAL PARAMETERS OF GAMMA-RAY SPECTROMETER

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The sensitivity of a gamma-ray spectrometer depends on few factors,such as background,system energy resolution,energy calibration ,detector effeciency,sample shape,time allowed for measurement,accuracy required for results and data analysis.

In this work we studied some of these parameters,such as sensitivity of the FWHM of full energy peak as a function of energy per channel,statistical accuracy,counting rate and effect of digitization.The value of FWHM was found to increase if the peak lies between two channels or if the energy per channel exceeds 1.2 KeV.The FWHM was found to be optimum at statistical accuracy better than 2 % and increases for higher values.

In energy caliberation we found that to use a single nucleus emitting gamma-rays with different energies is more convient to avoid and reduce uncertainties arising from the geometry variations of different sources. ^{226}Ra was found to be suitable for these studies.The temperature of the measuring room was kept constant during the measuring time to prevent thermal effects on the electronics.The counting rate did not exceed 1000 count per second to minimize summation.A combined function[1]),was used to fit the full energy peaks of the emitted gamma-rays and its tailing.High order polynomial and a straight line formulae were used for energy calibration.Deviation from linearity between the input and the output values of energies were found to be less than 20 eV in the energy range between 184 and 2447 KeV.

The relative and absolute effeciency of the detector used were measured and compared with an imperical function and with a physical model for effeciency[2]).The imperical function was found to be quite satisfactory,while a clear deviation for the physical model values from the expermental results can be noticed. Relative intensities could be calculated with accuracy better than 0.05 % for energies between 500 and 2447 KeV.For energies less than 500 KeV the accuracy reaches 1.7 %.

The discripancy between the physical model results and the experimental data may be due to the difficulty of explaining a coaxial detector geometry by physical model and could be due to self-absorption in the source and the effect of the dead layers in the path between the source and the detector.

In conclusion after calculating the minmum detectable activity of some energies and compare it with the available data it seems that in order to acheive small progressin sensitivity a large expenditure is needed.

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February 1979.

MEASUREMENT OF THE ^{32}Si HALF-LIFE USING TANDEM ACCELERATOR MASS SPECTROMETRY

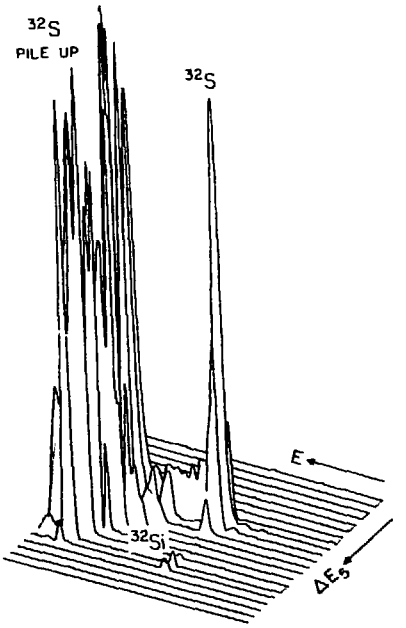
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In one of the first applications of tandem accelerator mass spectrometry[1]) to nuclear physics problems, we have determined the ^{32}Si half-life (~300 years) by counting both the decay rate and the number of atoms of ^{32}Si in an enriched sample ($^{32}Si/^{28}Si \approx 10^{-10}$) and then using the relation $dN/dt = -\lambda N$. Because of its convenient half-life, this nuclide is extremely useful in dating groundwaters with an age up to a few thousand years[2]). Unfortunately, uncertainties in the production cross sections for ^{32}Si have hitherto prevented an accurate measurement of its half-life by conventional methods. An unconventional method[3]) was to measure the specific ^{32}Si activity of polar ice as a function of depth, assuming a constant production rate.

We determined the number of ^{32}Si atoms by placing ~5 mg of SiO_2 in the Cs sputter negative ion source of the accelerator, then measuring the stable $^{28,29,30}Si$ currents and ^{32}Si counts following magnetic and electrostatic analysis[4]). The interfering ^{32}S had a rate of $\sim 10^4$ s^{-1} when the ^{32}Si rate was ~1 min^{-1}; with no background, this was adequate for 10% statistics. The $^{32}Si \rightarrow {}^{32}P \rightarrow {}^{32}S$ decay rate was determined by allowing ^{32}P ($t_{1/2}$=13 d) to reach equilibrium, then flushing it from the sample and counting it.

The figure shows the good separation between the ^{32}Si and ^{32}S ions counted in the gas heavy-ion detector. E is the total energy and ΔE_5 is the energy lost under the final ΔE plate. Lower ΔE_5 ^{32}S ions were removed from the spectrum with a hardware gate. We expect that after corrections, e.g. for dead time, pileup, mass fractionation and beam current calibration, these data should yield a half-life accurate within about 15%.



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* Supported by the National Science Foundation under grant PHY. 77-27943.

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NUCLEAR POLARIZATION OF ^{15}N VIA ION-BEAM-FOIL INTERACTION

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The ion beam surface interaction at grazing incidence (IBSIGI)generates highly oriented atomic states,and nuclear spin polarized ions are produced via hf-interactions. Both single and multiple IBSIGI were reported[1]. By single reflection,nuclear polarizations of P_I= 14% in ^{14}N(I=1), and P_I= 6.8% in ^{7}Li(I=3/2) were produced.

In this paper,the transmission rather than reflection technique is used. A 600 kev $^{15}N^{+}$(I=½) beam passed through a foil tilted 60° with respect to the beam axis,and a perpendicular foil(both made of 20 $\mu g/cm^2$ thick carbon). After the first foil,highly oriented atomic states are produced,which result in large circular polarization fractions in the fluorescent radiation.By hf-interaction,the orientation can be transferred from the electronic shell to the nucleus,or vice versa.In the second foil,which is perpendicular,and therefore does not produce any polarization,the interaction does not affect the nuclear spin,but attaches a new unoriented electronic shell to the nucleus.Thus the circular polarization in the fluorescence after the second foil must stem from the transfer of orientation from the nucleus to the electronic shell and is therefore a direct measure of the nuclear spin orientation.To determine the degree of circular polarization, the Stokes parameter S/I is measured.

For ^{15}N II $2s^2 2p3s\,^3P$-$2s^2 2p3p\,^3D$ 5676Å line,after a tilted foil the S/I is equal to 8.5±0.8%;after double foils(60° tilted foil + perpendicular foil),S/I=1.6±0.4%. From the later values,the nuclear polarization of ^{15}N is calculated: P_I= 10.2 %.

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POLARIZED ALKALI ION BEAMS

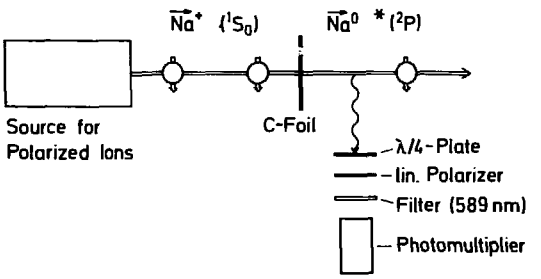
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Beams of aligned heavy ions, especially those having large deformations serve as a new tool for the investigation of heavy ion reactions [1]).Up to now such experiments have been performed using the ^{6}Li- and ^{7}Li-beams available at the Heidelberg EN-Tandem.For ^{23}Na as well it is possible not only to produce a polarized beam in an ion source but also to maintain the polarization to a large extent during the acceleration process.

1) Source for Polarized Alkali Ions

An atomic beam is polarized with the aid of a sextupole magnet and adiabatic high frequency transitions [2])(P_z resp. $P_{zz} \simeq 0.4$).The polarization is changed by switching the rf power.Highly efficient ionization occurs at the surface of a hot tungsten ribbon. Charge exchange to negative ions is performed in cesium vapor. Prior to acceleration the nuclear polarization of the ion beam can be determined by beam foil spectroscopy via the polarization of the light emitted after excitation of the ions in a thin carbon foil(see fig.).In order to increase the degree of polarization a more refined type of ion source is being tested:polarization of the atomic beam is achieved by optical pumping with circularly polarized light using a dye laser tuned to the Na-D_2-line. In a first experiment a polarization of more than 0.8 was detected by beam foil spectroscopy.



Detection of the nuclear polarization by beam foil spectroscopy

2) Depolarization during the acceleration process

The negative and the singly charged positive alkali ions in their ground state have an electronic spin $J = 0$. In the case of ^{23}Na the electrons can not be stripped off completely by the foil in the terminal of the tandem (terminal voltage 6 MV). One has to face the problem of depolarization via hyperfine interactions. Charge states with an even number of electrons were selected: Na^{7+} (current at the target 100 nA) and Na^{9+} (100 pA). The polarization was deduced from the anisotropy for coulomb excitation to the first excited state of ^{23}Na. The backward scattered particles and the 440 keV-γ-rays were detected in coincidence. Up to now values of 30 to 60 % of the initial alignment have been observed with a Na^{9+} beam.

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THE EVALUATION OF THE NEUTRON AND GAMMA-RAY RESPONSE OF TWO DETECTORS FOR NEUTRON-CAPTURE STUDIES

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Two special hydrogen-free scintillators have been tested in order to determine their suitability for detection of the γ-rays induced by neutron capture. These were NE 226, based on fluorocarbon, and NE 230, based on deuterium. Evaluation was carried out in a standard detector assembly appropriate to neutron-capture measurement.

Neutron sensitivity was measured using the mono-energetic neutrons from the ^{7}Li (p,n) ^{7}Be reaction, at the 3 Mev Van de Graaf at U.K.A.E.A., Harwell. A neutron energy range of 25 keV-220 keV was covered for both free-standing and heavily shielded detector configurations. γ-ray sensitivities were determined from measurements from a range of γ-ray sources, and the resultant response matched to a computer calculation.

Operational tests were carried out on the 30 Mev electron linac of the above establishment, whose 6 ns pulsed beam was employed to provide a neutron flux for neutron capture on europium.

The low neutron sensitivities observed were approximately 10^{-4} for the NE 230 detector when unshielded, and in general a factor of 2 more for the NE 226 - but further enhanced at 30 keV neutron energy by a resonance in the neutron capture cross-section of fluorine. Use of shielding further increased the neutron sensitivity by nearly an order of magnitude, when used in a nearly isotropic neutron flux.

PHOTOGRAPHIC IMAGE ENHANCEMENT USING THE PHOTOFISSION OF URANIUM

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A method is described for enhancing photographic images through the mechanism of etch tracks of fission fragments in glass. The photographic negative is first toned with natural uranium. It is then pressed against a glass plate and irradiated with high energy x rays (greater than 5 MeV). The induced photofission of the uranium then transfers the image in the negative to the glass plate. This process allows some discrimination against base fog. Information which was not otherwise visible in the original negative has been extracted by this method from film that was underexposed as much as six "f" stops.

A Systematic Study of the Transport Characteristics for the Gas-jet Technique with a Long Capillary Transport Line

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A gas-jet transport system with a capillary of 30m long has been used to transport and measure the reaction products produced by 14.1Mev neutron on Al and Mg,as well as the neutron-induced fission fragments of U(Fig.1). A systematic study of the transport characteristics is described as follows:

The relative transport efficiency was first measured for pure C_2H_4, He, N_2, CO_2 and mixtures of any two of these gases with different mixing proportions. Then by using an UV aerosol producer, the selectivity of the pump oil, CCl_4, $AgCl$ as additives was studied for the transport of various products. Our experiments indicate, we have to add additives to the pure He to get high transport efficiency, while for C_2H_4 no addition is needed, but in the former case higher transport velocity can be obtained. From the experiments for gas mixture we have got the optimum ratio of mixture of C_2H_4+He for the transport efficiency and velocity.

We have theoretically analysed how various dynamical parameters of gases influence upon the transport characteristics. The result of the experiments shows: to obtain both the maximum transport velocity and efficiency, the Reynolds number Re should be taken as Re≈2800 in turbulence region, in which the optimal option is the using of the large i.d. capillary (Figs.2 & 3, curveⅡ) instead of the high pressure in the target chamber (curve I) as well as in laminar region, and the Re-number for further increase of the transport velocity at the expense of the efficiency is indicated in Figs.2&3.

The absolute transport efficiency and transport time have been measured for C_2H_4+He. The transport efficiency was found to be (39±3)% and (69±5)% for ^{27}Al (n, p) ^{27}Mg products, and ^{238}U(n, f) fission fragments respectively, the reproduction of the relative efficiency was within about 2% for 5 hours. The experimental transport time of this system was 1.4±0.4 sec, which is in agreement very well with our theoretical value of 1.49 sec.

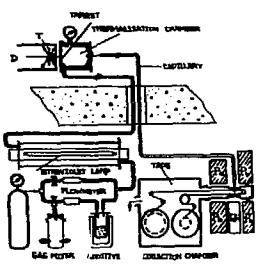


Fig.1

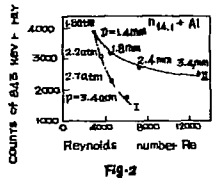


Fig.2

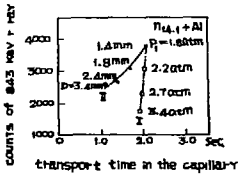


Fig.3

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A HYBRID STREAMER CHAMBER FOR LOW ENERGY NUCLEAR PHYSICS*

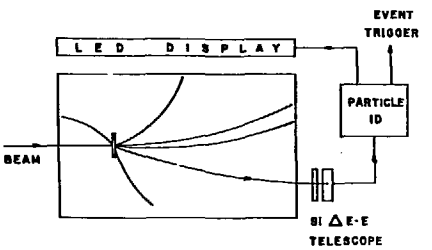
K. Van Bibber,** M. M. Murphy, W. W. Pang, B. G. Harvey, D. L. Hendrie, J. Mahoney, R. Legrain, W. D. Rae, T. J. M. Symons

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A small streamer chamber of active volume (17.1 x 11.2 x 5.1 cm^3) has been constructed and used at the Lawrence Berkeley Laboratory 88" cyclotron. In the first application of this visual technique to low energy nuclear physics, approximately 50,000 photographs of the reactions ^{16}O + Ne, ^{12}C + Ne were taken over the past year in a survey of reaction mechanisms in the range 20-35 MeV/nucleon.[1)]

We report here our first experiences with the chamber operated in a hybrid mode. Thus rather than sampling with an unbiased trigger (normally consisting of an array of scintillator-phototube detectors), more exclusive channels are identified and selected by means of a solid-state ΔE-E telescope. The leading particle nuclear charge, Z, is thus included in the same photographic frame as the remainder of the final state by means of a hardwired particle identifier and light-emitting diode display. Although the energy of the trigger particle exists virtually in the film plane (Z and Bρ), it is envisioned that ultimately ΔE and E will be event-mode recorded by computer along with an event number which simultaneously indexes the photograph, affording superior particle identification and energy information.

The hybrid chamber currently is being used to study the transition from transfer to fragmentation in the interaction of ^{16}O + CsI between 10 and 20 MeV/nucleon by means of the associated charged particle multiplicity and angular correlation with the fragment Z.



* This work supported by the Nuclear Science Division of the U.S. Department of Energy, under contract number W-7405-ENG-48.

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PERFORMANCE AND FIRST EXPERIMENTS WITH THE "SPIN-SPECTROMETER" AT THE HHIRF*

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A 4π γ-ray multidetector system consisting of an array of 72 NaI detector elements forming a spherical shell has been constructed. This spectrometer has been installed at the Holifield Heavy-Ion Research Facility. The data acquisition system permits one to record simultaneously on an event-by-even basis the γ-ray multiplicity, the total and individual detector pulse heights, the associated neutron multiplicity, the angular correlations and time relationships among most of the γ-rays in each cascade.

The 18-cm thick detector shell has a 36-cm diameter cavity enclosing a spherical 33-cm diameter scattering chamber. The individual detector elements were tested separately before installation in the spectrometer. The average energy resolution for 662 keV γ-rays is 8.6% and varies from 7.7% to 9.0%. The average timing FWHM and FWTM are 2.1 ns and 4.7 ns, respectively, measured with ^{60}Co source using an 80-keV threshold. The total scattering from all the detectors into one detector element is 19% for 662 keV and 24% for 835 keV relative to the total singles counting rate, as measured with all detectors inserted in the spectrometer. The five nearest neighbors account for 77% of the total scattering yield.

The measured responses of the entire spectrometer for a large variety of experiments with heavy-ion induced reactions will be discussed. These include the response to γ-cascades $\{E_i\}_{i=1,\ldots M_\gamma}$ of multiplicity M_γ in terms of (1) total pulse height H, and number of responding detectors k, (2) the spectral response of each detector element incorporating the effects of scattering and coincidence summing, and (3) the response to neutrons including identification by time-of-flight. Results from the first experiments scheduled for late spring will be discussed.

*Work supported by United States Department of Energy.

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THERMALIZATION OF 14 MeV NEUTRONS FROM A PHILIPS PW5310 NEUTRON GENERATOR†

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A Philips PW5310 Neutron Generator was used to produce 14 MeV neutrons. (The neutrons are produced from D(T,n) and T(D,n) reactions in a hermetically sealed 'neutron tube' and the tanget is of 'self-loading' type in which a titanium tanget is kept saturated with tritium and deuterium and accelerated deuterons and tritons collide with the tritium and deuterium held by the titanium. The neutron tube is filled with a mixture of deuterium and tritium and a pressure regulator is used to achieve continuous replenishment of the tanget.)

Paraffin wax was as moderator. The neutron tube was placed vertically in a cylindrical cavity in a 75 cm x 75 cm x 75 cm block of paraffin. The neutron source was at the centre of the block. Samples for irradiations were positioned in other cylindrical cavities. In our arrangement samples were approximately in the horizontal plane containing the neutron source and at three distances, d_1=10.5 cm, d_2=19 cm and d_3 = 29 cm, from the source. Excluding the radii of the cavities, the pathlengths in the paraffin were 4 cm, 12.5 cm and 22.5 cm respectively. We investigated the activation of NaI and Ag NO_3. Samples were solutions in water and were contained in small vials (10 cm^3 volume). The activities of interest were 25 minute-half-life β activity of ^{128}I and 2.42 minute-half-life β activity of ^{108}Ag. The irradiation times were 50 and 12 minutes respectively. Several samples of different concentrations were used and to account for epithermal (i.e. epicadmium) neutrons bare as well as cadmium-covered samples were irradiated. The β activity was measured by using Mullard G.M.tubes of type MX 124/01 which are specially designed for liquid samples. In each case the activity at the time of cessation of irradiation was determined from several integrated counts. Supplementary half-life measurements enabled us to take appropriate actions to exclude counts due to the possible presence of other activities.

We determined the relative thermal neutron flux at the three distances and values of 1, 0.48 and 0.11 at d_1, d_2, d_3, respectively, were obtained. The counting efficiency of the G.M. tube was estimated by using reference sources of ^{32}P and ^{90}Sr. Consequently, we estimated the thermal neutron flux at d_1 to be approximately $2 \times 10^4 n/cm^2/s$ for the 14 MeV neutron output of $10^8/s$ in 4π.

†This project was a result of M. Irfan's sabbatical leave at University of Malaya.

SPURIOUS ROTATIONAL ENERGIES IN THE YRAST LINE OF RARE EARTH NUCLEI

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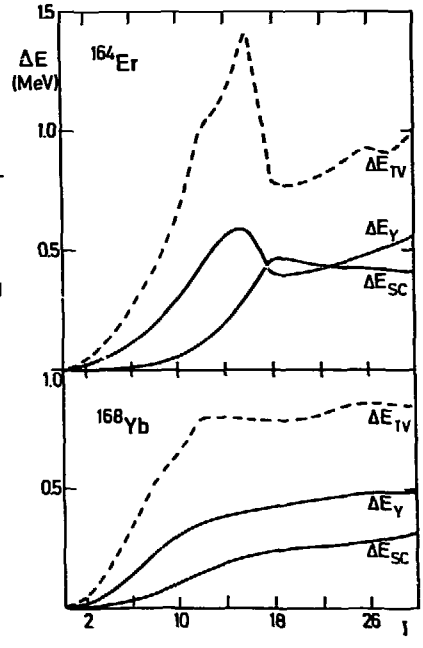
P. Ring

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Most of the microscopic methods to describe the strange behaviour of the yrast line in deformed nuclei are based on the cranking model. It is a mean field approach which conserves the quantum numbers of angular momentum and particle number only on the average. The energies calculated in this model contain spurious contributions of the form

$$\Delta E = \frac{\langle \Delta J^2 \rangle}{2\mathcal{J}}$$

which have to be substracted. There are several ways to determine the moment of inertia $\mathcal{J}$, which characterizes this energy shift. In the figure we show calculations in the pairing plus quadrupole model of Baranger + Kumar[1] for the nucleus ^{164}Er, which is a strong backbender and for ^{168}Yb which is not. ΔE_{TV} is obtained from the moment of inertia of Thouless and Valantin[2]; it corresponds to the RPA-ground-state correlations connected with the spurious rotational motion. ΔE_{Y} is calculated with the moment of inertia of Yoccoz, it is justified by projection onto good angular momentum[3]. ΔE_{SC} is obtained from the selfconsistent moment of inertia. All three curves are normalized to I=0. We find that the spurious energy ΔE changes between I=0 and I=28 more rapidly for ^{164}Er than for ^{168}Yb. In the backbending region we observe strong annomalies which might cause serious doubts in the validity of the cranking approach in this region. However, one has to keep in mind, that there are additional correlation energies connected with vibrational motions not taken into account so far. It has been shown[1] within the RPA approach that they also show a strange behaviour in the backbending region, which cancels to a large extend the anomalies resulting from the rotational spurious energy.



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HYDROGEN FILLED SELF-SHUNTED STREAMER CHAMBER

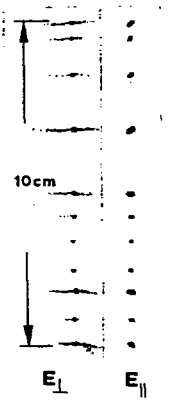
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The self-shunted streamer chambers (SSSC) offer the opportunity of seenig the vertex of the interactions on the nuclei of the filling gas and of photographing all the charged particle trajectories coming from the interaction (even the short ones) as in a cloud chamber [1, 2]), but with the difference that the SSSC are triggerable by external hodoscopes of counters several times per second ($\sim 3 + 5\ s^{-1}$) and are able to handle up to $\sim 10^6$ beam particle per second. On the basis of former results [3, 4]) and in view of foreseen experiments on $\bar{p}$ interaction on H, ^{2}H, ^{3}He and ^{4}He-nuclei[5]) to be performed at the new LEAR facility of CERN [6]) we have begun a systematic study of the 1 atm hydrogen filled SSSC. The figure shows a cosmic ray track photographed contemporary with two cameras placed with the axes at 50 degrees. The lens aperture was of f/5.6, the same for both the objectives. For this reason the points in the front view ($E_{\parallel}$) appear more luminous and larger than in the lateral view ($E_{\perp}$). The film was ILFORD HP5 400 ASA. As one can see the tracks in the SSSC are a succession of well localized plasma dots. The 13 sections high voltage pulse generator was that of Arkadiev-Marx type described in ref. 1 and the electric field on the SSSC electrodes was about 195 kV. The SSSC we used was a glass cylinder of 23 cm internal diameter and 7 cm internal height. The walls were 1 cm thick. The filling gas was an admixture of 98.5% of hydrogen and 1.5% of methane fluxed at 50 l h^{-1}.



[o]Present adress; JINR, Dubna, USSR.

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THE PLASTIC BALL, A 4π DETECTOR FOR RELATIVISTIC HEAVY ION REACTIONS

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Single particle inclusive data from high multiplicity events tend to indicate strong thermalization in relativistic heavy ion reactions. However, Bevalac and similar high energy accelerator research has passed from the stage where only one particle from each event is measured and has advanced to attempts to measure many or all of the charged particles produced in each event in order to look for collective effects that are predicted by different theories and indicated by latest experiment.

The GSI-LBL collaboration at the Bevalac is currently engaged in the design and fabrication of a spectrometer having nearly 98% of 4π solid angle acceptance. The spectrometer consists of two systems: the Plastic Ball and the Plastic Wall.

The Plastic Ball is a multidetector system covering a solid angle of 96% of 4π. Each element is a ΔE-E detector where the ΔE counter is a 4-mm thick CaF_2 crystal and the E detector is a 36-cm long plastic scintillator. Both are optically coupled and read out by one photomultiplier. The ΔE and E signals are separated by pulse shape analysis (phoswich idea). The shape and the geometrical arrangement of the counters was adopted from the SLAC Crystal Ball detector. In order to take into account the strongly forward peaked particle distribution a finer division was necessary in the region between 10° and 30°. This region contains 160 modules. 655 counters cover the angular range from 30° to 160°. Each detector provides particle identification and measures the particle energy in the range from 30 to 210 MeV for protons, from 45 to 330 MeV for deuterons, from 55-390 MeV for tritons, from 124 to 880 MeV for ^{3}He and from 135 to 980 MeV for ^{4}He. For slower or faster particles only a multiplicity information is obtained. Positive pions from 15 to 120 MeV are in addition to the ΔE-E identification detected by their delayed decay.

The Plastic Wall is a multielement time-of-flight detector that is placed 6 m downstream from the target and covers the most forward angles. The Plastic Wall serves together with an upstream counter as a trigger counter. Selection criteria concerning the multiplicity and the velocity of the forward particles may be applied, allowing, e.g., the study of extreme types of events where no beam velocity particles are in the forward cone. In addition certain patterns in the wall can be selected and used as a trigger, e.g., for semi-peripheral collisions.

Since the detection scheme is based on stopping the particles, the main domain of the spectrometer is the investigation of central collisions at low and intermediate Bevalac energies. The initial experiment, scheduled for summer 1980 will use a ^{40}Ar beam on ^{40}Ca and ^{208}Pb targets.

THE PLASTIC WALL

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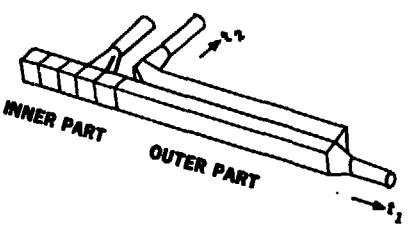
The Plastic Wall is a multisegmented TOF detector to measure at small angles the shower of reaction products from relativistic nuclear collisions. It covers an area of 192 x 192 cm^2 and consists of scintillators arranged in an inner and an outer area. The inner one is a square of 48x48 cm^2 consisting of 36 individual counters each 4 cm thick. At a distance of 600 cm from the target this area covers an angular region of about 0° to 2.5°. The outer region extends to ~9° and consists of 60 pairs of position-sensitive scintillation detectors. The Wall can be moved on rails and comparison of the time of flight at two different known distances allows an absolute time calibration if the mass of the detected fragment, e.g., the beam particle, is known. The distance of 6 m corresponds to flight times varying from 24 nsec at 800 MeV/n to 65 nsec at 50 MeV/n. The width of the scintillators of 8 cm results in an angular resolution of 0.75°.

The inner region of the Plastic Wall will provide the event trigger for both the Plastic Ball and the Wall. For high intensity experiments the inner part is removed.

The purpose of the Wall's outer region is to detect the reaction products of projectile fragments at angles between 2° and 9° with sufficient angular resolution and sufficient multiparticle detection capability. It is made of 60 position-sensitive double modules, each consisting of two scintillator rods with dimensions of 72 x 8 x 4 cm^3. Each scintillator of the double module is viewed by one photomultiplier at different ends (Fig. 1). The time difference between the two photomultiplier signals gives the longitudinal position of the particle the mean time gives the flight time from the upstream detector.

For high energy charged particles the dE/dx in one or both scintillators combined with time-of-flight determines Z and E/n. For energies below 120 MeV/n, particles are stopped in the wall. Thus the velocity measurement and the E information determines the mass of the stopped particles. The double coincident dE/dx information for particles above 80 MeV/n, furthermore, allows one to discriminate against neutron and γ response in the scintillators, which is rather important since as many neutrons as protons are expected for light projectiles at forward angles. In tests with beam particles, a time resolution in a double module of 350 psec (FWHM) was obtained without any off-line walk correction.

TOF-PLASTIC WALL



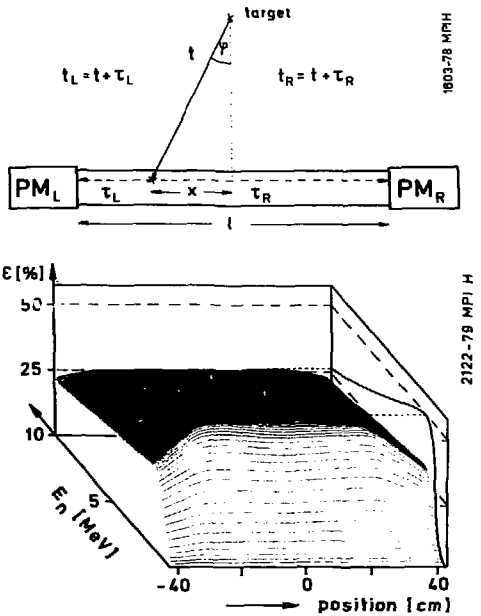
A LARGE POSITION SENSITIVE NEUTRON DETECTOR†

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For the measurement of neutron angular distributions a large position sensitive neutron detector has been developped. It consists of a quartz-tube of 1 m length with rectangular profile (11.5 cm height x 6 cm) filled with NE-213 and viewed from both ends by RCA 8854 photomultipliers (PM), see fig. upper part. The counter is designed to cover an angular range of about 50° (~145 msr) for a flight path of 1 m. Container materials and geometry have been optimized by means of Monte-Carlo-Simulations.

The position information is obtained from the difference between the light travelling times to the PMs (τ_R and τ_L in the figure): $x=1/2(\tau_L-\tau_R)\cdot c/n$ with c=light velocity, n=refraction index of NE-213. The energy is calculated from the neutron time-of-flight. Therefore a time signal is derived which is independent of the neutron detection position. Using the fact that the sum of the light paths is determined by the constant scintillator length, $l=(\tau_R+\tau_L)\cdot c/n$, the time-of-flight is given by $t=1/2(t_R+t_L-l\cdot c/n)$. The scintillator light is attenuated by absorption in the quartz walls and in the scintillator itself. This gives rise to a weak position-dependent light collection (factor 1.06 in the sum of lightoutputs between middle and far end) and to the fall off of the efficiency curves (see fig., measured with ^{252}Cf-source) only at the ends of the detector. In spite of its length the counter shows good n-γ-discrimination properties. The time resolution obtained for γ-rays is about 600 ps and depends on 3 components: 1) Geometry: ratio between thickness of scintillator and distance from the target, 2) signal to noise ratio and 3) variance of light paths. The latter is also given by the geometry and determines simultaneously the minimum position resolution of 5 cm. This value is already reached at energies of ~3-4 MeV and smears out to about 15 cm at low n-energies (1 MeV).



The detector has been succesfully used in measurements of a preequilibrium neutron component during deep inelastic collisions.

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A WIDE RANGE COMPUTER CONTROLLED ENERGY VARIATION OF CYCLOTRON AND BEAM HANDLING SYSTEM[+]

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At the Bonn Isochronous Cyclotron a versatile microcomputer system is developed enabling an automatic energy variation of about 75 % of the full energy range (7 - 14 MeV/amu). The beam handling system consists of two 90^{0} analysing magnets and ten quadrupole lenses. The computer control is supported by several autonomous beam stabilization control circuits yielding the optimum beam alignment and beam energy matching between cyclotron and analysing system. The analysing magnets are NMR stabilized to about $3 \cdot 10^{-6}$. The main task of the whole system is the study of extremely narrow and weak and/or broad resonances over a wide energy range.

The energy variation is carried out stepwise. The total number of steps, the step width and the starting energy are adjusted according to the experimental requirements. An energy change-over is performed within 20 - 40 s depending on the step width.

For reasons of reliability and versatility a rather small system was developed with utmost transparency of the hardware, software and application. For this reason there is a double bus system, i.e. a 12 bit bus and a 24 bit bus. The interconnection between these systems is handled by a BIN/BCD, BCD/BIN and a BIN/BIN interface. A high performance arithmetic processor is implemented. There is the additional possibility to transfer calculations to a scientific pocket calculator (TI-59). The minicomputer is a PDP 8 equivalent with real time clock, direct memory access and a 32 K memory address field.

[+]The work has been supported by the Bundesministerium für Forschung und Technologie.

NUCLEAR ORIENTATION OF ON-LINE SEPARATED ISOTOPES

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Although on-line separation has become a widespread technique, no attempt has been reported yet at combination with low temperature nuclear orientation. The usefulness of this combination is obvious in clarifying decay schemes as well as in the study of nuclear moments. Even with small production rates, anisotropy coefficients can easily be measured for γ- and β-transitions through singles counting. Therefore a new experimental set-up has been coupled to the Leuven Isotope Separator On LIne at the Cyclone cyclotron. It allows for continuous implantation of a beam of separated ions into a ferromagnetic foil at temperatures below 30 mK : this means that almost any isotope can be oriented to a useful degree without loss of activity. The central part of the set-up is a high power ^{3}He-^{4}He dilution refrigerator coupled through helium cooled transport lines and adjustable baffles to the central beam transport line of the isotope separator.

To circumvent the limitation to lifetimes below the spin-lattice relaxation time (which can amount to several minutes in unfavorable cases) a secondary "in beam" orientation facility has been installed in the connecting beam line. The orienting mechanism then is based on the effect of hyperfine polarization achieved through pick-up polarized of d-electrons during scattering at grazing incidence on a magnetised nickel single crystal[1]).
Implantation at low temperatures is still required, this time for preservation of the orientation for a period of time at least equal to the lifetime of the separated isotope. Both methods complete each other for systematic orientation study down to the shortest lifetime. A system of deflection plates and moveable beam transport lines allow to switch from one mode to the other in a short time. The collecting low temperature foils can be changed also without stopping the cooling cycle. First tests of the set-up have been performed and some preliminary results obtained.

* This work is supported by the National Science Foundation of Belgium.
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DIOGENE, A 4π DETECTOR SYSTEM FOR RELATIVISTIC HEAVY ION PHYSICS

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High energy nuclear collisions present a great interest for the study of collective effects in highly excited nuclear matter. They can give firm signatures of exotic processes like shock waves, phase transitions, super-dense matter, pion condensation. Such investigations need new types of detectors, which must be able to detect not only a large multiplicity of charged particles, but also their nature, their angle of emission and their energy, in a large solid angle, in order to perform as much exclusive measurements as possible. The first experiments which are planned at Saturne by our group [1] are measurements of the ratio between π^- and p multiplicities for heavy ions between 100 MeV/A and 600 MeV/A. We are also interested by the multiplicity distributions of pions. Measurements of this type are of fundamental interest for an approach of exotic phenomena in nuclear matter.

"Diogène" is a well suitable detector for such studies. It consists of a cylindrical time projection chamber (TPC) associated with a trigger system. The TPC is divided into 10 sectors, each of them having a plane of anode wires separated by potential wires. An electric field of 1.5 KV.cm^{-1} is used for drift time measurements, and the pressure inside the chamber is about 4 atm. (Ar + C_3H_8). The trajectories of the particles are recorded in three dimensions. The three coordinates are respectively given by the drift time, the wire number and the ratio of the charges at both end of each wire. The momenta of the fragments are obtained by measuring the curvature of the trajectory, by a 1 Tesla axial magnetic field. Measuring both momentum and energy loss of the fragments permits their identification.

The trigger is composed of 30 plastic scintillators associated with a 32 input coincidence circuit (majority adjustable from 1 to 30). Also, multiwire proportional chambers are used upstream and downstream the TPC for forward and backward detection. This trigger will be used to select the most central collisions by a multiplicity cut off. One sector of the TPC is being tested with cosmic rays and secondary beams at Saturne. The whole detector will be operational in spring 1981 when heavy ions are available.

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STUDY OF THE p + d → t + π^+ REACTION AT 0.8 GeV*

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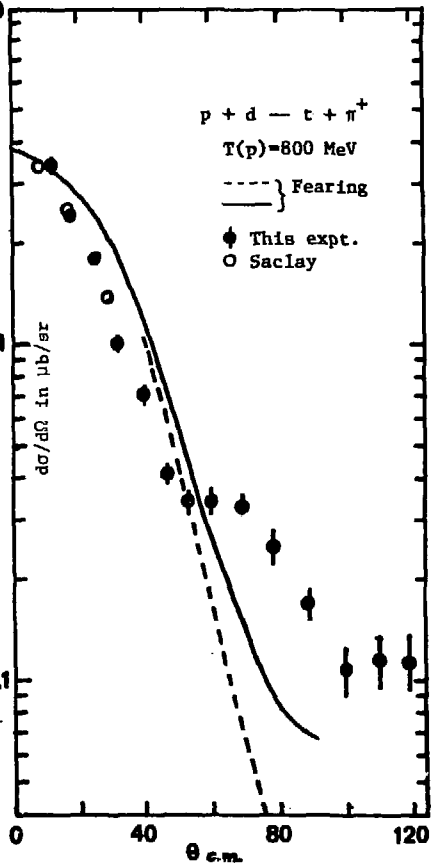
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Differential cross sections for the reaction p + d → t + π^+ have been measured at T_p=0.8 GeV at the HRS at LAMPF in the angular region θ(cm)=11° to 120°. The data is characterized by a sharp fall from 11° to 50°, a region of gentler slope from 50° to ∿100° and indications of a rise at back angles. In these characteristics the data is very similar to that for elastic scattering of 800 MeV protons from deuterium[1] and must reflect the dominant influence of the deuteron form factor.

The experimental results will be compared with recent results for the related reactions[2,3,4] p + d→^{3}He + π^+ and n+d →^{3}He + π^- and the most recent theoretical calculations.[5,6] It will be shown that these calculations are not successful in describing even the general characteristics of the data. In particular they fail to reproduce the back angle behavior.



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PION-DEUTERON EXCITATION FUNCTION AT θ_π=180° AND THE J=3 DIBARYON RESONANCE

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The π^+D excitation function at θ_π=180° has been measured recently at SIN (Switzerland)[1]) in the c.m. total energy range W corresponding to the $^3F_3$ dibaryon resonance observed in pp scattering at 2.20-2.26 GeV [2]). This differential cross section is plotted (fig.1) versus W in comparison with a full relativistic three-body calculation of Lamot et al.[3]) where all the S and P πN waves (except P_{11}) and the $^3S_1$-$^3D_1$ NN waves are included. The general slope is well reproduced except for 2200<W<2260 MeV. In the hypothesis that the J=3 NN resonance may couple to the πD channel, we can calculate the total cross section by mean of a Breit-Wigner multichannel resonance formula

$$\sigma_T = \frac{4\pi\lambda^2}{3}(2J+1)\frac{x}{1+\varepsilon^2} \quad \text{with } x = \frac{\Gamma_{\pi D}}{\Gamma} \text{ and } \varepsilon = 2(W-W_r)/\Gamma$$

For W_r=2236 MeV (T_π=250 MeV, λ^2=4.17 mb) that yields $\sigma_T(J=3)$=12,22mb for Γ=100MeV and x= 0.1. This value is closed to the difference (Δ) between σ_T calculated by Giraud et al.[3]) and the accurate experimental value of ref.[4])($\Delta\simeq$8 to 15mb). A Breit-Wigner resonance formula can also be written for the elastic differential cross section at θ_π= 180°. Using the formulae of ref.[5]) with the special values of Legendre functions at cosθ=-1 leads to

$$\frac{d\sigma}{d\Omega}(180°) = \frac{\lambda^2}{3}\left[(J+1)^2+J^2\right]\frac{x^2}{(1+\varepsilon^2)}$$

. The result of this calculation with the above numerical values for W_r and x, Γ is shown on figure 1 (curve b).

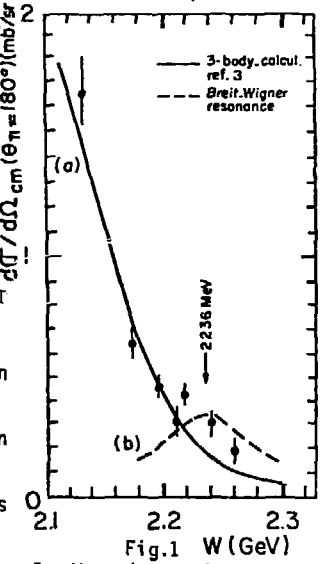


Fig.1

Two remarks must be done : 1) the adjonction of P_{11} πN wave in the 3-body calculation can also reduce the discrepancy between the calculated and experimental cross-sections ; 2) more experimental data are needed to allow a valuable phase shift analysis in this energy region.

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PRECURSOR OF PION CONDENSATION IN THE QUASI-ELASTIC PEAK

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The phase transition of pion condensation is heralded in the disordered phase by an increase in the life-time of the fluctuations for the staggered magnetization. This precursor phenomenon entails, in ordinary nuclei, a slowing down of the nuclear quasi-elastic response when observed with spin-sensitive probes.

We have investigated this effect starting from the RPA expression of the response function of the infinite nuclear matter

$$\Pi^{RPA}(\vec{q},\omega) = \frac{\Pi^{(0)}(\vec{q},\omega)}{1 - V_{ph}^{\sigma\tau}(\vec{q},\omega)\,\Pi^{(0)}(\vec{q},\omega)} \qquad (1)$$

where $\Pi^{(0)}$ includes the Lindhard function and the Δ-particle - nucleon hole propagator and the particle-hole interaction is

$$V_{ph}^{\sigma,\tau}(\vec{q},\omega) = 4\frac{f_n^2}{\mu_\pi^2}\left[\frac{q^2}{\omega^2/c^2 - q^2 - \mu_\pi^2} + g'\right]\Gamma^2(q^2) \qquad (2)$$

$\Gamma(q^2)$ being the form factor of the πN vertex.

The "collective singularities" of (1) coincide with those of the pion propagator

$$D^{-1}(\vec{q},\omega) = \frac{\omega^2}{c^2} - q^2 - \mu_\pi^2 - q^2 4\frac{f_n^2}{\mu_\pi^2}\Gamma^2(q^2)\frac{\Pi^{(0)}(\vec{q},\omega)}{1 - g' 4(f_n^2/\mu_\pi^2)\Gamma^2(q^2)\Pi^{(0)}(\vec{q},\omega)}$$

We have then explored, in a convenient range of values of the Migdal parametar g', at which densities ρ_c and momentum q_c the $\omega = 0$ singularity (the one associated with the pion condensation) occurs.

Next the attention has been focussed on the $\mathrm{Im}\,\Pi^{RPA}(\vec{q},\omega)$, which is proportional to the response of the system. We have found that this quantity is enhanced at low frequencies for $q \approx q_c$ still at the ordinary nuclear density $\rho_0 (< \rho_c)$.

In conclusion we shortly discuss the possibility of detecting this effect with backward inelastic electron scattering (which is dominated by the magnetic interaction) in light nuclei.

HYPERNUCLEAR PRODUCTION VIA THE (π^+,K^+) REACTION

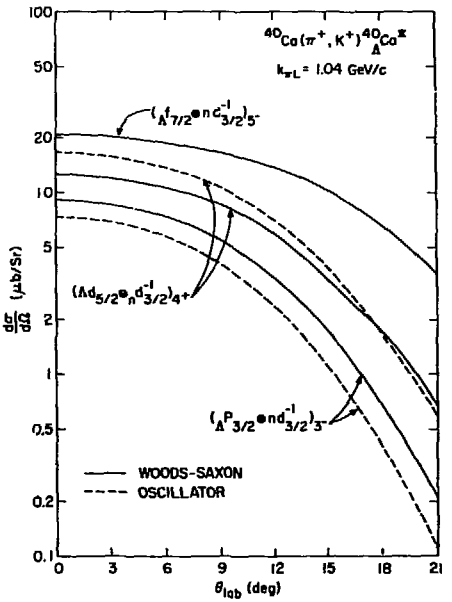
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We have investigated the possibility of producing hypernuclei with energetic pion beams via the (π^+,K^+) process. Due to the sizable momentum transfer involved ($q \simeq 300$ MeV/c at $\theta_L=0°$), the (π^+,K^+) reaction is found to preferentially populate the highest spin natural parity configurations which can be obtained by coupling a Λ or Σ^0 particle to a neutron hole. We have calculated differential cross sections to various hypernuclear final states in plane wave approximation (PWA), distorted wave impulse approximation (DWIA) and the eikonal (EIK) approach. The DWIA and EIK cross sections are in good agreement, and typically reduced in magnitude by a factor of 5-10 relative to the PWA, due to absorption. Sample results for the (π^+,K^+) reaction at 1.04 GeV/c on a ^{40}Ca target are shown in the figure. Cross sections of 5-20 μb/st at 0° are typical for high spin "stretch" configurations in a wide range of hypernuclei. The cross sections for the population of the natural parity ground states ($\Lambda S_{\frac{1}{2}}$) remain above 2μb/st at 0° for closed shell targets with A≤60. We have also calculated the quasi-free continuum background. Because of the large q for (π^+,K^+), this background is much broader and smaller in average magnitude as a function of excitation energy than that for the (K^-,π^-) reaction, for which q is small. Thus it should be possible to resolve discrete Λn^{-1} states with a few μb/st of cross section from the quasielastic background, using existing pion beams in the 1-1.5 GeV/c range, for instance at the Brookhaven AGS. The class of high spin hypernuclear states populated at 0° in a (π^+,K^+) reaction is complementary to those seen in the "crossed" (K^-,π^-) reaction at 0°, where only low spin states are seen. The (π^+,K^+) reaction thus offers unique possibilities for extending our knowledge of hypernuclear structure.



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†† Supported in part by the National Science Foundation.

STRONG ABSORPTION MODEL FOR ELASTIC AND INELASTIC SCATTERING OF HIGH ENERGY PROJECTILES FROM NUCLEI+

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Most of the experimental data on high energy scattering of strongly interacting particles from nuclei (such as pions, nucleons, and composite systems of nucleons) have been analyzed within the framework of Glauber's theory[1]) of multiple scattering and/or of the optical model[2]) of Kerman, McManus and Thaler. Both of these theories have been very successful in reproducing the experimental data. However the numerical results in both of these theories can be obtained only by extended computing facilities.

In the present paper a simple model within the framework of partial wave expansions in the adiabatic approximation is developed to calculate the elastic and inelastic scattering of high energy nucleons or composite systems of nucleons from nuclei. The approach of the present work is closely related to that of the papers of Chou and Yang[3]) for very high energy proton-proton scattering. It is shown that the present model[4]), apart from a multiplicative form factor depending on scattering angles and the nuclear surface thickness, is approximately equivalent to that of the diffraction of waves by a black sphere of radius equal to that of the target nucleus in the Fraunhofer approximation. There appear two parameters into the formulation. One is the effective equilibrium radius of the target nucleus and the other is the effective thickness of the nuclear surface.

The model is applied to analyze the recent experimental data from Saclay[5]) on elastic and inelastic scattering of 1.37 GeV α-particles from ^{40,42,44,48}Ca. It is found that the calculated differential cross sections of elastic and inelastic scattering and those measured experimentally are in excellent agreement. Application of this model to high energy nucleon-nucleus scattering is also discussed.

+Major part of this work has been carried out during the author's stay at the Niels Bohr Institute, University of Copenhagen, while he was on sabbatical leave from Polytechnic Institute of New York, Brooklyn, N.Y. 11201

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IMPORTANCE OF SHORT RANGE CORRELATION IN PION-NUCLEUS BACKWARD SCATTERING

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Pion-nucleus elastic scattering was studied at all scattering angles (0^{o} to 180^{o}) in the (3,3) resonance region. We started our analysis with the use of a parameter-free first-order optical potential supplemented with a phenomenological second-order optical potential.(1) While it is possible to obtain an excellent fit to pion-helium scattering data at all angles by using (uncorrelated) shell-model nuclear wave functions, it is not possible to account for the pion-carbon backward scattering data (2) with the same prescription. Our analysis indicates that both short range nucleon-nucleon correlation and higher-order pion-nucleus reaction mechanism are needed to explain the data. We believe further experimental studies of backward pion-nucleus scattering should provide valuable information on these aspects of nuclear structure and pion-nucleus dynamics.

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ASYMMETRY IN THE REACTION $\vec{p} + d \to t + \pi^+$ at 0.8 GeV.*

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Polarization asymmetries have been measured for the reaction $\vec{p}+d \to t+\pi^+$ at T(p) = 0.8 GeV with a polarized proton beam at the high resolution spectrometer (HRS) at LAMPF. Data has so far been taken only in the angular range θ(cm) = 11° to 75°. A remarkably strong structure has been observed in the asymmetry (see Fig. 1). Unlike TRIUMF experiments at ~300 MeV,[1] this structure bears no easily recognizable relation to the asymmetries in the elementary reaction $\vec{p} + p \to d + \pi^+$ measured by us at 800 MeV.[2] On the other hand, in the angular range 11° to 60° the structure is found to be very similar to that observed by Winkelman et al.[3] in the elastic scattering of 800 MeV polarized protons from deuterium. However, above 60°, there are strong indications of differences, the elastic scattering asymmetries begin to fall, while pion production asymmetries keep rising. We expect to extend these very provocative measurements up to θ(cm) = 150° in the near future. The results should be of critical importance in determing at what point the effects due to deuteron form-factor cease to dominate and the characteristic aspects of the pion production channel emerge.

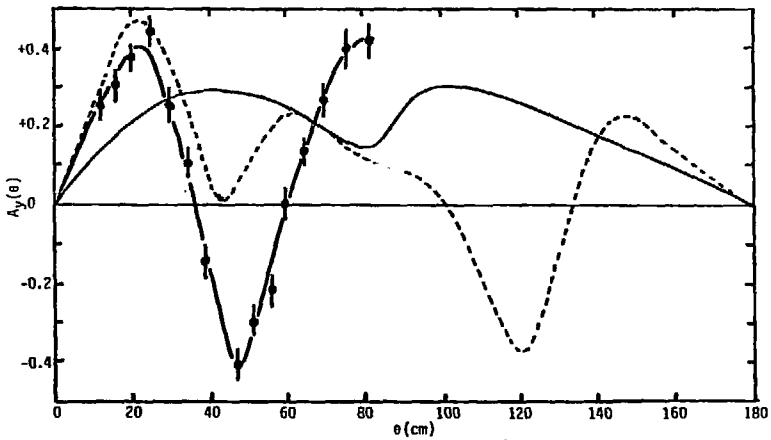


Fig. 1. Measured analyzing power, A_y, for the reaction $\vec{p} + d \to t + \pi^+$, thick line with data points. A_y for $\vec{p} + d \to p + d$ from ref. 3, dashed line. A_y for $\vec{p} + d \to d + \pi^+$ from ref. 2, thin line. T(p) = 800 MeV for all reactions.

*This work was supported in part by the U.S. Department of Energy.

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Comparison of the reactions $^{16}O(\pi^+,p)^{15}O$, $^{16}O(\gamma,n)^{15}O$ and $^{16}O(\gamma,p)^{15}N$

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First measurements of the $^{16}O(\gamma,n)^{15}O$ reaction leading to the ground state and the $3/2^-$-state are compared with measurements $^{16}O(\gamma,p)^{15}N$ and $^{16}O(\pi^+,p)^{15}O$ for momentum transfers of $1.6\ fm^{-1} \leq q \leq 3fm^{-1}$. The ratios

$$R_n = \frac{^{16}O(\gamma,n)^{15}O_{3/2^-}}{^{16}O(\gamma,n)^{15}O_{G.S.}}, \quad R_p^{1)} = \frac{^{16}O(\gamma,p)^{15}N_{3/2^-}}{^{16}O(\gamma,p)^{15}N_{G.S.}} \text{ and } R_\pi^{2)} = \frac{^{16}O(\pi^+,p)^{15}O_{3/2^-}}{^{16}O(\pi^+,p)^{15}O_{G.S.}}$$

as a function of momentum transfer are shown in fig. 1. A strong deviation from the value 2, derived from the occupation numbers, as a function of momentum transfer is observed. This deviation of the ratio is predicted qualitatively (line and dotted line) in calculations with a model[3] assuming the absorption of the photon or the pion takes place by correlated neutron-proton pairs. In this model the formfactor of the residual nucleus dominates the form of the cross section as a function of momentum transfer. Whereas the $^{15}N_{G.S.}$ or $^{15}O_{G.S.}$-systems have deep *minima in* the formfactor, the quadrupole contribution in $^{15}N_{3/2^-}$ and $^{15}O_{3/2^-}$ fills in these minima. The peak in these ratios occurs at a momentum transfer close to these minima.

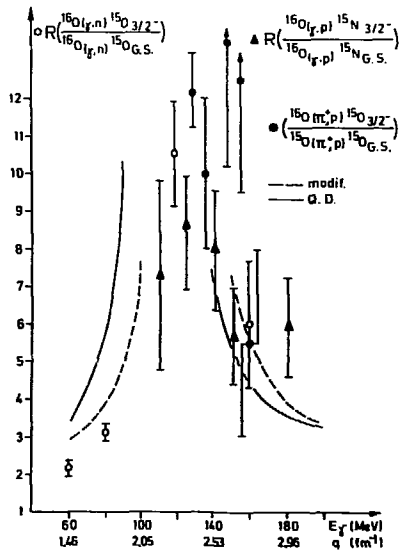


Fig. 1

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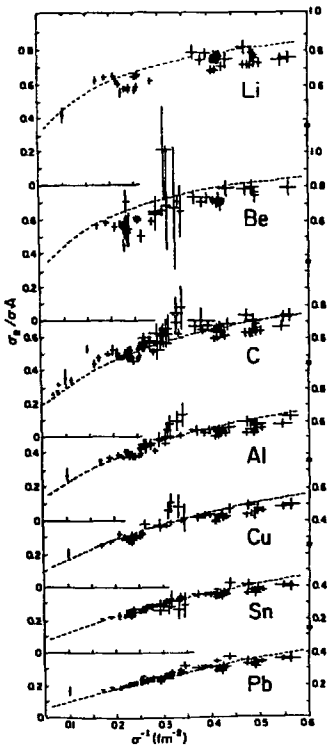
GENERAL FEATURES OF TOTAL HADRON-NUCLEUS REACTION CROSS SECTIONS

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Total reaction cross sections σ_R for many hadronic projectiles (π^+,π^-, p,n,$\bar{p}$,K^+,K^-,$\bar{d}$) and bombarding energies from 200 MeV to 300 GeV on several target nuclei (Li,Be,C,Al,Cu,Sn,Pb) have been compiled. For each measurement of σ_R the corresponding experimental spin-and isospin-averaged free projectile-nucleon total cross section σ is also determined. It is found that σ_R and σ are well correlated for any given target (see figure). This implies that a model to calculate σ_R has to depend only on the elementary cross section σ and not explicitly on charge, mass, energy, etc., of the projectile. The Glauber model in the optical limit (which fulfills this condition) provides a good representation of the data (dashed line in figure).

In addition, the data indicate a possible oscillatory fluctuation of σ_R around a smooth average value (best seen for the targets C, Al, and Cu). Arguments will be presented which support the existence of such an oscillatory behavior. A mechanism which would explain such oscillations has so far not been found.

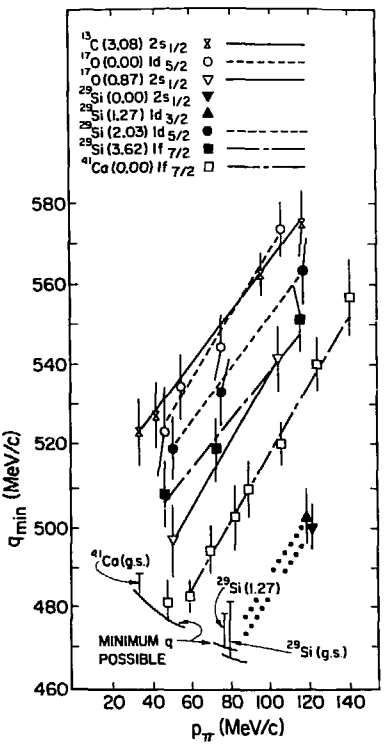


POSITIVE-PION PRODUCTION BY 149-165 MeV PROTONS ON ^{16}O AND ^{28}Si[†]

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The energy dependence of the (p,π^+) reaction on targets of ^{10}B and ^{40}Ca leading to the ground states of ^{11}B and ^{41}Ca, respectively, has been studied previously in the near-threshold region ($T_p \leq 200$ MeV).[1] Similar data for transitions leading to the ground and first excited states of ^{17}O and the ground, 1.27, 2.03 and 3.62 MeV final states of ^{29}Si have been obtained at proton energies of 149-165 MeV to help determine whether the main features of the angular distributions are due to nuclear structure or the reaction mechanism. When combined with the Uppsala measurements[2] (T_p=185 MeV), the results cover a range of pion energies from 7 to 45 MeV. Generally, the angular distributions are characterized by a single minimum in the forward hemisphere. A prominent energy dependent feature of these distributions is the shift of the minimum to larger values of momentum transfer q with increasing pion momentum p_π. This was also observed for the transition to the ^{41}Ca ground state,[1] where it was observed that q at the minimum q_{min} varied linearly with p_π according to $dq_{min}/dp_\pi = 0.82\pm0.09$. Assuming a linear dependence for the final states in ^{17}O and ^{29}Si, least squares fits to the data yield values which are consistent with the ^{41}Ca results (see figure). Another feature which is indicated by the figure is that for transitions involving the same neutron orbital the minimum occurs at larger values of q as the target mass A decreases. This result suggests that angular distributions for transitions to states involving p-shell orbitals have no minima[1] simply because the reactions have been measured at values of q which are too small for q_{min} to occur.



[†]This work supported by the National Science Foundation.

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STUDIES OF π° PRODUCTION NEAR THRESHOLD

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We have begun a series of measurements which will measure the cross section for (p,π°) reactions on a range of nuclei with both unpolarized and polarized beams. The energy and angle of the π° is inferred from its decay gammas by a measurement of the angle and energy of each gamma.

To analyze the (p,π°) experiments for an unpolarized beam, we expand the differential cross section in the center of mass assuming only s and p waves $\frac{d\sigma}{d\Omega} = a + b \cos\theta + c \cos^2\theta$. The angular distribution of gammas in the lab can be related to the parameters for this differential cross section. By measuring the angular distribution of gammas in the lab and fitting their distribution to obtain the parameters a, b, and c, we obtain the angular distribution of pions in the center of mass. Since we are not reconstructing each event to obtain the π° distribution in the center of mass, an energy measurement is not required but is useful in discriminating against background events.

The counter arrangement consists of lead-glass, wire-chamber hodoscopes on opposite sides of the target. Pions in the target decay to gammas which are detected in the gamma counters. The system measures the angles of the gammas relative to the direction of the incident proton and the opening angle between the two gammas. To measure the angle of the gamma, we use the technique described by Heusch[1]. The gamma is converted in lead glass and the trajectories of the converted electrons are measured with wire chambers. The track is extrapolated back to the converter to find the interaction point. The gamma angle can be determined once an interaction point is known relative to the target.

Large lead glass counters behind the wire chambers measure the remaining energy of the converted electrons which can be added to the energy recorded in the converter to obtain a crude energy measurement and complete the identification of the gamma. The total energy resolution is about 40% and the solid angle is 0.38 Sr.

We have collected data on beryllium and oxygen at different energies and have completed our analysis of the 144.1 MeV ^{9}Be data. The data (226 points) were subjected to a maximum likelihood fit which yielded the following relative values for the parameters a, b, and c respectively: 1.000, -0.505 ± 0.176, 0.065 ± 0.045.

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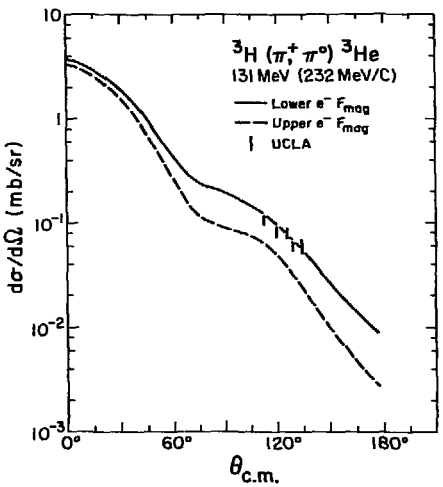
A UNIFIED STUDY OF THE PION-^{3}He INTERACTION FROM 0-300 MeV†

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Department of Physics, Oregon State University

Elastic and charge exchange scattering of pions from the three nucleon system (^{3}H and ^{3}He) were studied in the energy range from threshold to 300 MeV with the purpose of extracting reliable nuclear structure information. The calculation was done within the multiple scattering formalism with the first order optical potential containing the charge and magnetic form factors determined by electron scattering measurement. Binding energy corrections and nucleon recoil effects have been incorporated into the pion-nucleon t-matrix elements. The t-matrix elements were obtained using the most recent pion-nucleon phase shifts[1] and a consistent separable potential model[2].

The pion annihilation effect is included in two different ways. In the initial, phenomenological treatment, the terms second order in the proton and neutron densities are added to the optical potential. Assuming the dominance of deuteron-like absorption and an isobar model, realistic spin and isospin dependence is achieved. The absorptive parameters are determined by comparing the scattering length predictions with the relevant pion absorption rates for different channels.



In our second treatment of annihilation, the microscopic description developed by Phillips et al.[3], is modified and applied within a theoretical optical potential framework. Also investigated were several extensions of the lowest order theory, including multiple isospin-flip scattering, Coulomb force effects, and the spin dependence of annihilation.

In general the agreement between the theoretical predictions and experimental data on elastic and charge exchange scattering is very good - even without parameter adjustment.

† This work was supported by the National Science Foundation, the Research Corporation, the OSU Computer Center, and Oregon State University.

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SYSTEMATICS OF (π^+,π^-) DOUBLE CHARGE EXCHANGE†

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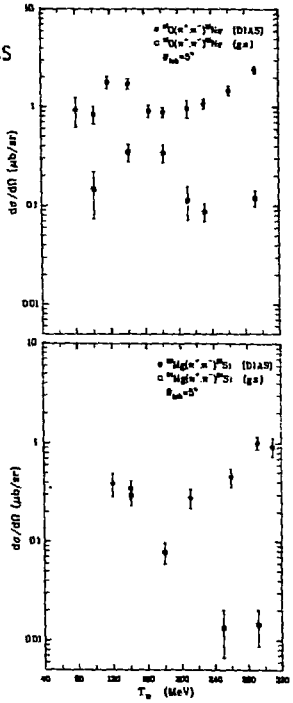
C.L. Morris and H.A. Thiessen

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Data for the (π^+,π^-) double charge exchange (DCX) reaction to discrete final states has been acquired on a variety of nuclei. The reaction requires interaction of the pion with two nucleons in the target nucleus. Consequently, two nucleon interactions may play an important role in the reaction mechanism.

The nuclei $^{16,18}O$, $^{24,26}Mg$, and ^{209}Bi were the targets for a systematic study of DCX using the EPICS spectrometer at LAMPF. Angular distributions and energy excitation functions at forward angles were taken for the isobaric analog transitions from ^{18}O and ^{26}Mg. Excitation functions were also taken for the non-analog transitions from ^{16}O and ^{24}Mg. These are compared in the figure. As can be seen, the two neutron excess of the core ■ 2n configuration is an important factor for each isotopic pair. The ratio of cross sections between ^{18}O and ^{26}Mg are seen to scale nearly as predicted in the semi-classical theory of M. Johnson[1]. There is a distinct rise in the ^{18}O energy excitation function near 120 MeV and both ^{18}O and ^{26}Mg show a rise above the (3,3) π-nucleon resonance as compared to ^{16}O and ^{24}Mg.

The angular distribution of ^{18}O at 164 MeV shows a non-simple diffractive minimum near 22° lab angle and moves outwards at 292 MeV.



†Work supported in part by the U.S. Department of Energy, the Associated Western Universities, and the Robert A. Welch Foundation.

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π^- ^{18,16}O DOUBLE CHARTE EXCHANGE REACTION

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The $^{18,16}O(\pi^+,\pi^-)^{18,16}Ne_{g.s.}$ double charge exchange (DCEX) reactions at the (3,3) resonance energy region have some interesting phenomena[1]. Because $^{18}Ne_{g.s.}$ is the isospin analog state of $^{18}O_{g.s.}$ and $^{16}Ne_{g.s.}$ is not isospin analog state of $^{16}O_{g.s.}$, in studying these phenomena, it is necessary to deal with both the reaction mechanism and nuclear structure. We use Glauber multiple scattering theory and the random phase approximation (RPA) wave function Ψ_i, Ψ_f to calculate the DECX reaction amplitude and to study the influences of nuclear structure for these reactions.

We have calculate the differential cross section, $\frac{d\sigma}{d\Omega}(0^0)$ vs T_π, and the ratio $R = \frac{d\sigma}{d\Omega}(^{18}O(DCEX))/\frac{d\sigma}{d\Omega}(^{16}O(DCEX))$ at $\theta = 0^0$ in the (3,3) resonance energy region. Some of the results are shown in figure 1 and 2. The angular distribution pattern of $^{18}O(\pi^+,\pi^-)^{18}Ne_{g.s.}$ agrees with experiments, which exhibit a dip around 23° but quantitatively our computed values are larger than the experimental data by a factor 4. The ratoi R at T_π = 140 Mev. is 2.25, which also agrees with experimental value $R=2.3^{+1.2}_{-.8}$ The curves $\frac{d\sigma}{d\Omega}(0^0)$ vs T_π have a shallow dip agreeing with the experimental trend qualitatively. We think the above phenomena are due to mainly the influence of pair coherent nuclear structure.

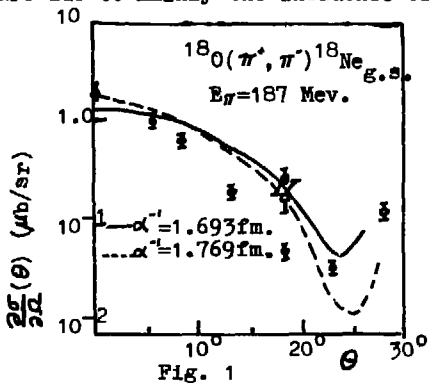


Fig. 1

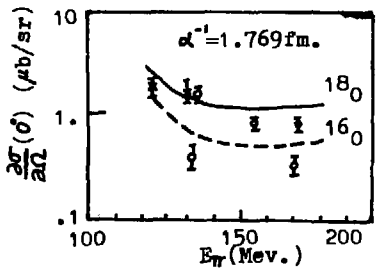


Fig. 2

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QUASI-Δ_{33} DOORWAY STATE DESCRIPTION OF PION-NUCLEUS SCATTERING

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According to the characteristic feature of the π-nucleus scattering at (3,3) resonance region, i.e. dominant by the Δ_{33} doorway states, we suggest a simple quasi-Δ_{33} doorway state model as a structure of the intermediate states in the (3,3) resonance scattering processes. We assume that the doorway states with the same excitation energy $n\hbar\omega$ which are called the quasi-Δ_{33} doorway states are approximate eigenstates of the Δ-h system and are represented as follows:

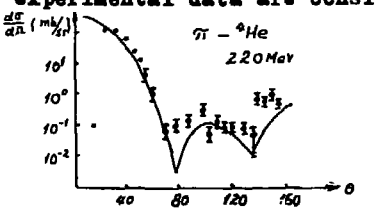
$$\varphi_{nLJ} = \sqrt{\frac{1}{N_{nL}}} \sum_{\substack{n_\Delta \ell_\Delta n_N \ell_N \\ (2n_\Delta + \ell_\Delta - 2n_N - \ell_N = n)}} (-1)^{\ell_\Delta} A_{\ell_\Delta \ell_N L} F_{n_\Delta \ell_\Delta n_N \ell_N L}(k) \left(a^+_{n_\Delta \ell_\Delta} b^+_{n_N \ell_N}\right)_{LSJT} \varphi_0 \qquad (S=T=1) \quad (1)$$

Thus, the amplitude of π- nucleus scattering is

$$-2\omega_k \langle \vec{k}'_\pi | T | \vec{k}_\pi \rangle = \sum_{nLJ} \frac{\langle \vec{k}'_\pi | H^+_{\Delta N\pi} | \varphi_{nLJ} \rangle \langle \varphi_{nLJ} | H_{\Delta N\pi} | \vec{k}_\pi \rangle}{E_{nLJ} - \omega_k} \qquad (2)$$

Where $$E_{nLJ} = E_n = M_\Delta - M + n\hbar\omega + \mu_\Delta + \frac{i}{2}\Gamma_\Delta \qquad (3)$$

Within the frame of the quasi-Δ_{33} doorway state model, the differential cross sections and the total cross sections of $\pi^- {}^4$He (T^{lab}_π=110, 150,180, 220, 260 Mev), $\pi^- {}^{16}$O (T^{lab}_π= 163, 220, 240, 254, 303, 380 Mev) and $\pi^- {}^{40}$Ca (T^{lab}_π= 115.5, 163.3, 241 Mev) elastic scattering have been calculated. In our calculations there are two parameters μ_Δ and Γ_Δ used to fit the experimental total cross sections. The results obtained are basically in agreement with experimental data. For $\pi^- {}^4$He scattering, since the spin-orbit coupling effects in the E_{nLJ} are included, the agreements with experimental data are considerably better.



THE α-CLUSTER STRUCTURE OF NUCLEI AND PION-CARBON SCATTERING

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Zhao En-guang

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In the recent studies of nuclear scattering, the rigid α-cluster model is used more often among the α-cluster models. [1] Its physical picture is classical and when it is used in the problems of multiple scattering, one are often confronted with some troubles which arise from the integrations of the higher order multiple scattering terms.

We have proposed an α-cluster model of light nuclei. [2] The basic assumption is that each α particle moves independently in an average field due to all the other α particles in the nucleus. The ground state wave functions of ^{12}C and ^{16}O are writen as

$$\Psi_g(\vec{r}_1 \cdots \vec{r}_N) = \tilde{\prod_{i=1}^{N}} \Psi_0^{\alpha_i}(\vec{r}_i) \qquad N = 3 \text{ or } 4, \text{ for } ^{12}C \text{ or } ^{16}O \qquad (1)$$

$$\Psi_0^{\alpha}(\vec{r}) = \frac{1}{\sqrt{2}} \left(O_{1s}(r) - O_{2s}(r) \right) Y_{00}(\hat{r}) \qquad (2)$$

where $O_{ns}(r)$ is a radial harmonic osilator wave function. With these wave functions, the elastic electron scattering experiments could be well reproduced. An advantage of these wave function is that when it is used in the problems of multiple scattering, each terms of the expansion can be integrated out analiticaly. This wave function give a spherecal shell with a diffused boundary in which the α particles are distributed. However, the rigid α model require that the α particles have to move on the surface of the sphere. Thus the rigid α model can be taken as the classical limit of our model.

Using our model wave functions, at the pion energies of 60, 75, 120, 150, 180, 220, and 260 Mev, we have calculated the cross sections of the elastic $\pi^- - ^{12}C$ scattering within Glauber theory. All the input $\pi - \alpha$ amplitudes are taken from the experiments. The theoretical results are in good agreements with experiments. In particular, there are considerable inprovements upon the other α model calculations in the lower energy region[3] Our results are also superior to the Glauber calculations with the π-N amplitude as input. This indicates that for the α particle nuclei, taking $\pi - \alpha$ amplitude as input has more advantages than taking $\pi - N$ amplitude as input. (for example, the $\pi - \alpha$ amplitude can automaticaly include some effects of pion absorption and binding correction, etc). From our calculations, it may be seen that the Glauber theory even can be used in the energy region lower than 100 Mev.

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THE $^{209}Bi(\pi^+,\pi^-xn)^{209-x}At$ PION DOUBLE CHARGE EXCHANGE REACTION[†]

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Two nucleon correlations in nuclear matter can be investigated through the study of pion double charge exchange, DCX, processes, e.g. (π^+,π^-) or (π^-,π^+). The reaction mechanism is generally viewed theoretically as two sequential single charge exchange steps, processes which are expected to be sensitive to both the neutron and proton distributions of the target and the isospin character of the initial and final states. In addition, the spectrum of excitation energies following inelastic DCX can be inferred from the measurement of cross sections for products formed by nucleon evaporation after the DCX step, i.e. (π^+,π^-xn).

A study of the $^{209}Bi(\pi^+,\pi^-xn)^{209-x}At$ DCX reaction has been performed at the P^3 channel at LAMPF, using pion energies from 100 to 300 MeV. Following pion irradiation of high purity Bi targets ($\simeq$0.3 to 3.0 gm/cm^2), At was isolated from the target by standard radiochemical methods. Chemical yields (typically $\simeq$ 30-50%) were determined by the addition to the target solution of known amounts of ^{211}At "spikes". The pion flux was determined from yields of ^{18}F and ^{24}Na which had been produced by pion activation of ^{27}Al monitor foils. The yields of various At isotopes (A = 205 to 211) were determined by either alpha- or gamma-ray spectroscopy or both.

The presence of ^{210}At and ^{211}At (not producible directly by π + Bi) in the astatine fraction indicated that secondary reactions (^{209}Bi (π,^3He or ^4He) followed by $^{209}Bi(^3,^4He,xn)At$) occur in the relatively thick Bi targets which were required at the pion fluxes available at LAMPF. Extensive studies of these secondary processes were performed at BNL (with 200 MeV proton simulations of the π^+ + Bi reaction) as well as by measuring At yields at LAMPF from π^- + Bi over the same energy range used in the π^+ studies. Calculation of ^3He and ^4He yields and their energy distributions were also performed using the ISOBAR + DFF computer codes. To first order, it is expected that the same distribution of ^3He and ^4He secondaries will be produced by π^- as by π^+ on Bi and that enhancement of At yields ($A \leq 209$) in π^+ irradiations over π^- irradiations is the signature of the occurrence of the DCX process.

At cross sections at 300 MeV for both π^+ and π^- are the same within errors for $^{209-211}At$; ^{207}At is observed to be produced with slightly higher cross section by 300-MeV π^+ versus 300-MeV π^- but not significantly so. Preliminary results from 100-MeV π^+ and π^- experiments reveal no discernible differences in cross section for $^{211-209}At$, but the ^{207}At π^+ cross section rises appreciably to $\simeq$100 μb while the ^{207}At π^- cross section continues to fall to $\simeq$5 μb. These results appear to confirm the earlier work of Batusov et al.[1] in which the (π^+,π^-2n) cross section at 90 MeV was reported to be 120 μb.

[†]Research supported by the Nuclear Science Division of the U.S. Department of Energy.

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THE SCATTERING OF 162-MeV PIONS BY ^{14}N

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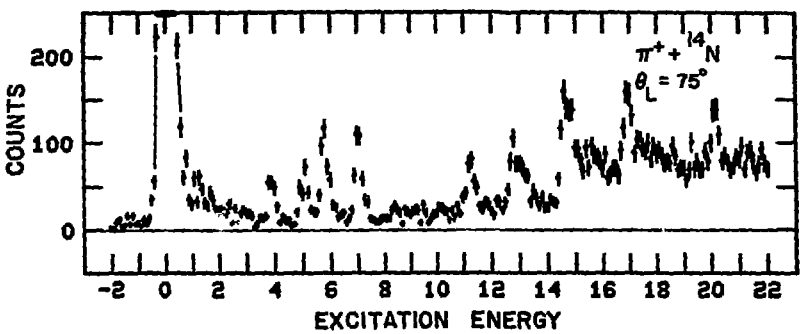
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The scattering of 162-MeV π^+ and π^- by ^{14}N has been studied on the EPICS system at LAMPF. Spectra at each angle were accumulated for a melamine ($C_3H_6N_6$) and a polyethylene target (CH_2). ^{14}N spectra were obtained from the difference between the spectra from the two targets. The system resolution was 300 keV. A typical spectrum, taken at $\theta_{lab} = 75°$ is shown below.

Data were taken in 5° angular steps, from 30° to 115° for π^+, and 25° to 75° for π^-. Due to the lower π^- flux, spectra with sufficient statistical accuracy to obtain high quality inelastic yields were only obtained at 35°, 55°, 75° and 95°. As illustrated in the figure, a large number of ^{14}N states are excited in this reaction. Angular distributions have been extracted for 13 states between 3 and 20 MeV excitation. Most of these angular distributions are characteristic of $\Delta L = 3$ excitation. The states at 14.6 and 16.9 MeV have angular distributions indicating a larger L value. Preliminary analysis indicates substantial π^+/π^- differences in the cross sections for a number of states at high excitation energies. The 0^+ T = 1 state at 2.31 MeV was not observed in this experiment. At 65°, the expected second maximum of the angular distribution, an upper limit of 5 μb/sr was set on the cross section for this state. While this is an order of magnitude smaller than the cross section for other ^{14}N states, microscopic DWIA calculations[1] do predict a very low differential cross section for this state, ~1 μb/sr at 65°.

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S-WAVE DISPERSIVE CONTRIBUTION TO ELASTIC πD SCATTERING AT LOW AND ZERO PION KINETIC ENERGIES

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The S-wave dispersive contribution to the elastic scattering of low-energy positive pions ($T_{\pi^+}^{lab} \lesssim 50$ MeV) by deuterons is studied in a simple scattering-length model of S-wave πN interaction. Effects of nucleon motion, crossing, meson-baryon form factors and NΔ intermediate states are included in the calculation which is carried out in a momentum-space approach developed earlier.[1,2] In this analytic approach one finds the evaluation of the contribution reduces to a single numerical integration. The effect of the perturbation is compared with results of a recent calculation[2] of P-wave single scattering which includes nucleon motion. Results will be given for the more extensive calculation at zero pion kinetic energy (i.e. the dispersive contribution to the πD scattering length). In this case effects of P-wave scattering at threshold and intermediate NN interactions are treated. Both Hulthén ($\alpha = 0.326$, $\beta = 2.029$) and McGee (7% D-state) wavefunctions are used.

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INVESTIGATIONS OF THE PION NUCLEUS OPTICAL POTENTIAL FROM PIONIC ATOMS[†]

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The explicit dependence of the zero energy π^- nucleus optical potential on its various parameters, as well as its implicit dependence on neutron radii, is investigated for a selected set[1-4]) of particularly accurate level shift and width data. Among the various effects studied are some possible variations in the form of the Lorentz-Lorenz term, term induced by the so-called "angle-transformation", and the smearing of the π 2N terms which allows for a finite range in the absorption process. The pionic atom data are equally well fitted by any of the several forms used for the optical potential.

Concerning the dependence on neutron radii, the most sensitive parameter turns out to be b_1, the coefficient of the iso-vector component of the local potential. Its value is determined essentially from the ^{18}O data[4]) and some conflict is then obtained between results from pionic atoms and the results from the scattering of protons and alpha particles off nuclei.

Finally, the recently reported[5,6]) saturation of widths is not reproduced by any of the potentials, which otherwise fit the data throughout the Periodic Table. Thus,if saturation of widths in pionic atoms is reconfirmed and extended to more nuclei, novel properties of the pion nucleus interaction might be called for.

[†]This work was supported in part by the Commission for Basic Research of the Israel Academy of Science.

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COMPARISON OF π^+ AND π^- INELASTIC SCATTERING FROM LOW-LYING COLLECTIVE STATES OF ^{40,42,44,48}CA AND ^{54}FE

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Measurements of differential cross sections, $d\sigma/d\Omega$, to the lowest 2^+ and 3^-states in ^{40,42,44,48}Ca and ^{54}Fe for $\pi^+$and π^- inelastic scattering at an incident energy of 180 MeV will be presented. The magnitudes and angular shapes obtained for π^+ and π^- scattering to the 3^- states of these isotopes are very similiar. However, dramatic differences exist in the magnitudes and positions of the minima in the 2^+ angular distributions for π^+ and π^-. These data are being analyzed to determine the isoscalar and isovector {βR} for these states.

Deviations from the simple collective picture in the ratios of π^+ to π^- cross sections which are given in the table can be seen for both the 2^+ and 3^- states. Explanations in terms of the shell model will be given. The inherent symmetry of our measurements and methods of analysis with respect to $\pi+$ and π^- makes our results more reliable than extracting neutron and proton contributions to transition strengths in the inelastic scattering of (e,e'), (α,α), (p,p'), and (n,n') from nuclei.

Experimental ratios of $(d\sigma/d\Omega)_{\pi^-}$ to $(d\sigma/d\Omega)_{\pi^+}$ for the 2^+ states (taken from the second maximum) and 3^- states (taken from the first maximum) and collective model predictions.

	R(2+) Experiment	R(3-) Experiment	R Collective Model
^{40}Ca	—	0.95 ± 0.03	1.00
^{42}Ca	1.33 ± 0.10	0.93 ± 0.01	1.10
^{44}Ca	1.42 ± 0.04	0.85 ± 0.02	1.20
^{48}Ca	2.15 ± 0.14	0.85 ± 0.02	1.40
^{54}Fe	0.95 ± 0.05	—	1.18

THE CLOUDY BAG MODEL OF THE PION-NUCLEON (3,3) RESONANCE

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By incorporating chiral invariance in the MIT bag model, we are led to a theory in which the pion field is coupled to the confined quarks only at the bag surface. An equivalent quantized theory of nucleons and deltas interacting with pions is then obtained. The pion-nucleon scattering amplitude in this model is found to give a good fit to experimental data on the (3,3) resonance, with a bag radius of about 0.72 fm.

This research was supported in part by the Natural Sciences and Engineering Research Council of Canada, and the U. S. Department of Energy.

PION CAPTURE BY NUCLEI (I)
Multiplicity of Gamma-Rays Following the π-Capture and Angular Momentum Effects

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Gamma-rays following the $\pi^{\pm}$-capture in flight have been studied to determine the γ-ray multiplicity (M) and the pion capture cross sections (σ) in the incident pion energy range of T_π = 30 - 300 MeV.

Figure 1 shows the experimental setup. Pion beams from the KEK low-momentum πμ-channel were used on 5 nuclear targets (Al, Ti, Cu, Sn, Au). The incident pions were identified by the time-of-flight between R_1 and R_2, and γ-rays following the π-capture were detected by 8 NaI(Tl) detectors (G_1-G_8) of 3"φx3" in coincidence with event-trigger signals $R_1*R_2*R_3*\bar{R}_4$. The γ-ray events due to inelastic-scattering and charge-exchange processes were subtracted by measuring pions with 7 sets of ΔE-E telescopes (P_1-P_7) in coincidence with γ-rays.

The γ-ray events with majority 1 and 2 are given as;

$$(Y1) = I_B N_T n\Omega\sigma\langle m\rangle , \qquad (Y2) = I_B N_T \frac{n(n-1)}{2}\Omega^2\sigma\langle m(m-1)\rangle$$

(I_B; # of incident pions, N_T; # of target nuclei, n; # of γ-detectors, Ω; efficiency of γ-detection). From (Y1) and (Y2) we obtained,

$$M = \langle m\rangle = \left(\frac{2}{(n-1)\Omega}\frac{(Y2)}{(Y1)} - 1\right)/(1+(s/M)^2)$$

where $s^2 = \langle m^2\rangle - \langle m\rangle^2$ is the variation of the multiplicity distribution. We assumed that s = (0.5 ± 0.5)M ; f = $(1+(s/M)^2)$ = 1.25 ± .25. This assumption was checked by measuring the M directly at T_π = 100 MeV with separate long-run experiments of (Ge) vs. 8x(NaI) coincidence measurements and we obtained; f(Au) = 1.32 ± .18, f(Co) = 1.10 ± .13, f(Al) = 1.23 ± .18.

The observed γ-ray multiplicities in π^+ + Au are shown in Fig. 2(a). Shown in Fig. 2(b) are, $\langle L\rangle_\gamma$; average angular momenta of the states after nucleon emissions following the π-capture calculated from the data in (a) as $\langle L\rangle_\gamma = 2(M-k)$ with the number of statistical transitions k = 2.5, 3 and 4, $\langle L\rangle_\pi$; average angular momenta brought in by the π, calculated with a purely geometrical model, and $\langle L\rangle_C$; calculated angular momenta assuming that one nucleon was emitted randomly after the π-capture with an energy equal to a half of the total energy brought in by the pion($m_\pi c^2 + T_\pi$). The result seems to indicate a picture of the process to explain the angular momentum effect: The pion is captured by (at least) two nucleons and only one of them is emitted carrying a large energy.

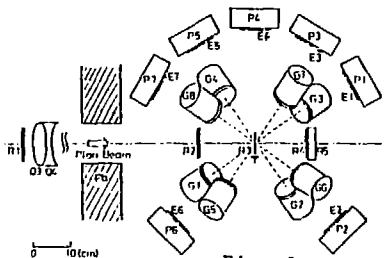


Fig. 1

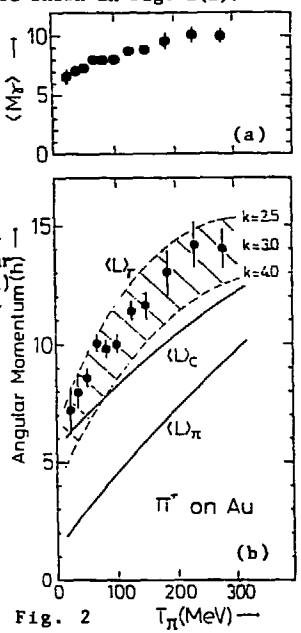


Fig. 2

PION CAPTURE BY NUCLEI (II)
Positive and Negative Pion Capture Cross Sections

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Cross sections for capture (or true absorption) processes of positive and negative pions by nuclei (Al, Ti, Cu, Sn, Au) in the incident pion energy range of 30 - 300 MeV have been determined from the measurements of multiple γ-rays following the process.

A brief description of the principle and experimental methods is given in the previous paper [Pion capture by nuclei (I)]. From the single (Y1) and coincidence (Y2) γ-counts taken by the 8 NaI(Tl) detectors in coincidence with the pion-capture-identifying signal, the cross section was deduced as,

$$\sigma = \frac{1}{I_B N_T}\frac{(n-1)}{n}\frac{}{2(Y2)}\frac{(Y1)^2}{(n-1)\Omega(Y1)}(1+(s/M)^2).$$

The notations are defined in the previous paper.

The results for Ti, Cu and Au are shown in Fig. 1 with the open(π^-) and closed(π^+) circles. Shown in the figure are only statistical errors, and additional uncertainty of about 20% has to be taken into account for the absolute values. The squares in (b) and (c) are data by Navon et al.(ref. 1). Those are in good agreement with the present data. The dashed curves in (b) for Cu show a result of an optical-model calculation with the MSU-type potential parameters. Good agreements are seen in the low-energy region (<50 MeV) where the capture process dominates the reaction cross section. While at high energies, the simple optical model fails to explain the data because multistep processes such as the pion capture following quasielastic scattering(s) become important.

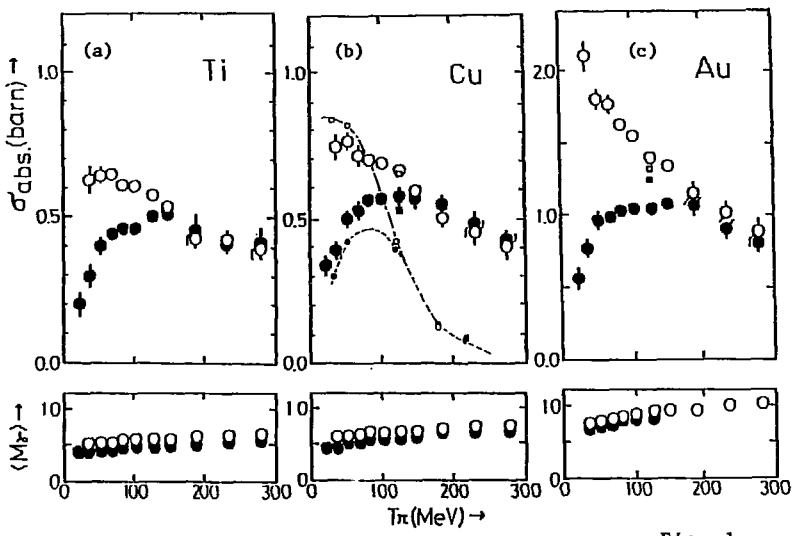


Fig. 1

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GLOBAL FITS OF PION ELASTIC SCATTERING[†]

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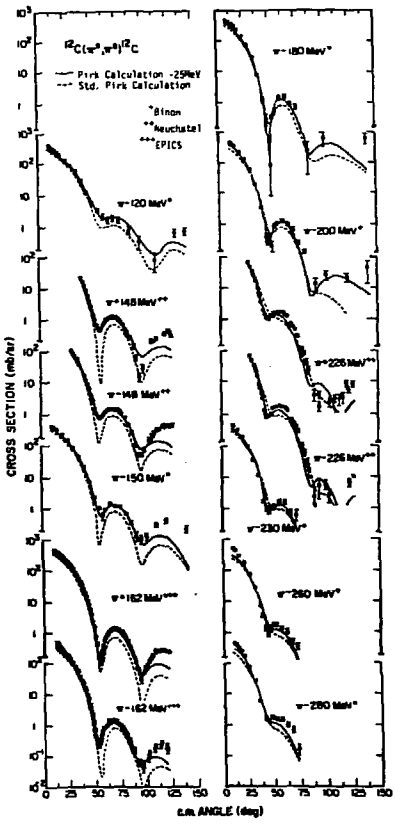
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Optical model calculations of $\pi^{\pm}$ elastic scattering from ^{12}C across the (3,3) resonance furnish vastly improved fits to the data when the elementary π-nucleon t-matrix is evaluated at an energy shifted by -25 ± 4 MeV relative to the incident pion energy. PIRK calculations are shown in the figure for $\pi^{\pm}$ scattering from ^{12}C with and without a -25 MeV shift. A simple Kisslinger potential and harmonic oscillator parameters from electron scattering were used. It is noted that at all energies an improved fit is obtained. Similar calculations for ^{16}O at pion energies between 114 and 240 MeV yield an energy shift of -22 ± 4 MeV. Comparable improvements in the quality of the fits was realized.



The apparent success of these one-parameter fits over a wide range of energies, including energies above 150 MeV, seems to be in disagreement with previous work.[1] The applicability of the energy shift in ^{12}C and ^{16}O over such a wide range of energies suggests a simple interpretation for this parameter. Calculations indicate that the π-nucleon energy shift is a straightforward way to correct for the Fermi motion of the target nucleons and binding effects. Previous attempts[1] to include Fermi corrections were found to be costly in terms of computation time, while the present method contributes negligibly to the time necessary for calculation.

[†]Work supported by the United States Department of Energy.

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A PHASE-SHIFT ANALYSIS OF π-d SCATTERING

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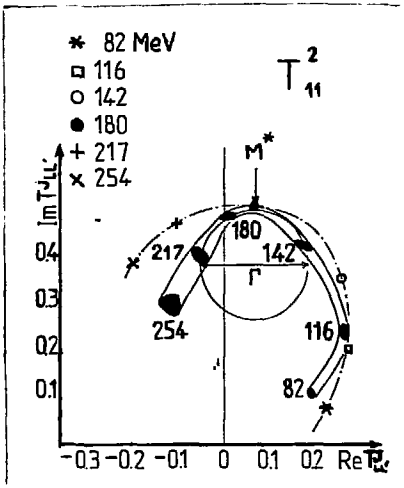
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Some indication of dibaryon resonances have recently been found in N-N cross-section measurements in pure spin-states. Such structures must also be observed in the π-d elastic channel leading to the same compound system. A large amount of new high quality data have been recently obtained, which allow for a phase-shift analysis to be made without major ambiguities. Elastic π^+ - d cross-sections have been extensively measured at SIN from 82 to 290 MeV in the angular range (20° - 135°). Backward angle data (137.5° - 167.5°) have been obtained at CERN and a few 180° points have been recently measured at SIN. Very precise total cross-sections are included in the analysis. Polarization data are still rather scarce : one data point for T_{20} at 140 MeV and 3 data points for iT_{11} at the same energy.

We use the theoretical predictions of recent Fadeev type calculations as starting values and vary only the phases (or amplitudes) which bring a statistically significant improvement to the χ^2 per degree of freedom. The most significant parameters are S_4, P_2, D_3 but some deviations from the theoretical amplitudes are also found for P_0, P_4 and E_2.

The Argand plot for $T_{LL'} = T^2_{11}$ is shown. The dotted line is the theoretical Argand path. The solid lines are envelops of solutions having a $\chi^2 < 1$ since different solutions may be obtained depending on which parameters are varied. Their number would be significantly reduced if more polarization data were available.

Deviations from the theoretical calculations are seen to significantly arise. The T^2_{11} Argand plot describes a broad structure centered around 170 MeV in the lab. system ($M^* = 2.17 \pm 0.01$ GeV) with a width of the order of 70-90 MeV. Since the pion has a negative parity this ($J = 2$, $L = 1$) structure in the π-d system would correspond to a $^1D_2$ state in the NN system (same J but $L_{\pi d} = L_{pp} \pm 1$) by parity conservation, in good agreement with the structure observed in $\vec{p}$-$\vec{p}$ at the same energy and with a width of 70 MeV. The T^3_{22} Argand plot also describes a broad structure centered around 220 MeV ($M^* = 2.22 \pm 0.01$ GeV) which would be in fair agreement with the corresponding $^3F_3$ dibaryon resonance seen in $\vec{p}$-$\vec{p}$ scattering at 2.22-2.26 GeV, and having a similar width of 100 MeV or larger. A more detailed account of this work will be published elsewhere.



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POSITIVE PION-NUCLEUS ELASTIC SCATTERING AT 20 MeV[@]

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M. A. Moinester,[∞] B. M. Preedom,[+] R. P. Redwine,[†] and J. Wu*

We have measured the elastic scattering of 20-MeV positive pions from ^{12}C, ^{16}O, ^{40}Ca, ^{90}Zr, ^{120}Sn, and ^{208}Pb targets. These measurements were performed at the Low Energy Pion channel at LAMPF. Detailed description of the experimental method and apparatus has been presented elsewhere.[1]) The absolute cross sections were obtained using the number of incident pions measured with a π-μ dE/dx detector. The detector counted the number of muons resulting from pion decays in the beam line and was calibrated at a reduced beam intensity by a direct counting of the incident pions.

These data (Fig. 1) are part of a continuing series of measurements made at low energies[2]) to obtain the energy dependence of the optical model parameters below 80 MeV. In a comparison of these data with those of ref. 2, we see that the lighter elements, ^{12}C and ^{16}O vary only slightly between 20 and 30 MeV; whereas for the heavier elements A > 40, some changes in their angular distributions are apparent; and at 20 MeV, the cross section appears to be dominated by Rutherford scattering. For Pb, the coulomb barrier is about 19.3 MeV. The optical model parameters for these data will be presented.

[@]This work is supported by U. S. D.O.E. and N.S.F.
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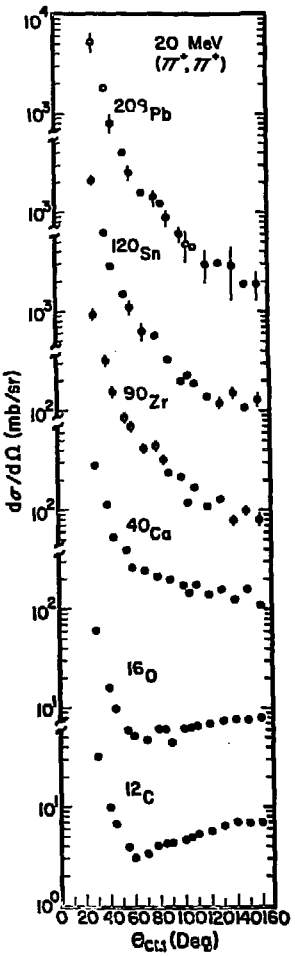


Fig. 1. Center of mass cross sections.

HOW MANY NUCLEONS ARE INVOLVED IN PION ABSORPTION IN NUCLEI?[†]

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Proton yields from the interaction of pions on nuclear targets with $12 \leq A \leq 181$ have been measured in the region of the $\Delta(3,3)$ resonance. The shift in proton energies with angle has been analyzed in terms of the average number of nucleons that participated in absorbing the pion's momentum and total energy. The effective number of interacting nucleons, for both π^+ and π^- incident, is found to be ~ 3 for ^{12}C and increasing to ~ 5.5 for ^{181}Ta. These effective numbers of nucleons are also consistent with the measured ratio of proton yields from the π^+ and π^- induced reactions.

[†]This work was performed under the auspices of the U. S. Department of Energy and the National Science Foundation.

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INELASTIC EFFECTS ON THE πNN VERTEX FUNCTION†

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The πNN vertex function with one nucleon off-mass shell was previously obtained from experimental data through sideways dispersion relations. The πNN form factor K(W), the nucleon dressed propagator $S_F^+(W)$ and the proper vertex function Γ(W), as defined in ref. 1, are real analytic functions, with cuts along $|W| \geq m_N + \mu_\pi$. This analytic structure and the discontinuity

$$\text{Im } K(W) = f^{*}_{\pi N}(W)\, K(W) + \sigma(W) \qquad (1)$$

are first exploited to find K(W). In eq. (1), $f_{\pi N}(W)$ represents the π-N scattering amplitude in the P_{11} wave [S_{11} wave] when one has : $W > m_N + \mu_\pi$ [$W < -(m_N + \mu_\pi)$ respectively] and the second term σ(W) which is different from zero for $|W| \geq m_\pi + 2\mu_\pi$, corresponds to inelastic contributions from higher mass (multiparticle) intermediate states. As is well known[2], the complete knowledge of σ overdetermines K ; it is sufficient to know the phase η(W) of σ(W) in order to get the solution K(W) of eq. (1). In ref. 3, the function K(W) was calculated with $\gamma = \pi/2$ whereas in ref. 1, the πNN proper and improper vertex function as well as the dressed nucleon propagator were computed with the choice $\gamma = 0$. In the present calculation, the phase γ is taken as a parameter and we test the sensitivity of the results with respect to the inelasticities. From its analytic structure, we easily see that $S_F^+(W)$ can have at most two zeros $W_\pm$ ($-m_N - \mu_\pi \leq W_- < m_N < W_+ \leq m_N + \mu_\pi$) ; clearly, the proper vertex function Γ(W) and the irreducible πN amplitude acquire ghost poles at these zeros. Our present calculations show that the pole W_- is well established and rather insensitive to γ whereas the pole W_+ is very sensitive to the inelasticities. For the existence of the pole at W_+ we can say nothing definite at present (W_+ disappears for $\gamma > .3$) although a generalized Lee model[4] supports its existence. These ghost poles of the irreducible πN amplitude have a possible influence upon some pion-nucleus amplitudes[1,5]. Indeed, in order to avoid overcounting of pionic interactions already accounted for in the dynamics of nuclear bound states as well as in the initial and final distorted waves, an effective pion nucleon scattering amplitude is to be used instead of the complete amplitude. This effective amplitude corresponds to the irreducible amplitude, the pole of which may have important effects under certain kinematical conditions. The irreducible amplitude which is unitary together with the total amplitude has also been computed ; its phase is rather sensitive to the value of γ, so that a model for inelastic contributions is needed.

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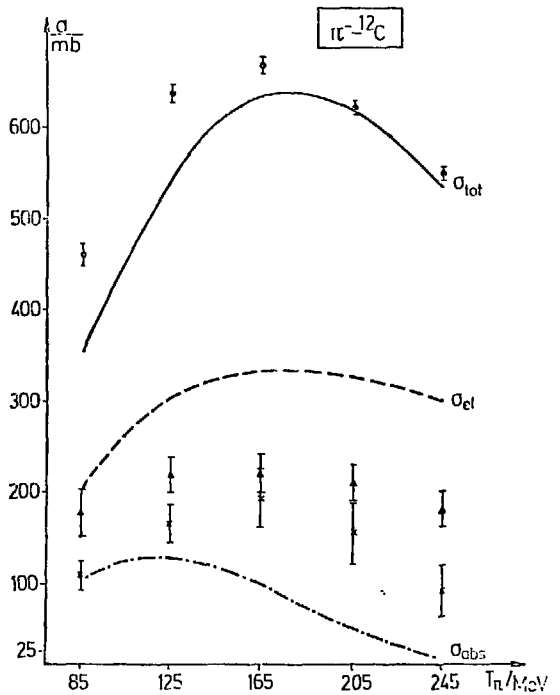
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PION SCATTERING AND ABSORPTION ON ^{4}He AND ^{12}C

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In the regime of the free Δ-resonance microscopic calculations for elastic pion scattering in the framework of the isobar doorway model yield a satisfactory description of the experimental data. However, in order to reproduce the magnitude of the observed cross sections additional damping due to true pion absorption has to be taken into account either phenomenologically or microscopically. We calculate the absorption effects microscopically without introducing new parameters. The exchange of off-shell pions or ρ-mesons may contribute to pion-absorption. The corresponding vertices are parametrized as for the $\pi^+d \rightarrow pp$ reaction. For the pion-helium-system we can reproduce the differential, elastic, total and absorption cross sections for various energies[1]. However, the results for the elastic cross section do not allow omission of the ρ-meson contribution[2].

In fig. 1 we present a preliminary calculation for π^--^{12}C cross sections, where only part of the absorption diagrams is taken into account. This is sufficient for the lowest energy considered. The experimental data is taken from ref. 3. The total cross section is reproduced fairly well, whereas for the large energies we overestimate the elastic cross section and underestimate the absorption cross section since, for these energies, still too many absorption diagrams have not yet been calculated. After having computed these missing terms we shall also be able to discuss the role of π- and ρ-contributions in the carbon case.



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S-WAVE REPULSION IN π-NUCLEUS OPTICAL POTENTIAL AND THE SUBTHRESHOLD πN t-MATRIX[+]

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Understanding the size of the s-wave repulsion in the low-energy π-nucleus optical potential has long been an outstanding problem. Phenomenological fits to pionic atom or low-energy scattering data require an s-wave repulsion which is about 8 times stronger than what one obtains from the impulse approximation.[1] One of the latest attempts to explain this anomaly involved an evaluation of nonlinear terms in field-theoretic Lagrangians with broken chiral symmetry.[2] Calculations were made with the "$\sigma+\omega$" and "Weinberg-ω" models and it was shown that both led to a repulsive π-nucleus potential of the desired magnitude.[2] These conclusions have, however, been contradicted recently.[3] In ref.[3] it was shown that the q^2-dependence of one of the terms in the optical potential obtained by Miller and Noble was simply due to their zero-range approximation for the πN interaction. In ref.[3] it was noted that the lowest-order nonlinear terms in the chiral Lagrangian for the πN system give large individual contributions ($\sim q$), but because of strong cancellations the net effect on the s-wave π-nucleus optical potential is insignificant.

With this motivation we calculated the momentum-space matrix elements $\langle k | V^{opt}_{\ell=0}(\varepsilon) | k \rangle$ of the first-order π-nucleus optical potential as a function of k for ^{16}O and ^{40}Ca. Two calculations were made, one with the Kisslinger potential proportional to q and the other with a covariant theory of the π-nucleus optical potential. In the latter calculation a complete integration over the Fermi motion of the target nucleons was carried out and the off-shell effects related to nuclear binding were treated carefully. Now the pionic atom and the low-energy π-nucleus scattering calculations are expected to be sensitively dependent on the subthreshold extrapolation of the πN t-matrix. In the full dynamical calculation mentioned above a separable model for the πN t-matrix was used. Comparison of the results of the two calculations shows an enhancement of the full dynamical results over the Kisslinger results by a factor of about eight, in the low-momentum region. Interestingly this is just the factor by which the optical parameter b_0 varied from its "free" value in the extensive phenomenological work by Seki.[1] In his work <u>all</u> the parameters in the optical potential were allowed to vary simultaneously to fit the shift and the width data for 59 pionic atoms. Thus an explanation for the enhanced s-wave repulsion could simply require a careful treatment of off-shell effects and a good model for the subthreshold πN t-matrix.

Considering the sensitivity of the results to the subthreshold region, we are at present redoing the above calculations with a more sophisticated model for the subthreshold πN t-matrix. This model allows both π and N to go off-mass-shell, has the correct s and u-channel nucleon poles, and also provides a good fit to the on-shell data up to $\sqrt{s} \simeq 1300$ MeV.

[+]Work supported in part by the NSF and the PSC-BHE Award Program of the CUNY.

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MEASURING ISOSPIN MIXING IN NUCLEI USING $\pi^{\pm}$ INELASTIC SCATTERING*

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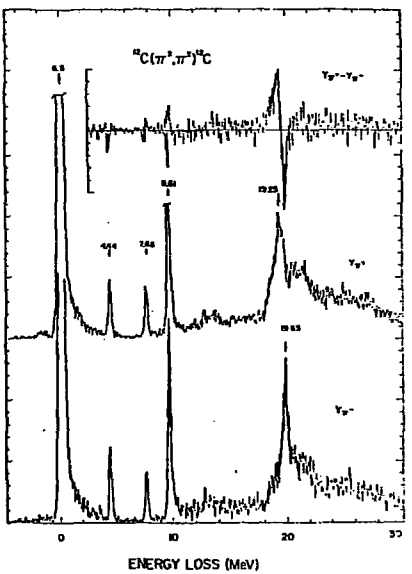
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The extent to which charge-dependent Hamiltonian matrix elements contribute to the coupling of T=0 and T=1 similarly structured states in light nuclei has been of considerable interest since the observation of a nearly maximally isospin-mixed 2^+ doublet in ^{8}Be at 19.6 and 19.9 MeV. Calculations of the Coulomb matrix elements between such states could account for only a small portion (≈-60 keV) of the ~150 keV isospin-mixing matrix element required to explain the observed properties of the states. Previous estimates of isospin-mixing in nuclear states have had to rely on assumption of spectroscopic factors or an assumed knowledge of the nuclear structure of the state and consequently the validity of citing such measurements as the evidence of a charge-dependent portion of the nuclear force remains a matter of controversy.

Here a new technique for the study of isospin-mixing is offered which has resulted in a new estimation for the isospin-mixing matrix element for the 1^+ states in ^{12}C and the discovery of two new isospin-mixed doublets in ^{12}C - a strongly mixed 2^- doublet at 18.7 and 19.5 MeV and a 4^- doublet at 19.3 and 19.6 MeV representing the second nearly maximally mixed states which has ever been observed. The technique (see figure) involves comparison of π^+ and π^- inelastic scattering near the (3,3) resonance from self-conjugate nuclei. The sensitivity of $\pi^{\pm}$ comparison to isospin-mixing can be understood by considering that for an isospin doublet, isospin-mixing results in increased proton (neutron) particle hole strength for the T=0 (T=1) state. Therefore the favoring of excitations of increased proton (neutron) particle hole strength for π^+ (π^-) inelastic scattering near the (3,3) resonance can be used to extract an isospin-mixing matrix element.



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MEASUREMENT OF $^{40,42,44,48}Ca(\pi^+,\pi^0)$ REACTIONS†

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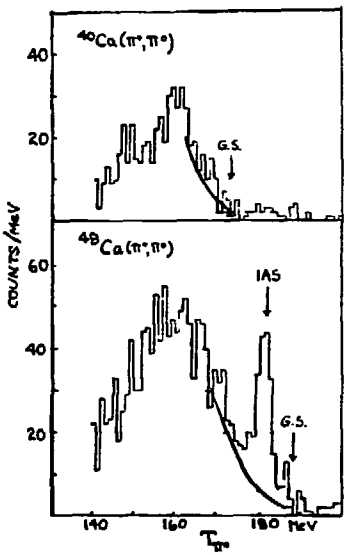
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The Ca isotopes are well suited for a detailed study of the isovector term $U_1(\vec{t}_\pi \cdot \vec{T})$ in the pion nucleus optical potential. The proton density distributions have been well determined in electron scattering studies, and some information on the neutron density distributions is available from hadronic scattering and absorption experiments. Also, π^+ and π^- elastic scattering were measured[1] recently at T_π = 180 MeV. The existence of such complete data makes it possible to perform a thorough analysis of the (π^+,π^0) cross sections to the isobaric analog states. Such a study has not yet been performed. It is necessary for the analysis of all pion elastic and inelastic scattering experiments on N>Z nuclei.

The experiment was performed with the LAMPF π^0 spectrometer mounted in the Low Energy Pion Channel (LEP). The targets were self-supporting plates with isotopic enrichments > 93%. The isobaric analog state (IAS) is clearly visible in the forward angle spectra of $^{42,44,48}Ca$. ^{40}Ca was measured to determine the shape of the quasi-free scattering spectrum. Spectra for $^{40,48}Ca$ at T_π = 180 MeV are shown in the figure. The angular acceptance for these data is 0 to 16°.



Preliminary analyses of the 0° cross sections indicate that there are dramatic deviations from the expected $(N-Z)A^{-4/3}$ dependence[2] across the isotope chain. These will be presented and the implications for neutron density distributions and optical potentials will be discussed.

†This work was supported in part by the U. S. Department of Energy

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OBSERVATION OF PIONS AND PROTONS EMITTED IN HADRON-NUCLEUS REACTIONS AROUND SEVERAL GeV/c

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Preliminary results are presented for a bubble chamber experiment on inelastic reactions of π^+ (at 2 and 4 GeV/c), π^- (2.3 and 4 GeV/c) and P (4 GeV/c) with nuclear targets. Three nuclear plates (0.92 g/cm^2 for Be, 2.69 g/cm^2 for Cu and 4.98 g/cm^2 for Ta) have been installed in the 1-m HBC at KEK. Due to the thickness of the target plates, protons and pions detected in this experiment are, on the average, those with momenta greater than 230 and 62 MeV/c for Be, 280 and 77 MeV/c for Cu and 310 and 86 MeV/c for Ta, respectively.

For the average multiplicity of secondary particles, it was found that (a) the multiplicity is proportional to the available energy E_{av} defined by

$$E_{av} = s^{1/2} - m_{in} - m_N ,$$

where m_{in} and m_N are masses of the incident particle and a nucleon respectively, and $s^{1/2}$ is the CMS energy of an incident particle and a nucleon, and (b) as the mass number goes larger, average number of protons increases approximately as $A^{1/2}$. On the other hand, the number of pions with the same charge as the incident one decreases as $A^{-1/6\sim-1/8}$, while the number of pions with the opposite charge is almost constant or rather decreasing as the mass number increases.

For inelastic reactions of $\pi^{\pm}$ at 4 GeV/c, the number of pions is almost independent of the number of protons (N_p) emitted simultaneously. Moreover, the ratio of total kinetic energy of protons to that of all charged particles increases linearly as N_p increases and amounts to 50 % around N_p=5. These observations show that the number of pions produced is proportional to the available energy independent of the type of incident particle. The available energy is, however, utilized more preferentially to knock out nucleons rather than to produce pions as the mass number of the nucleus goes larger.

PION SINGLE-CHARGE EXCHANGE ON CARBON ISOTOPES[†]

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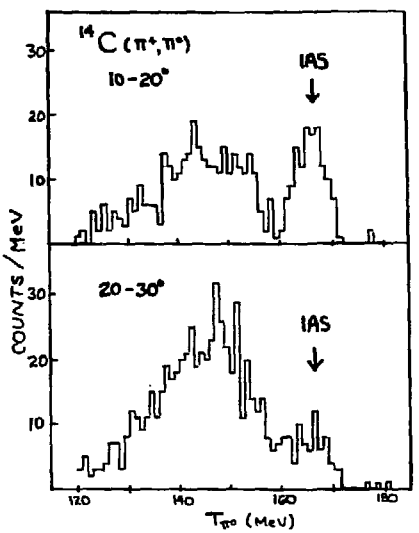
H. W. Baer, R. E. Anderson, J. D. Bowman, M. D. Cooper, F. Cverna,
C. M. Hoffman, G. Hogan, M. J. Leitch, and N. S. P. King

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The reactions $^{12,13,14}C(\pi^+,\pi^0)$ have been studied using the LAMPF π^0 spectrometer in the Low Energy Pion (LEP) channel at LAMPF. Data at 164-MeV pion kinetic energy were taken in the angular range 0 to 35°, which covers the region of the first diffraction peak and minimum for the isobaric analog state (IAS) transition. The IAS peak stands out clearly in the forward angle $^{13,14}C$ data. Spectra for $^{14}C(\pi^+,\pi^0)$ are displayed in the figure. These show the sharp drop with scattering angle of the IAS differential cross section. From the preliminary analysis, a value of ≈30° was determined for the first minimum. The ^{14}C target consists of 9.2 g ^{14}C encased in a graphite cell with 25-μm graphite windows.

$^{12}C(\pi^{\pm},\pi^0)$ spectra were measured for the purpose of studying the $\Delta T = 1$ excitation spectrum in pion inelastic scattering, and to measure the shape of the quasi-free spectrum. A dependence on scattering angle was observed for continuum states near 20-MeV excitation.



[†]This work was supported in part by the U. S. Department of Energy

INELASTIC INTERACTIONS OF 340 GeV/C π^- WITH EMULSION NUCLEI

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Here we present the preliminary results about the multiplicities of charged secondaries produced in interactions of 340 GeV/C π^- with emulsion nuclei. A (6 cm. x 15 cm. x (22 x 600) μm.)stack of Ilford G5 emulsion was tangentially exposed to the CERN-SPS-H2 π^- beam (August 1979). The incident flux was about $7x10^4$ particles/square cm. A sample of about 1000 inelastic events collected by along the track scanning gave a mean free path $\lambda = 40.09 \pm 1.5$ cm.
The average multiplicities of the produced showers,grey,black ,and heavily ionising particles are:

$\langle n_s \rangle = 13.38 \pm 0.18$, $\langle n_g \rangle = 2.25 \pm 0.10$, $\langle n_b \rangle = 5.69 \pm 0.11$, and $\langle n_h \rangle = 7.90 \pm 0.13$ respectively. The intercorrelations between the different secondaries are investigated.
Our value for the dispersion " D " of the shower particles multiplicity distribution together with those obtained for different targets and at different energies (FERMI LAB - PUB-79/47-EXP 7185. 178.), confirm the linear relation :

$$D = 0.55 \langle n_s \rangle - 0.59$$

The value of $D/\langle n_s \rangle$ is found to decrease with the increase of both n_g and n_h. While these observations are against the collective tube model " CTM " expectations , a qualitative description of the showers multiplicity distribution is obtained in the frame of that model.
The multiplicity distributions of the showers produced in 17,50,200,and 340 GeV/C π^- interactions with emulsion nuclei are fitted with the following like KNO scaling function:

$$\Psi(z) = 2.3 \, (z+0.14) \exp. (-0.059 \, z - 0.659 \, z^2)$$

with $z = n_s - \alpha / \langle n_s \rangle - \alpha$, and α is found to be zero.
The multiplicity distribution of the grey particles is studied in the frame of the pomeron interactions with nuclei and applying the tree approximation.
It is a pleasure to thank Professors L.Van Hove(RDG of CERN), E.Gabathuler,G.Vanderhaeghy,N.Dobel ,Lazerous,and all the members of the CERN-RB and the SPSC, for their kind helps in the execution of our irradiation proposal (SPSC/P 128-3 Juli 1979-EXP WA-61),and for the kind hospitality to one of the authors(O.E.B.).Thanks also to Mr.Mendola for processing the emulsions.

PION INDUCED CHARGE EXCHANGE AND NUCLEAR STRUCTURE

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The influence of nuclear structure upon calculated angular distributions and cross sections of pion induced single and double charge exchange on light nuclei is studied within the framework of Glauber theory. Results obtained using simple shell model wave functions which involve particle-hole components where appropriate are compared. In all cases the use of better wavefunctions enhance the (π^+,π^0) cross sections and suppress (π^-,π^0) cross sections. The effects of using realistic single particle wavefunctions generated from Woods-Saxon potentials and the effects of the antisymmetry of the nuclear wavefunctions are also investigated. Renormalization of the properties of the $\Delta(3/2,3/2)$ in the nucleus has also been considered and is shown to be essential to understand the behaviour of the experimental integrated cross section. Results are given for (π^+,π^0) on ^{7}Li, ^{13}C, ^{15}N, ^{16}O, ^{17}O, and ^{39}K, (π^-,π^0) on ^{13}C, ^{15}N, and ^{17}O and (π^+,π^-) and (π^-,π^+) on ^{12}C, ^{16}O and ^{18}O leading to the ground state and excited states of the final nucleus.

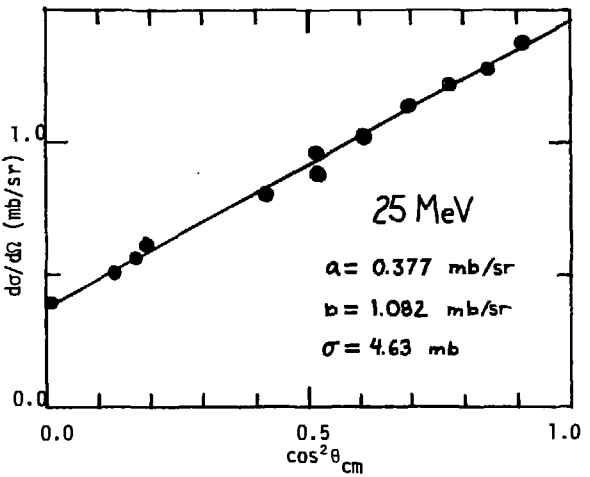
ANGULAR DISTRIBUTION AND TOTAL CROSS SECTIONS FOR THE $\pi^+ + d \rightarrow p + p$ REACTION WITH T_π = 20 to 65 MeV

B. G. Ritchie, F. E. Bertrand, M. Blecher, R. L. Burman, R. Carlini, R. D. Edge, K. Gotow, E. E. Gross, M. E. Hamm, M. J. Leitch, D. J. Malbrough, M. A. Moinester, F. E. Obenshain, B. M. Preedom, and J. R. Wu

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O. R. N. L.**
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Angular distributions were measured for the $\pi^+ + d \rightarrow p + p$ reaction at the low-energy pion channel at LAMPF. Laboratory pion energies were 20, 25, 30, 35, 40, 45, 55, and 65 MeV, with a range in laboratory angle from 15° to 110°. The target material was CD_2, with background measurements taken using a CH_2 target. The protons were detected in coincidence using a plastic scintillator array. Decay muons from the pion beam were monitored to provide relative normalizations. Absolute normalizations were made by calibrating the relative monitor using two in-beam dE/dx counters. Correction factors for the pion absorption in the in-beam counters were computed and applied to the calculations of the pion flux. An exemplary angular distribution is shown in the figure below; the fit shown is $a + b \cos^2\theta$.

The angular distributions were integrated over 2π to provide total cross sections. These cross sections, with errors <5%, were compared to previous measurements below 100 MeV for this reaction. The experimental values reflect the general trends of the previous data, showing a smooth drop to lower values of the total cross section with decreasing pion energy.



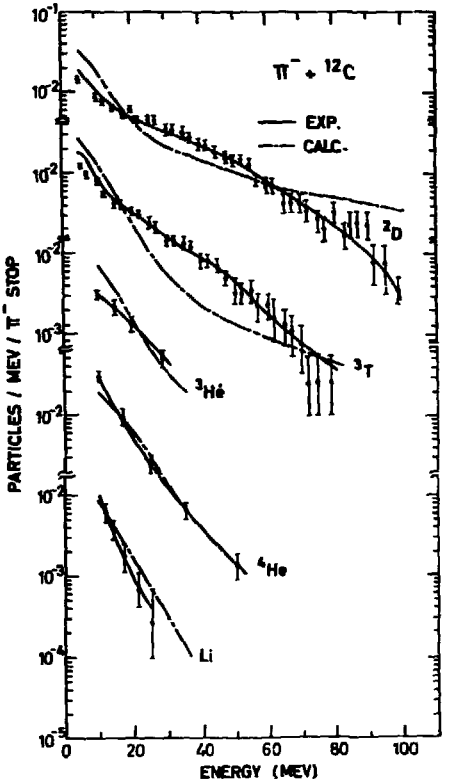
* Supported by D.O.E.
**Supported by D.O.E.under contract with Union Carbide Corporation
† Supported by N.S.F.

EMISSION OF COMPOSITE PARTICLES FOLLOWING THE ABSORPTION OF NEGATIVE PION

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In order to learn more about the absorption vertex we have calculated the spectra of composite particles following absorption. Viewing in reverse, as a first step the calculations are done in the "coalescence model"[1]. Results for the absorption of at rest on ^{12}C are shown in the figure along with the experimental data[2]. Except for mass 3 particles the spectra are reproduced reasonably well. The required values of p_0 are given in the table below.



Table

particle	d	t	^3He	^4He	Li
p_0(MeV/c)	49	49	52	67	64

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PION-DEUTERON ELASTIC SCATTERING FOR MOMENTA FROM 408-600 MeV/c†

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Using the LAMPF P^3 beam we have measured pion elastic scattering from deuterium at momenta of 408, 441, 539 and 600 MeV/c with momentum resolution of 1%. Measurements were made in steps of 10° from 60° to 140° in the center of mass. The statistical accuracy of the data is of the order of 3%, which is considerably better than obtained in our earlier experiment.[1] The apparatus consisted of a liquid D_2 target with a simple vertical bend magnetic spectrometer to detect the recoil deuterons, along with a detector system of large solid angle to record the pions scattered in coincidence. The elastically recoiling deuterons were identified by combining a measurement of time-of-flight with the measurement of the momentum. The results were normalized against πp scattering measurements made when the target was filled with liquid H_2. Most of the data were taken with π^+ mesons but some data with π^- mesons (both on ^1H and ^2H) were also obtained. From charge symmetry, the π^+d and π^-d will have the same cross sections so that our data can be used to check existing values of the ratio of π^+p to π^-p cross sections as well as to test the internal consistency of our measurements.

The data confirm the existence of the dip in the cross section previously observed [1] at angles around 100°, but the behavior is smoother than observed before. The results will be compared with various theoretical models.

†This work was supported by the U.S. Department of Energy.

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SURVEY OF (π,πN) REACTIONS ON LIGHT NUCLEI[†]

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An understanding of the mechanism for the (π, πN) reaction is necessary before it can be used to extract nuclear structure information. In the present paper we report the results of a survey of ($\pi^{\pm}$, πN) reactions on light nuclei in which the cross sections for discrete final states were measured by detecting the deexcitation γ-rays. The purpose of the experiment was to acquire data from several target nuclei in order to determine the general characteristics of the reaction mechanism. The use of the γ-ray technique facilitates the measurement of discrete final states but introduces ambiguities that require careful interpretation.

We measured nuclear γ-ray spectra from the interaction of 220 MeV π^- and 190 MeV π^+ on ^{12}C, ^{16}O, ^{19}F, ^{23}Na, ^{24}Mg, ^{27}Al, and ^{40}Ca. γ-rays were detected with a Ge(Li) detector in coincidence with incident π's from the SREL synchrocyclotron. γ transitions from residual nuclei formed by single nucleon removal were identified and cross sections for excitation of specific states were determined. The relative uncertainty in a measured cross section is $\approx$10%, but the uncertainty in the absolute normalization is $\approx$15%.

The one common characteristic of all the spectra is that when the effects of γ-ray feeding from higher states are accounted for, the states most strongly excited are those with the largest direct reaction spectroscopic factors. For π reactions on the self-conjugate target nuclei ^{12}C, ^{16}O, ^{24}Mg, and ^{40}Ca, we previously reported[1] that the ratio of n to p removal averaged 1.8 for π^- and 1/1.8 for π^+. If the reaction were one step quasi-free, the expected ratios would be 3 and 1/3 respectively. The reduction of this ratio from 3 has been explained by a semiclassical model[2] which assumes that the nucleon can charge exchange before it leaves the nucleus.

The interpretation of the results of the odd mass targets ^{19}F, ^{23}Na, and ^{27}Al is more difficult. The residual nuclei are not mirror nuclei and thus the spectroscopic factors and γ-decay schemes are different. One surprising aspect of the results is that with the exception of $\pi^+ + {}^{19}\text{F} \rightarrow {}^{18}\text{F}$, the cross sections are insensitive to the charge state of the incident π. For each target, the cross sections for n removal are larger than for p removal. This is probably due to γ-decay systematics. If it is assumed that all states in single nucleon removal are populated proportional to their direct reaction spectroscopic factors and then decay according to the known decay schemes, then the observed n to p ratios are obtained without taking into account the charge state of the π. This insensitivity to the charge state of the π is puzzling because the selection of states with large spectroscopic factors would indicate a quasi-free reaction.

[†]Supported in part by the NSF and NASA.
[††]Other authors' institutions are: Florida State U., College of William and Mary, Virginia State U., and Utah State U., respectively.

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π^+ AND π^- ELASTIC SCATTERING FROM ^{12}C, ^{40}Ca, ^{90}Zr, ^{208}Pb AT 80 MeV[@]

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Angular distributions for the elastic scattering of 80 MeV π^+ and π^- beams from ^{12}C, ^{40}Ca, ^{90}Zr, and ^{208}Pb have been measured using the Bicentennial Spectrometer (BCS) at the Low Energy Pion Channel of the Clinton P. Anderson Los Alamos Meson Physics Facility (LAMPF). The scattered pions were detected by a verticle drift chamber[1]) (VDC) located near the focal plane of the BCS. Relative beam flux normalization for each angle and target was obtained by detecting decay muons from the pion beam in two scintillator telescopes oriented at an angle with the beam less than the Jacobian peak angle.

The data, preliminary at the time of this writing, are shown in Fig. 1. Absolute normalization for π^+ is obtained from the π^+p scattering of Bertin et al. and for π^- from the Arndt and Roper[2]) phase shifts. Only relative errors are indicated and the forward angle points have not been corrected for the finite angle acceptance of the spectrometer.

The angular distributions show considerable structure with the minima more closely spaced for larger A. Also, the π^- minima are systematically at slightly smaller angles than those of π^+, presumably due to the coulomb shift between π^+ and π^-. At the time of this writing, the data have just been obtained so no optical model fits are available, but are expected to be available by the time of the meeting.

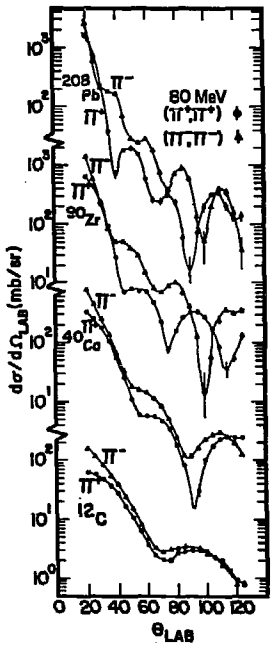


Fig. 1. Curves are to guide the eye.

[@]This work is supported by U.S. DOE and NSF

[††]Los Alamos Scientific Laboratory
[†]Virginia Polytechnic Institute and State University
*Oak Ridge National Laboratory
**University of South Carolina
"University of Tennessee
[‡]Massachusetts Institute of Technology

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MEASUREMENT OF THE RATIO $\sigma(^4He(\pi^+,\pi^+p)^3H)/\sigma(^4He(\pi^-,\pi^-p)^3H)$

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The finding [1] that at the (3/2, 3/2) resonance the ratio $R = \sigma(^4He(\pi^+,\pi^+p)^3H)/\sigma(^4He(\pi^+,\pi^+n)^3He) \cdot \sigma(^4He(\pi^+,\pi^0p)^3He)$ is significantly lower than the expected value $R \simeq 3$ of PWIA prediction, suggested us to study the energy and angular behaviours of the ratio R' of the cross sections for the reactions $(\pi^\pm,\pi^\pm p)$: $R' = \sigma(^4He(\pi^+,\pi^+p)^3H)/\sigma(^4He(\pi^-,\pi^-p)^3H$. We report the result of the measurement of the cross sections of the pion-induced proton-knockout reactions $^4He \rightarrow {}^3H$ performed at 135 MeV with positive and negative pions of JINR synchrocyclotron. The detector consisted of a 4 atm self-shunted streamer chamber filled with helium and surrounded by an hodoscope of scintillation counters [2]. Only the events with the pion scattered in the $(20 \div 170)^o$ angular region (l.s.) have been taken into account. The total reaction cross sections shave been extracted by fits with Legendre polynomials of the differential cross sections. The experiment has been extended from 68 to 156 MeV of $\pi^\pm$ energies and these events are under analysis. Fig. 1 shows the angular distributions of the pions from $\pi^+p\ ^3H$ and $\pi^-p\ ^3H$ reactions we obtained at 135 MeV compared with those of free scattering obtained by Bussey et al [3]. The lines are the fits with Legendre polynomials. Fig. 2 shows the R' (θ) angular behaviours, the lines are the ratio of the fit values. As one can see only in the forward angle region the R' (θ) values for free scattering are close to values for knockout reactions in ^4He. The $R = 4.13 \pm 0.46$ value of the total cross sections is significantly lower than the value deduced in PWIA prediction [4] as in the case [5] of R' values of the pion-induced proton-knockout reaction $^{12}C \rightarrow {}^{11}B$ at 180 MeV, measured at 100^o and 110^o.

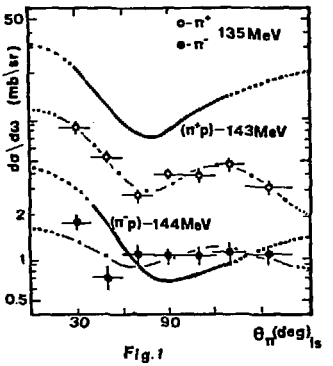


Fig.1

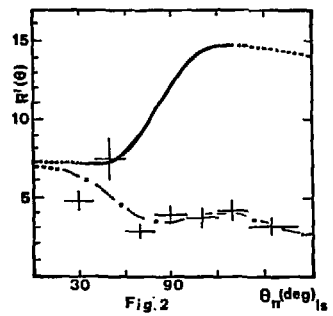


Fig.2

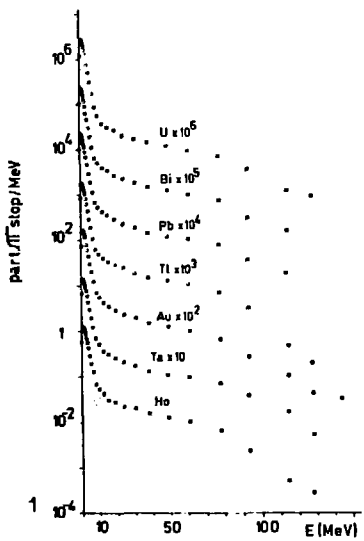
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NEUTRON SPECTROSCOPY AFTER π^--ABSORPTION IN HEAVY NUCLEI.

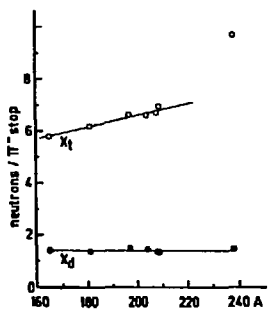
Ch. Eisenegger*, R.Engfer**, R.Hartmann***, E.A.Hermes**,
H.P.Isaak**, T.Kozlowski*, H.J.Pfeiffer*, H.S.Pruys**,
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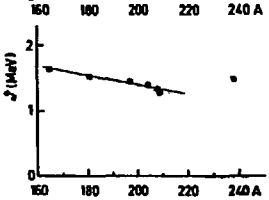
Neutron energy spectra were measured for a number of heavy elements (Ho, Ta, Au, Tl, Pb, Bi and U) to study the A-dependence of the nuclear temperature and neutron multiplicity. Elements around the magic nucleus Pb were chosen to see whether or not there are any shell effects at high excitation energies (∿60 MeV). Neutrons were detected with liquid organic scintillators using n-γ-pulse-shape discrimination (E_n > 1 MeV). The neutron energy was determined by time-of-flight (TOF). The TOF distance was 2 m and the time resolution 1.2 ns FWHM. Fig. 1 shows the neutron energy spectra from π^--absorption in Ho, Ta, Au, Tl, Pb, Bi and U. The spectra can be separated into a low energy evaporation part and a high energy precompound part by fitting the low energy neutrons to an evaporation law of the form: $dN/dE \sim E^{5/11} \cdot \exp(-E/\theta)$, where θ is the nuclear temperature. Fig. 2 shows the A-dependence of the high energy (direct X_d) and total (direct+evaporation X_t) neutron multiplicity. The yield of evaporation neutrons increases with A, that of direct neutrons is roughly the same for all nuclei. The nuclear temperatures shown in Fig. 3 decrease with increasing A, showing no large shell effects. Due to fission neutrons, both θ and Xt are higher than expected for U.



1



2



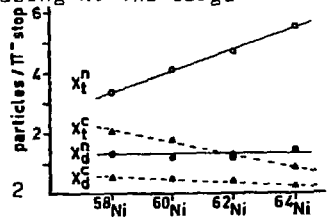
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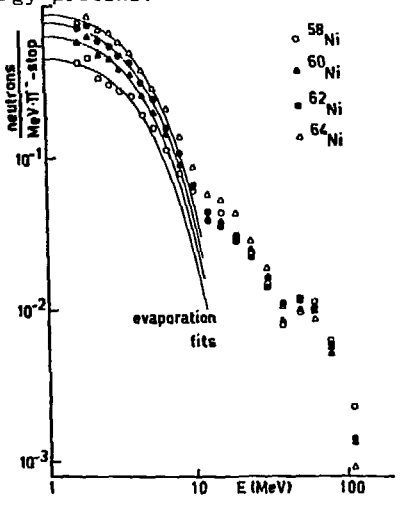
PARTICLE SPECTROSCOPY AFTER π^--ABSORPTION IN ^{58,60,62,64}Ni.

R.Engfer*, R.Hartmann*+, E.A.Hermes*, H.P.Isaak*, T.Kozlowski**, H.J.Pfeiffer**, H.S.Pruys*, F.W.Schlepütz*, U.Sennhauser**, H.K.Walter**, A.Zglinski*.

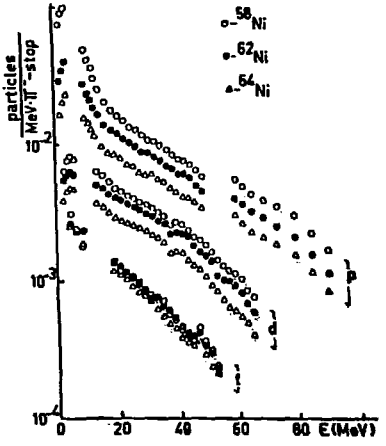
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Energy spectra of neutrons and charged particles following π^--absorption in the Nickel isotopes ^{58,60,62,64}Ni (100 mg/cm^2) were measured at SIN. The neutron energy (E_n> 1 MeV) was determined by time-of flight (distance 2 m, time resolution 1.2 ns FWHM) using liquid organic scintillators. Low energy charged particles were identified with a large Si detector (500 µ, 20 cm^2) by measuring the energy and time-of-flight (distance .6 m). High energy charged particles were measured with ΔE-E Si detector telescopes (ΔE: 500 µ Si, E: 2·3.6+5 mm Si(Li)). The neutron and charged particle energy spectra are shown in Fig. 1 and 3 respectively. Multiplicities for high energy (direct: X_d^n, X_d^c) and total (direct+ evaporation: X_t^n, X_t^c) neutrons and charged particles are given in Fig. 2. The yield of low energy (evaporation) neutrons increases with increasing neutron number N, that of high energy (direct) neutrons is roughly the same for all 4 isotopes. The yield of both low and high energy protons decreases with increasing N. The large isotope effect for low energy neutrons and protons can be understood from differences in binding energy. Differences in the ratio of np to pp pairs in the nucleus could explain the large isotope effect for the high energy protons.





1



3

THE CHARGE DEPENCENCE OF THE KNOCK-OUT REACTIONS $^{12}C(\pi^{\pm},\pi^{\pm}p)^{11}B$, $^{12}C(\pi^{\pm},\pi^{\pm}d)^{10}B$ and $^{12}C(\pi^{\pm},\pi^{\pm}t)^{9}B$

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In the energy region around 180 MeV the cross section of the pion nucleus interaction should be dominated by the (3/2,3/2) resonance. While many reaction channels are open and will contribute to inclusive cross sections a coincidence experiment allows one to select reactions representing only certain well defined mechanisms. At the S.I.N. in Villigen, Switzerland, we have carried out such an experiment designed to identify direct knock-out processes by comparing the cross sections of various knock-out reactions obtained with positive and negative pions.

The ^{11}B excitation energy spectra obtained with π^+ and π^- in the reaction $^{12}C(\pi,\pi p)^{11}B$ are shown in figures 1a and 1b. For the region $E_{exc} < 9.75$ MeV we find $\sigma^+/\sigma^- = 14 \pm 3$ in agreement with the value for the ratio of the differential cross sections observed on free protons. This suggests that the observed events are due to direct proton knock-out.

The excitation energy spectra for the $(\pi,\pi d)$ reaction observed with π^+ (Fig. 2) and π^- (not shown) are very similar. The presence of a strong peak at or near $E_{exc} = 0$ suggests a direct reaction for this case as well. We find $\sigma^{\mp}/\sigma^- = .99 \pm .18$ as one would expect from charge symmetry if the ^{10}B is left in its isoscalar ground state.

The spectra of the reactions $^{12}C(\pi^{\pm},\pi^{\pm}t)^{9}B$ are also similar to each other but show no peak near $E_{exc} = 0$. This, and the fact that $\sigma^+/\sigma^- = .9 \pm .3$ suggest triton formation through neutron pick-up by primary deuterons. In that case the rate of triton production will be independent of the charge of the pion that knocked out the initial deuteron.

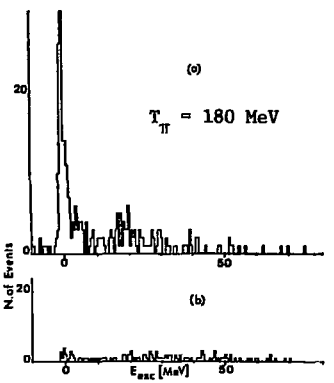


Figure 1

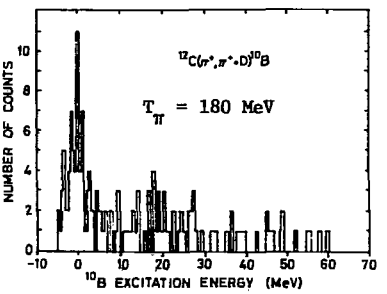


Figure 2

EVIDENCE FOR THE PRODUCTION OF A DIBARYON RESONANCE IN $^{12}C(\pi^+,\pi^+d)^{10}B$

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Dibaryon resonances have been used (2) to fit the free π-d elastic differential cross-section in the backward region and invariant mass range covered in our experiment (1). There appears to be a T=1 $^1D_2$ dibaryon resonance at 2140 MeV with a width of 75 MeV (2), which is in this range. In order to look for structure in the π-d invariant mass distribution of our data (1) we have weighted each event by the normalisation $N(T_\pi)$, the kinematic factor $k(P_R)$ and the momentum distribution $|G(P_R)|^2$ of our model (3) in order to remove nuclear effects.

Figure I shows the πd mass distribution for two angular regions. The structure near 2115 MeV shows angular dependence. In order to increase the statistical accuracy we have combined the two spectra by scaling the curve at 100° by the mean ratio in the region where they overlap. The result in Figure II shows the structure more clearly.

A provisional calculation of the distortion effects for the outgoing pion suggests that they will not significantly affect these results. It is possible that this enhancement is due to the NΔ system near threshold instead of a dibaryon resonance. However a provisional analysis of our data on $^{12}C(\pi^+,\pi^+p)^{11}B$ suggests that when the Δ(1232) is formed in a nucleus it is not shifted in mass by more than 10 MeV either way. Therefore the mass of the NΔ system is unlikely to be less than 2160 MeV and it would probably produce a broader structure. So it is unlikely that this structure is due to an NΔ system.

Our model (3) suggests that the presence of the ^{12}C nucleus tends to enhance two nucleon effects at the expense of single nucleon effects. Another process where such an enhancement may occur is double charge exchange. A bump has been observed (4) in the cross-section for the reaction $^{18}O(\pi^+,\pi^-)^{18}Ne$ at a mass of 2120 ± 10 MeV and with a width of 40 ± 10 MeV, which is compatible with our data. We tentatively identify both structures with the supposed $^1D_2$ (2140) dibaryon resonance, which has been shifted to about 2120 MeV and possibly made narrower by the nuclear potential.

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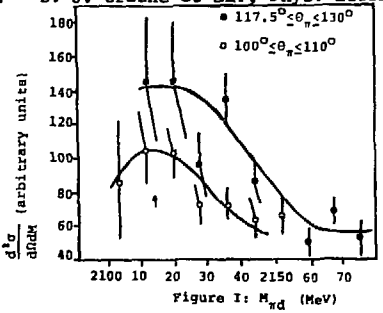


Figure I: $M_{\pi d}$ (MeV)

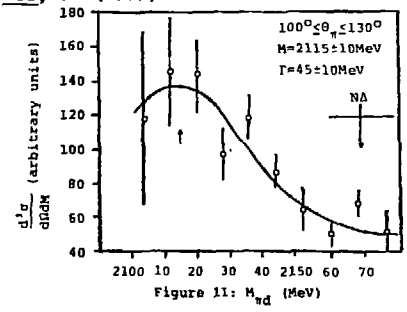


Figure II: $M_{\pi d}$ (MeV)

ANGULAR DISTRIBUTION FOR THE REACTION $^{12}C(\pi^+,\pi^+p)^{11}B$

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We have measured the differential cross section for the reaction $^{12}C(\pi^+,\pi^+p)^{11}B$ as a function of the scattered pion angle at different incident pion energies near the (3,3) resonance in a coincidence experiment at the S.I.N. Villigen, Switzerland. The energy of the scattered pions was measured with the SUSI spectrometer of SIN and the proton energy with a high resolution Ge spectrometer. The observation angle for the pions was varied from 60° to 130° the proton angle was fixed at -30°. Figure 1 shows the angular distribution, at T_π = 160 MeV, of those events for which the ^{11}B remained in the ground state or a state of low excitation (E_{exc} < 9.75 MeV). We have fitted to these data an angular distribution calculated in the plane wave impulse approximation (PWIA) making three different assumptions for the energy at which we evaluated the free πp differential cross section:

a) The incident pion energy seen from the rest frame of the exchange proton.
b) The energy given in a) minus the energy needed to lift the exchange proton back onto its mass shell.
c) The energy needed in free πp elastic scattering to give the same invariant mass for the outgoing πp system as we observe.

The first of these choices (a) gives a satisfactory agreement at T_π = 160 MeV. At T_π = 200 MeV the second choice (b) provides a better fit (Figure 2). We conclude that the PWIA qualitatively reproduces our data to a degree that is surprising in view of the simplified assumptions that enter into it.

We have also shifted the energy at which we evaluated the free πp differential cross section by a fixed amount to see if there is a systematic downshift of the (3/2,3/2) resonance due to the average nuclear potential. We find that if such a shift exists it does not exceed 10 MeV.

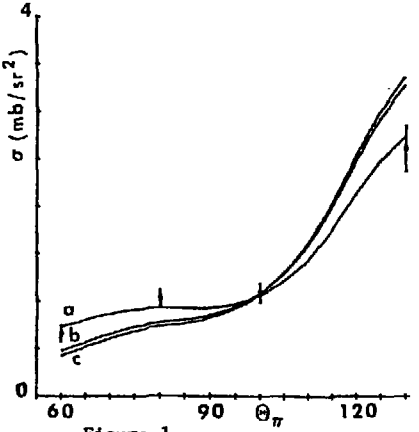


Figure 1

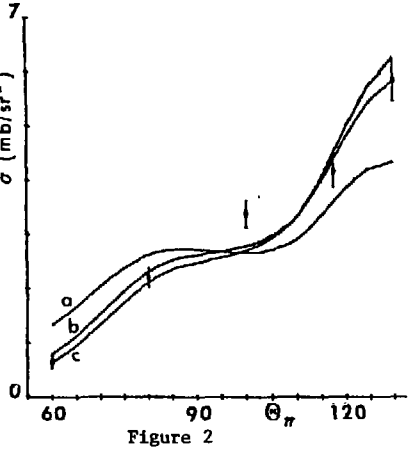


Figure 2

A SHELL MODEL BASED MECHANISM FOR THE REACTION $^{12}C(\pi^+,\pi^+d)^{10}B$

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We have made two PWIA models of pion induced quasi-elastic deuteron knock-out from ^{12}C. Both fit well our angular and momentum distributions (1) for the quasi-elastic data, where $E_x < 10$ MeV. The simplest model assumes that the deuteron is in an S-state with respect to a ^{10}B core. Doubting that this is a viable model for a ^{12}C nucleus we constructed the other model based on the shell model.

Sakamoto (2) has shown that the cross-section can be written as:

$$\frac{d^3\sigma}{d\Omega_\pi dp_\pi d\Omega_d} = N(T_\pi) \cdot k(P_R) \cdot \left|\frac{d\sigma}{d\Omega}\right|^{\pi d}_{el} \cdot |G(P_R)|^2$$

where $N(T_\pi)$ is a normalisation parameter for this PWIA calculation, $k(P_R)$ is a kinematic factor, P_R is the ^{10}B recoil momentum, $\left|d\sigma/d\Omega\right|^{\pi d}_{el}$ is the free π-d elastic differential cross-section and $G(P_R)$ is the fourier transform of the relative wave function, $\psi(\bar{R})$, of the n-p "cluster" and the ^{10}B core, weighted by a factor, P_d. P_d depends on the cluster and deuteron wave functions and we assumed it was one. We then constructed $\psi(\bar{R})$ from the single particle shell model wave functions for a p-shell proton and neutron, since $E_x < 10$ MeV. We assumed that the "cluster" was a T=0, S=1 system, which is justified by our data (3) which shows that $\sigma(^{12}C(\pi+,\pi^+d)^{10}B)/\sigma(^{12}C(\pi^-,\pi^-d)^{10}B)$ is approximately one. We also assumed that the proton and neutron were at the same spacial point and that $\ell_p = \ell_n = 1$ and $j_p = j_n = 3/2$. Then $L = 0$ or 2 and $J = 1$ or 3. Our excitation spectra of ^{10}B are compatible with this. Then:

$$|G(P_R)|^2 = \left[.926\ \left(1 - \frac{P_R^2 b^2}{3}\right) + 1.67\ \frac{P_R^4 b^4}{36}\right] \exp\left(-P_R{}^2 b^2/2\right)$$

where $b = .005.\ \sqrt{6/13}\ .\ r_{RMS}\ (\mathrm{MeV/c})^{-1}$. The first term, which is like an S-state, is dominant, so that the good fit of the first model is probably coincidental. The fit of this latter model to the momentum distribution is shown in Figure I, ref. (1). The χ^2/DF is 1.68 and r_{RMS} is $2.6 \pm .3$ fm in good agreement with electron scattering data. Using this value for r_{RMS} we obtain a reasonable fit to the angular distributions (e.g. Figure II, (1)) with a χ^2/DF of 2.4, which will be reduced considerably when we put in the systematic errors. The fits to our angular distributions support the assumption of factorization implicit in the impulse approximation.

We conclude that the pion appears to knock-out quasi-elastically a p-shell proton and neutron which happen to be in a T = 0, S = 1 state and close together spacially at the moment of interaction.

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ANGULAR AND MOMENTUM DISTRIBUTION FOR $^{12}C(\pi^+,\pi^+d)^{10}B$

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There is evidence for pion-induced quasi-elastic deuteron knock-out from carbon-12 at 180 MeV (1). The rate of deuteron knock-out, when compared to the proton rate, is unexpectedly high, i.e., 1:1 for π^- induced reactions provided $E_x < 10$ MeV, where E_x is the ^{10}B excitation energy (1). Quasi-elastic scattering implies that the pion interacts with the deuteron as if it was a single particle and knocks it out in a one step process. These results are surprising since the deuteron is similar in size to a ^{12}C nucleus and is weakly bound. In order to investigate the mechanism for this process we have made coincidence measurements of the angular and momentum distributions. The scattered pion was detected by a magnetic spectrometer and the deuteron by a solid state spectrometer, which separated protons by E, ΔE cuts so that each event was completely determined kinematically. The deuteron angle was 30^o in the laboratory frame. Figure I shows the cross-section versus the scattered pion momentum at $T_\pi = 200$ MeV and $\theta_\pi = 117.5^o$. The solid points represent all the data and the open points the potentially quasi-elastic events with $E_x < 10$ MeV. For the angular distributions, the magnetic spectrometer was centered on a scattered pion momentum of 170 MeV/c and the cross-section averaged over its momentum bite of 62 MeV/c. Figure II shows the angular distribution for an incident pion energy of 180 MeV. The solid points are all our data and the crosses are our data for $E_x < 10$ MeV. The peaking of the cross-section as the scattered pion angle increases is compatible with quasi-elastic scattering. We also have angular distributions at $T_\pi = 160$ and 200 MeV (not shown). This data shows that the cross-section appears to increase in the region of 180 MeV.

1. R. J. Ellis et al., Physics Letters 88B, 253 (1979).

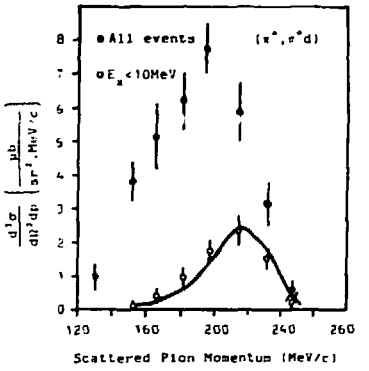


Figure 1

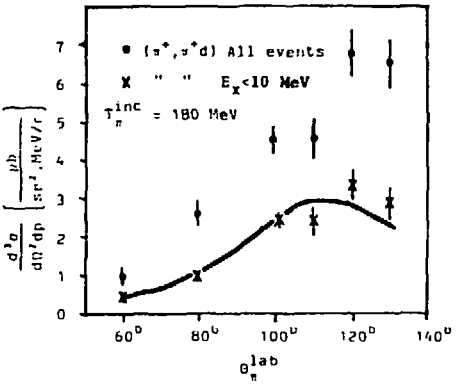


Figure 2

MOMENTUM DISTRIBUTION FOR THE REACTION $^{12}C(\pi^+,\pi^+p)^{11}B$

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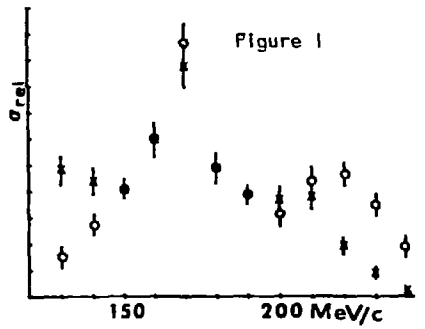
J. Arvieux, J. Bolger, E. Boschitz, R. Corfu and J. Piffaretti
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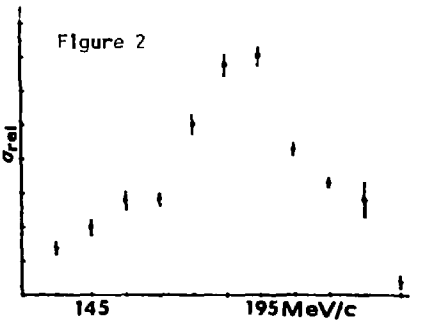
In a coincidence experiment $^{12}C(\pi^+,\pi^+p)^{11}B$ carried out on the SIN pion channel we have measured the triple differential cross section $d^3\sigma/d\Omega_\pi d\Omega_p dp_\pi$ as a function of the scattered pion momentum, $p_{\pi'}$. Figure 1 shows the results obtained with an incident pion energy of 200 MeV, and pion and proton angles of 117.5 and -30° respectively. For the circles in Figure 1 the excitation energy of the ^{11}B nucleus was $E_{exc} < 9.75$ MeV. The crosses refer to the events: $E_{exc} > 9.75$ MeV. The difference between these 2 curves can be largely explained in terms of the plane wave impulse approximation (PWIA) by the momentum distribution of the exchange proton scattering the pion: In the former events the pion scatters on a $p_{3/2}$ shell proton while in the latter it sometimes scatters on an s-shell proton.

In the PWIA the differential cross section can be factorized in terms of the momentum density $D(p_x)$ of the exchange proton.

One can show that the momentum of the exchange proton ($p_x = -p^{11}B$ recoil) is an approximately parabolic function of $p_{\pi'}$. The position and depth of the minimum of this function are dependent on the incident pion energy, pion and proton angles, and the excitation energy E_{exc} of the recoiling nucleus. As one varies $p_{\pi'}$ one changes the contribution of the momentum density term by sampling it at different values of p_x. The momentum density of the $p_{3/2}$ protons has a single peak at $p_x \simeq 100$ MeV/c. If the minimum value of p_x is less than 100 MeV/c one thus has 2 values of the scattered pion momentum where the term $D(p_x)$ is largest resulting in 2 peaks as seen in figure 1. If the minimum value of p_x is > 100 MeV/c one has only one peak. Figure 2 shows the measured differential cross section as a function of the scattered pion momentum for such a case (T_π = 178, θ_π = 100°, θ_p = 45°).

The s-shell momentum density is a monotonically decreasing function of p_x. Thus $D_s(p_x)$ is always a maximum at the minimum value of p_x and gives rise to a single peak in the cross section there. Since the s-shell protons are more strongly bound than the $p_{3/2}$ shell protons by ~20 MeV, a quasi-elastic knock-out of an s-shell proton leaves the recoiling ^{11}B nucleus excited by ~20 MeV. This shifts $|p_{\pi}(p_{x\,min})|$ to just where the first peak in figure 1 is seen. The second peak in figure 1 is the result of secondary interactions which excited the recoil nucleus to $E_{exc} > 9.75$ MeV after the pion was scattered by a $p_{3/2}$ proton.



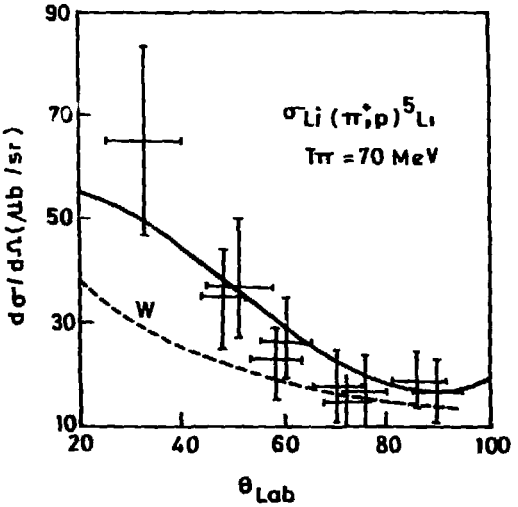


STUDY OF (π^+,p) REACTION ON ^{12}C AND ^{6}Li

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The present work aims at studying the (π^+,p) reaction on ^{12}C and ^{6}Li systems for 70 MeV incident pions. This takes into account the distortion of the incident pion in the coulomb and nuclear field of the absorbing nucleus, the short range correlations of the absorbing neutron and the final state interactions of the proton in the field of the residual nucleus. The Klein-Gordon equation has been solved employing the density dependent Kisslinger optical potential. The nuclear short range correlations are partially accounted by employing Unitary Model Operator Approach (UMOA) to determine the neutron wavefunctions. The distortion of the outgoing proton is taken into account through the Glauber approximation. The density functions employed in the Kisslinger potential are the usual Gaussian distribution and also the density function obtained from the UMOA wavefunctions. This has been done with the two-fold purpose of aiming at consistency in our calculation and also to determine the sensitivity of the crosssection to the nuclear density.



The study indicates that particularly for small angles, the inclusion of both correlations as well as the pion distortion suppresses the steeper fall in the crosssection with angle in the case of ^{12}C. The crosssections are stabilised with variations in parameters like the oscillator well depth parameter etc, unlike some of the earlier calculations. In the case of ^{6}Li (see Figure) our calculations fit the data well, reproducing the experimental minima. The only other calculation in ^{6}Li is that of Wienke (W in Fig.) employing field theoretic method. The experimental points are taken from Amato et al [1].

1) J. Amato et al, Phys. Rev. C9 (1974) 501.

π^- ELASTIC SCATTERING SURVEY AT LOW ENERGIES*

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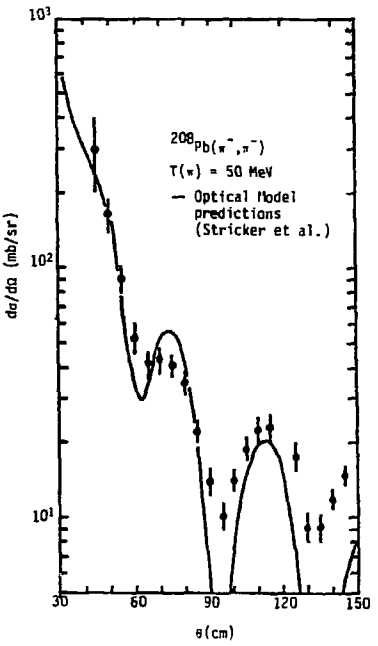
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We have measured π^- elastic scattering differential cross sections at $T(\pi^-)$ = 30 and 50 MeV for targets of $^{12,13}C$, ^{16}O, $^{40,48}Ca$, ^{90}Zr and ^{208}Pb, using a range spectrometer. In the order seen by the pions, the spectrometer consisted of a time of flight counter, two lucite Cerenkov detectors and 24 range defining scintillator elements of thicknesses ranging from .050" to .250". Two additional veto counters helped reject particles which entered or exited the stack from the sides. Isotopic targets of > 95% enrichment and thicknesses from 70 to 250 mgm/cm^2 were used, and data was taken in the angular range 30° to 145°.

The quality of the data obtained is illustrated in Fig. 1 by the on-line preliminary cross sections obtained for ^{208}Pb. Results of more complete analysis of the data will be presented, and isotopic differences and π^+/π^- differences will be discussed in terms of optical model calculations.[1]



*Work supported in part by the U.S. Department of Energy.

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1. K. Stricker, H. McManus and J.A. Carr, Phys. Rev. C19 (1979) 929.

π^--ABSORPTION IN ^{3}HE

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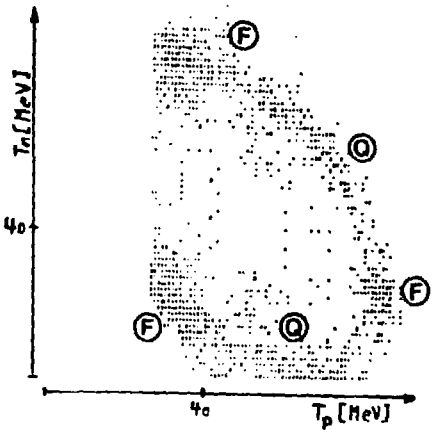
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The commonly used picture for π-absorption with the two-nucleon-model seems to account for only half of the absorption processes in nuclei. In order to investigate possible absorption mechanisms where more than two nucleons are involved a kinematically complete study of the π^--absorption in ^{3}He has been made at SIN.

The pions were stopped in a gaseous ^{3}He target cooled to 5 K. Two of the emitted nucleons of the reaction $\pi^- {}^3\text{He} \rightarrow pnn$ were detected in coincidence. In addition triple coincidences with the 2p-1s X-ray transition were recorded in order to discriminate between absorption from atomic s- and p- states.

Since the process depends only on two variables the data can be presented in the form of a Dalitz plot with the energies T_n and T_p of one outgoing neutron and the outgoing proton as variables. Then the phase space is constant and the event density is directly proportional to the matrix element. The figure shows a sample of our data in the narrow band for the angle between p and n from 178° to 180°. Broad maxima are clearly visible in the regions which correspond to quasifree reactions (Q). However, substantially more events have been observed concentrated in regions of final state interaction (F).

Another result of the experiment is the strong 180° correlation of the recorded events. The results are discussed in terms of possible reaction mechanisms.



Dalitz plot of $\pi^- {}^3\text{He} \rightarrow pnn$

CALCULATION OF PION ABSORPTION CROSS SECTION

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True pion absorption cross sections have recently been measured by Nakai et al. for various targets in wide energy range.[1] We calculate the absorption cross sections using an optical potential given by Stricker et al. (MSU).[2] The optical potential consists of a term proportional to the Pauli-corrected πN amplitudes (quasi-elastic term, $U_{q.e.}$) and a term due to absorption ($U_{abs.}$). The reaction cross section σ_r can be divided as

$$\sigma_r = \sigma^{(1)}_{q.e.} + \sigma^{(1)}_{abs.} = -\frac{1}{k}\int\phi^*(\vec{r})\ \mathrm{Im}\ U_{q.e.}\phi(\vec{r})d\vec{r} - \frac{1}{k}\int\phi^*(\vec{r})\ \mathrm{Im}\ U_{abs.}\phi(\vec{r})d\vec{r}$$

where $\phi(\vec{r})$ is the pion distorted wave. $\sigma^{(1)}_{q.e.}$ ($\sigma^{(1)}_{abs.}$) is the cross section for which the first non-elastic process is the quasi-elastic (absorption).

Because pions may be absorbed after quasi-elastic processes, $\sigma^{(1)}_{abs.}$ can not be directly compared with experimental absorption cross sections. These contributions can be calculated by further dividing $\sigma^{(1)}_{q.e.}$ into three branches, i.e. quasi-elastic, absorption and escape from nuclei.

$$\sigma^{(1)}_{q.e.} = \sigma^{(2)}_{q.e.} + \sigma^{(s)}_{abs.} + \sigma^{(2)}_{esc.}$$

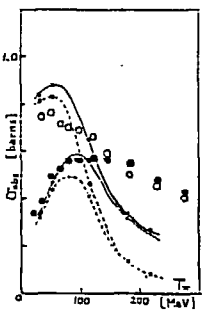
The brancing ratios are classically estimated using mean free path argument. The mean energy loss of the pion due to the quasi-elastic process is calculated in the Fermi gas approximation, and is taken into consideration in estimating the mean free path for each process. We also assume that pions never reappear once they have escaped from nuclei or have been absorped. The above procedure can be repeated further

$$\sigma^{(n)}_{q.e.} = \sigma^{(n+1)}_{q.e.} + \sigma^{(n+1)}_{abs.} + \sigma^{(n+1)}_{esc.}$$

and the absorption cross section is given by

$$\sigma_{abs.} = \sigma^{(1)}_{abs.} + \sigma^{(2)}_{abs.} + \cdots$$

Fig. 1 shows $\sigma_{abs.}$, $\sigma^{(1)}_{abs.}$ thus calculated together with the experimental data in the case of π^- on Cu. The deviation at low enerties for π^- may be due to the defect of the optical potential parameters since $\sigma^{(1)}_{q.e.}$ is small in this region. The calculation underestimates the cross sections at higher energies, which should be ascribed to the rudeness of the branching ratio estimate at each step. A more refined calculation is under way.



In the figure, the solid and dashed lines represent $\sigma_{abs.}$ and $\sigma^{(1)}_{abs.}$, respectively.

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DEEP-INELASTIC SCATTERING AND ABSORPTION IN 190-MEV $\pi^{\pm}$ ON ^{27}AL REACTIONS

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The decomposition of the total pion-nucleus cross section into elastic scattering, inclusive inelastic scattering and absorption has been reported by Navon et al.[1] Detecting γ-rays in coincidence with the scattered pion or one of the ejected protons enables us to further decompose the inelastic scattering and absorption reactions according to the number and combination of nucleons removed and in some instances according to specific reaction mechanisms.

These data were taken on the P^3 channel at LAMPF. A large ΔE-E scintillator telescope set at 35^{o} cleanly separated pions, protons and deuterons and a Ge(Li) detector set at 90^{o} observed the prompt γ-rays. Reactions from both incident positive and negative pions at 190 MeV on ^{27}Al were studied.

Single nucleon removal agrees with a simple quasi-free impulse model when the nucleon charge exchange (determined to be about 33% for 35^{o} pions) is included and also the increased neutron density on the extreme outer surface of ^{27}Al. The observed proton energy spectra requires the average Fermi-momentum of the removed nucleons to be about 150 MeV/c, consistent with an outer surface reaction.

The differential cross sections for 2N removal are significant only for np removal which suggests stronger correlations for np than either nn or pp. For incident π^{-} they are 230 ± 52 , and 57 ± 50 μb/sr for pions and protons respectively and for π^{+} they are 190 ± 40 and 350 ± 80. The comparison of the proton cross section for negative and positive pions sugest that pion absorption dominates the proton events. That this isn't the case, however, is shown by the proton energy spectra. Most of the protons have energies less than 100 MeV and the shape is characteristic of a knockout reaction. Monte Carlo generated knockout and absorption spectra when fitted to the observed proton spectra, show absorption accounts for only 10-15% of the proton events. The low proton cross section for incident negative pions can now best be explained by a mechanism whereby the second nucleon is acting principally as a spectator and wouldn't be seen with energy less than 30 MeV. The pion energy spectra for np removal is sharply peaked and consistent with either πN or πd quasi-free scattering.

The removal of three nucleons in the combination p2n dominates the multinucleon removal reactions in all cases. The absorption accounts for no less than 20% of this reaction and may contribute as much as 50% depending on the angular distribution of the protons. The pion spectra show that ~30% of the pions multipli-scatter, and the remainder scatter through a one step process. Direct triton knockout may be significant.

The removal of 2p2n and 3p3n have many more possible reaction mechanisms. Hence, it is more difficult to identify them and decribe the results in such limited space. Absorption reactions are less than 40% of the total and again multiple scattering of the pion can be shown to be much less than single scattering as in the p2n case described above. Direct reaction with clusters seems probable.

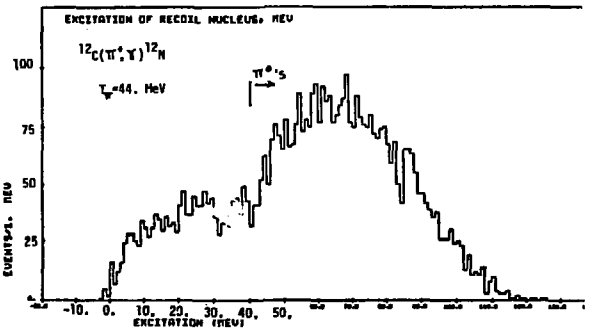
1. I. Navon et al., Phys. Rev. Lett. 42 (1979) 1465

STATES WITH ENERGIES IN THE REGION OF THE E1 PHOTORESONANCE ARE STRONGLY EXCITED BY $^{13}C(\pi^-$ at rest,$\gamma)$ AND $^{12}C(\pi^+ T=45$ Mev,$\gamma)$

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Measurement of the photon spectrum from radiative capture of stopped π^- in ^{13}C is presented. Parent analogs of states in ^{13}C having energies 21.6, 22.7, and 25.3 Mev are excited with branching ratios $10.\cdot10^{-4}$, $8.6\cdot10^{-4}$, $17\cdot10^{-4}$ per stopped pion respectively, with relative uncertainties of 16%. Nearly a quarter of the radiative capture strength with $E_\gamma > 50$ Mev lies in these peaks. Calculation of the corresponding strength in appropriate single particle units will be presented, supporting the interpretation of these states as a spin-isospin giant resonance predicted theoretically.[1)]

The photon spectrum from in-flight radiative capture of π^+ has also been measured and is shown below. The total radiative cross section is 56 ± 15 μb/sr and the ratio of $(\pi^+\pi^0)$ to (π^+,γ) yields is 11 ± 3. The instrumental resolution is ~ 4 Mev, limited by target thickness. The total radiative cross section is in agreement with a calculation using phenomenological electron scattering matrix elements.[2)] Differences between the observed energy spectrum and the theoretical prediction will be discussed.



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1. J. D. Walecka, p. 59 in Preludes in Theoretical Physics A. De Shalit et. al., eds. Wiley & Sons, New York, New York (1966).
2. F. Cannata, et. al., Can. J. Phys. 52 (1974) 1405.

A COMPLETE COINCIDENCE MEASUREMENT OF THE[@] $(\pi,\pi'p)$ REACTION IN ^{12}C AT 220 MeV

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We have measured the quadruple differential cross section, $\frac{d^4\sigma}{d\Omega_\pi dT_\pi d\Omega_p dT_p}$, for the reaction $^{12}C(\pi,\pi'p)^{11}B$ with 220-MeV positive pions. Scattered pions were momentum analyzed with a magnetic QQD spectrometer, while the coincident protons were detected in an array of scintillator telescopes which were deployed to sample a proton angular range of 80° for a single pion angle and momentum setting. Singles measurements were performed concurrently in each arm.

At each of four scattered pion angles of 61°, 81°, 105°, and 127°, complete proton angle and energy distributions were measured for several pion momentum settings chosen to cover the entire pion quasielastic peak. The overall energy resolution was good enough to allow separation of bound states from continuum states in the residual ^{11}B nucleus.

We will present comparisons of the angular and energy distributions for the coincident events with the corresponding singles distributions in the so-called quasielastic region. There are striking differences between the data in these two modes. A detailed analysis should provide some of the much sought for information on the pion-nucleon reaction mechanisms inside nuclear matter.

[@]This work is supported by the U. S. DOE and NSF
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STRUCTURE IN ^{200}Tl AND THE ODD-EVEN STAGGERING IN $\pi h_{9/2} \otimes \nu_{13/2}$ BANDS †

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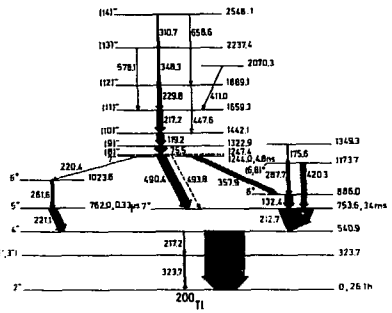
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High spin states of ^{200}Tl, populated through the ^{198}Pt(^{6}Li, 4n) reaction at E=30 to 40 MeV, were studied using in-beam γ-ray spectroscopy techniques. an almost completely new level scheme is presented (shown in the figure) comprising the $\pi h_{9/2} \otimes \nu i_{13/2}$ two quasiparticle band[1,2] which in this case is built on an $I^{\pi}=7^{-}$ isomeric state, while the bandhead has $I^{\pi}=8^{-}$ in all the lighter doubly odd Tl isotopes studied up to now.

The amount of odd-even staggering seen in these bands is remarkably constant in the mass range A=192 - 196 while it diminishes for ^{198}Tl. In addition, the same dependence is observed for $\pi h_{9/2}$ bands in neighboring odd Tl isotopes[3] for A=193 to 199. The present results confirm this trend as in ^{200}Tl the staggering is further attenuated. This effect reflects the behavior of the E_2+ energies in the even-even Hg core nuclei which remain constant (around 425 keV) for A=192-196 and decrease monotonically down to 368 keV for ^{200}Hg. In terms of the particle plus rotor model a smaller E_2+ energy means a more adiabatic situation and hence a diminished Coriolis interaction thus strongly suggesting that the mechanism behind the staggering entails, also in the doubly odd nuclei, an interaction of the particles with the core rather than among the valence particles themselves.



†This work was supported by the CONICET, Argentina and the National Science Foundation and DOE of the U.S.A.

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2) A.J.Kreiner, Z.Physik A288 (1978) 373
3) J.O.Newton, F.S.Stephens and R.M.Diamond, Nucl.Phys. A236 (1974) 225

ODD - EVEN STAGGERING OF NUCLEAR RADII IN THE RARE EARTHS

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The change of the charge radius upon addition or subtraction of a neutron has been calculated in linear response theory using a density dependent effective interaction. The average magnitude of $\delta\langle r^2\rangle$ could be well reproduced, as well as the trend that it decreases with increasing mass number. However, the odd-even staggering (the fact that the rms charge radius of odd-neutron nuclei is generally less than the average of the even neighbours' ones) could not be obtained: the calculations yielded staggering with the opposite sign, i.e. larger than average radii for the odd-neutron isotopes. Changes of parameters entering the theory (s.p. shell model and force parameters) had little or no effect on the results, as long as it was requested that the excitation energies of the lowest 0^+ states of the even nuclei were approximately reproduced in the quasiparticle-RPA.

Staggering of charge radii is common over the whole nuclide table, and has been explained for spherical nuclei to be due to the blocking of zero-point quadrupole vibrations by the odd neutron.[1]) A separate calculation ruled this effect out at least for the Rare Earth nuclei.

In order to get some hint on the physical reasons of staggering, the spurious reversed effect of our calculations has been analyzed. The unphysical increase of the charge radius of odd isotopes is brought about by an interplay of two effects: The blocking of pairing correlations in the neutrons reduces the diffuseness of the Fermi surface and thus increases the population of neutron states below the Fermi energy. The short-range attraction between neutrons and protons tends to pull protons into levels with the same quantum numbers as the neutron levels mentioned above, since matrix elements between these levels outweigh the other ones, due to the large overlap of the wavefunctions. For protons, these levels are above the Fermi energy. If their population is increased at the expense of lower ones with smaller rms radii, the charge radius is increased.

Blocking of pairing correlations by odd nucleons is a well established fact, so from the other sign of experimental staggering we can conclude that the large size of interaction matrix elements between protons and neutrons with the same quantum numbers is unphysical. The reason for this may lie in the very nature of the nucleon-nucleon force, where the hard core leads to strong short range correlations, thereby making interlocking density distributions of two nucleons more favourable than completely overlapping ones.

Preliminary results supporting this view are given, but for quantitative agreement a consistent treatment of short range correlations and linear response seems to be necessary.

1. B.S. Reehal and R.A. Sorensen, Nucl. Phys. A161 (1971) 385

STUDY OF KURATH SUM RULE IN ^{28}Si BY STATISTICAL THEORY*

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The isovector magnetic dipole operator is

$$M1(T=1) = \sqrt{\frac{3}{16\pi}} \sum_i \{-\ell_i \vec{\tau}_i + (g_n - g_p)\, \vec{s}_i \vec{\tau}_i\} \qquad (1)$$

and the Kurath approximation[1] to the linear-energy-weighted sum rule (LEWSR) for such excitations from the ground state is, in ds-shell nuclei,

$$S_{EW}^{Ku} = 4.286\ (2\, n_{5/2} - 3\, n_{3/2})\ \mu_o^2\ \text{MeV} \qquad (2)$$

where $n_{5/2}$ and $n_{3/2}$ are the ground state occupancies of the orbits $d_{5/2}$ and $d_{3/2}$ respectively. We evaluate this for ^{28}Si using three sets of occupancies. From the extreme single-particle model (j-j coupling) one gets 103 μ_o^2 MeV. This goes down to 47 μ_o^2 MeV when occupancies are obtained (by the spectral distribution method[2]) from a Kuo Hamiltonian (with ^{17}O Single particle energies). The value is 49 μ_o^2 MeV if experimental occupancies[3] are used. However, the total LEWSR is experimentally determined[4] (by the known isovector M1 strengths) to be at least 77 μ_o^2 MeV, indicating substantial contributions from the two-body part of the Hamiltonian. A part of the two-body contribution can be included in a unitary sum rule[5], but this increases the value to 59 μ_o^2 MeV only. We therefore calculate the LEWSR with the full (1+2)-body Kuo Hamiltonian using the spectral distribution methods. The value is 127 μ_o^2 MeV (of which the spin-flip part, obtained by neglecting the $\vec{\ell}\,\vec{\tau}$ term in eqn. (1) is 70 μ_o^2 MeV - this means that the spin-flip part accounts for about 74% of the isovector magnetic dipole operator), compared to the experimental value of at least 77 μ_o^2 MeV. The experimental measurements include transitions to a few low lying states only, and hence are expected to be somewhat lower than the theoretical result.

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NEW METHOD OF DETERMINING THE NUCLEAR LEVEL DENSITY

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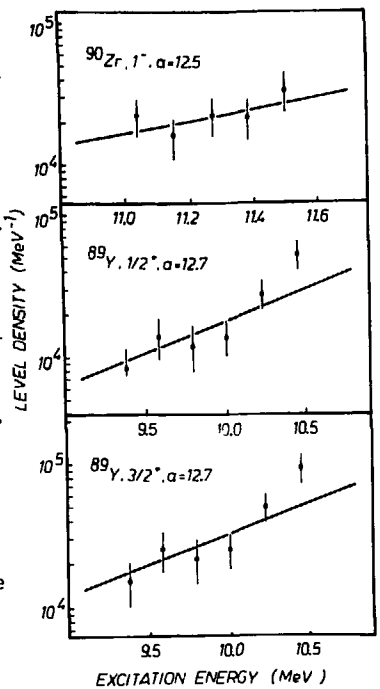
A new method is presented of determining nuclear level density in the excitation energy range with $\Gamma < D$. This method is based on statistical analysis of fluctuation in the excitation functions for (p,γ) reaction measured with the energy resolution $\delta E > D$, at proton energies changed in steps of δE_p, preferably $\delta E_p \approx \delta E$. The fluctuations observed in the cross sections are due to Porter-Thomas fluctuations of the partial widths Γ_p and Γ_γ; the effect of the fluctuation of the spacing D between levels is negligible. Then the variance of the measured reaction cross section is

$$\langle \sigma^2 \rangle - \langle \sigma \rangle^2 = 8 \langle \sigma \rangle^2 / \langle N_{\delta E} \rangle \qquad /1/$$

All values in the equation are averaged over the energy interval $\Delta E \approx 200$ keV. $N_{\delta E}$ is the number of levels in the energy interval $\delta E \ll \Delta E$. The variance and the average cross section can be determined from statistical analysis of the experimental excitation function and we can find $N_{\delta E}$ from eq./1/, and hence the level density.

The above method was applied to obtain level density for ^{89}Y and ^{90}Zr nuclei. The excitation functions for $^{88}Sr(p,\gamma_0)^{89}Y$ and $^{89}Y(p,\gamma_0)^{90}Zr$ reactions were measured in the energy range 2.1-3.7 MeV and 2.7-3.6 MeV, respectively, the proton energy step being $\delta E_p \approx 2.1$ keV.

Our preliminary results for $1/2^+$ and $3/2^+$ levels for ^{89}Y, and 1^- levels for ^{90}Zr are presented in the figure. The solid line presents a fit of the independent-particle Fermi-gas model formula, with pairing [1,2], to the experimental points. The method presented here allows us to determine the level density, especially for A= 70-100 in the excitation energy range 8-12 MeV. In the given ranges other methods of direct measurement of level density cannot be applied.



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$^{20}Ne + n \rightarrow {}^{21}Ne(T=3/2)$ RESONANCES[+]

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The total neutron cross section of ^{20}Ne has been studied in the energy range 1.5-40 MeV using the 190 m neutron time-of-flight facility of the Karlsruhe Isochronous Cyclotron. The high time-of-flight resolution of 5.5 ps/m enables the study of sharp T=3/2 resonances in ^{21}Ne with an effective energy resolution of about 4000:1. The first and fourth ^{21}Ne T=3/2 levels have been observed as weak anomalies allowing the precise determination of the total width Γ, the partial width Γ_{n_o}, and the resonance energy E_R. Upper limits for the partial n_o decay widths are deduced for those T=3/2 levels which do not appear as resonance anomalies.

The resonance parameters of the ^{21}Ne first T=3/2 state are compared with the results of previous measurements. The first precise determination to date of Γ_{n_o} is discussed with respect to the systematics of isospin-nonconserving decay widths of T=3/2 resonances in A=4n+1 nuclei. The information permits a comparison of the resonance parameters E_R, Γ, and $\Gamma_{partial}$ of analogous T=3/2 states in mirror A=4n+1 nuclei and a discussion of the charge dependence of T=1/2 impurities in the T=3/2 levels.

[+]The work has been supported by the Bundesministerium für Forschung und Technologie.

THE EXTENDED SKYRME FORCE AS A REALISTIC PARTICLE-HOLE INTERACTION : APPLICATION TO DOUBLE-CLOSED-SHELL NUCLEI ^{16}O and ^{40}Ca.

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In a further exploration of the abilities of SkE2 [1] in reproducing nuclear excited states, we search for the reliability of SkE2 in reproducing p-h matrixelements. Therefore, we try to describe negative parity states of double-closed-shell nuclei, which are mainly 1p-1h excitations, and positive parity states, which are mainly 2p-2h excitations. In a self-consistent way , we perform H.F. calculations on the considered nucleus, thus obtaining the single-particle wavefunctions, even for unbound levels, for which we extrapolate the nuclear potential to infinity (as for the harmonic potential). With the wavefunctions thus obtained, we evaluate the SkE2 interaction matrixelements, from which we extract the various particle-particle, hole-hole and particle-hole matrixelements. Application has been done on ^{16}O and ^{40}Ca. Similarly,as for the 2p- matrixelements in ^{42}Ca [2], a strong resemblance with realistic interactions turns out. The negative parity levels in ^{16}O and ^{40}Ca are well described, even with the self-consistently obtained HF single-particle energies. The low-lying energy spectrum can be reproduced very well allowing some small adjustments of the single-particle energies.

Another interesting point is the description of the positive parity levels especially the excited 0^+ states in ^{40}Ca. In particular, the structure of the 3.35 MeV first excited 0^+state is of much importance. Experimentally, evidence for a deformed 4p-4h character exists. We try to describe these low-lying 0^+ states within a large space of spherical 2p-2h and 4p-4h configurations (up to dimension of 2000). We stress the importance of various spurious 0^+ states, originating from the excitation of the centre-of-mass motion. Projection has to be carried out of these spurious states.

This calculation would be a good test for the SkE2 matrixelements and at the same time for the model, in describing a deformed 4p-4h state as a superposition of a large number of spherical 2p-2h, 4p-4h configurations.

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GAMOV-TELLER STRENGTH IN ^{208}Bi

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Recently, magnetic dipole strength has been studied in ^{208}Bi via a (p,n) reaction at ε_p = 120 and 160 MeV[1]. Gamov-Teller strength was found 400 keV above the isobaric analogue state accounting for 30 % of Ikeda's sum rule[2].

We show that this state cannot be described in the framework of standard Landau Migdal theory[3] without obtaining a wrong symmetry energy since inclusion of pion and rho exchange places the isobaric analogue state more than 1 MeV below the experimental energy. We feel that the coupling to 2p2h configurations might explain this discrepancy. In the case of the isobaric analogue state, the core-coupling diagrams and the induced interaction are expected to cancel. Therefore only the bare Brueckner HF potential determines the single particle energies. These effects may qualitatively be taken into account by employing an effective mass m^*/m = 0.76 determined with the interpolation formula of ref. 4 in a standard RPA calculation. The isobaric analogue state is found at 18.3 MeV, as compared to 18.1 MeV in experiment, whereas the Gamov-Teller state is found at 19.2 MeV in fair agreement with the experimental energy of 18.5 MeV relative to ^{208}Pb. In addition a strong M1 state with dominant components $(\pi i_{13/2}\, \nu^{-1}_{13/2})_{1^+}$ and $(\pi h_{9/2}\, \nu h^{-1}_{9/2})_{1^+}$ is found at 9 MeV which may account for the missing sum rule strength.

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A STUDY OF ELECTRONUCLEAR SUM RULES IN LIGHT AND MEDIUM WEIGHT NUCLEI

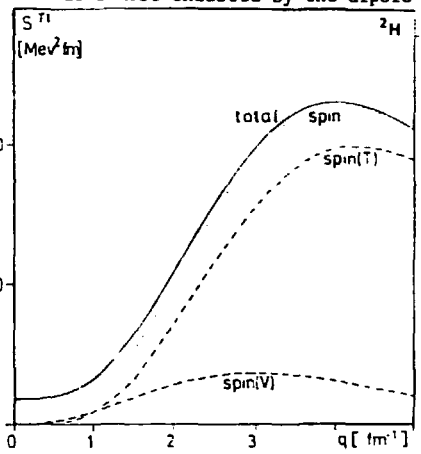
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Sum rules for electroexcitation are a continuation of photonuclear ones into the region of virtual photons[1]. Of particular interest are the sum rules at constant momentum transfer q, because they may be expressed by ground state expectation values and used to study the spatial distribution of exchange forces and tensor correlations in nuclei. We have studied the energy weighted sum rules at constant momentum transfer for light and medium weight nuclei[2] for the Coulomb and transverse part of the nuclear response function, performing also a multipole analysis. For light nuclei we have used exact wave functions obtained with realistic forces, while for heavier nuclei RPA results are obtained using a shell model basis with effective forces.

The Coulomb sum rule is considerably enchanced by exchange effects whose momentum dependence is governed by the range of the potential and the two-body density, and varies little with the mass number but strongly with the potential model. Calculations for light nuclei with realistic forces have borne out the importance of tensor correlations. The multipole decomposition shows that the enhancement due to exchange effects is almost exausted by the dipole contribution.

As shown in figure for ^2H, the total transverse sum rule S^{TI} is dominated by the spin current (dotted line) except at very low q. Such a spin contribution is governed by the almost model independent kinetic term (spin (T)), while exchange effects (spin(V)) contribute appreciably only at low and medium momentum transfer. In the region $2m_\pi < q < 3m_\pi$, where precursor phenomena of pion condensate should show up[3] the magnetic sum rule depends rather strongly on the potential. Again the potential contribution is appreciable only for the lowest multipoles.



+Supported by the Deutsche Forschungsgemeinschaft, contract no. Eh 10/4.

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SPINS OF THE 3176 and 3646 KEV LEVELS IN ^{44}Ti

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Earlier studies of the $^{40}Ca(\alpha,\gamma)^{44}Ti$ reaction have shown that the 3176 and 3646 keV levels of ^{44}Ti either have spins 3^- and 4^- respectively, or 2^+ and 3^+ respectively. Nevertheless, Endt and van der Leun[2] have assigned 2^+ to both levels, mostly on the basis of (^{6}Li,d) work[3], in spite of the difficulty of distinguishing spin 2 from 3 or higher in this reaction.

We have now completed new studies of these levels using improvements in target and detector technology. The two levels are populated preferentially at a resonance in the $^{40}Ca(\alpha,\gamma)^{44}Ti$ reaction at an alpha-particle energy of 4.22 MeV. Angular distributions of the primary γ-rays restrict each primary transition to the form $J \rightarrow J,J\pm1$ at the 0.1% confidence limit. Analysis of the interconnecting 470 keV γ-ray shows that the two levels differ in spin by at most one unit, and have the same parity because of the large mixing ratio. At this stage in the analysis only four possibilities for the primary - 470 keV cascade remain at the 0.1% confidence limit: $2^+ \rightarrow 2 \rightarrow 2$, $2^+ \rightarrow 3 \rightarrow 2$, $3^- \rightarrow 4 \rightarrow 3$ and $4^+ \rightarrow 4 \rightarrow 3$. Analysis of the 3176 $\rightarrow$ 1083 transition eliminates the first of these. The second possibility is eliminated by combining the probability of being acceptable (0.009) with the hypothesis that the $R \rightarrow 2454(4^+)$ transition (also seen) is a $2^+ \rightarrow 4^+$ transition; the latter probability is 0.00145 for zero mixing ratio.

In summary, the only possible assignments from angular distribution and strength arguments are that the 3176 keV level has spin 3 and the 3646 keV level has spin 4. Since the (^{6}Li,d) and (p,t) reactions excite the 3176 keV level reasonably strongly, we conclude that the 3176 keV level has natural parity and therefore is 3^-. It follows that $J^\pi(3646) = 4^-$.

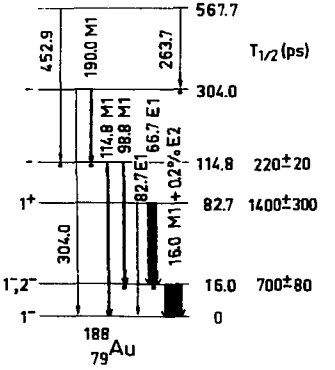
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LEVEL SCHEME OF ^{188}Au FROM THE ^{188}Hg → ^{188}Au DECAY (3.3 MN)

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The ^{188}Hg activity has been produced by Au (p,xn) reaction with 200 MeV protons at the Orsay synchrocyclotron and isotopically separated with the on-line separator ISOCELE II. The EC+β^+ decay scheme has been studied by $\gamma-\gamma$ and γ- X coïncidences with Ge(Li) and Si(Li) detectors, with a 180° magnetic spectrograph for an accurate determination of the low-energy electron spectrum, and with a Gerholm-Lindskog spectrometer for lifetime measurements by $e^-.\gamma$ or $e^-.e^-$ delayed coïncidences. A partial and preliminary level scheme of ^{188}Au is presented. Spin and parity assignments are based upon the strong feeding of the 82,7 keV level, the known (1) spin of the ground-state and the multipolarity of transitions as determined from internal conversion ratios.



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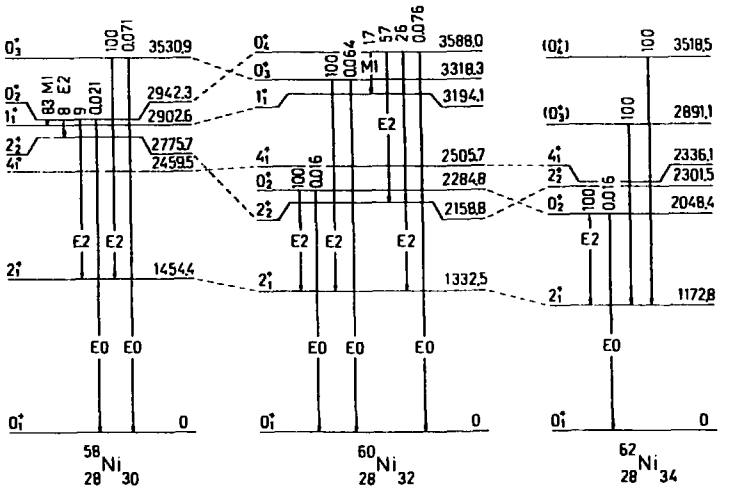
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HIGH-RESOLUTION STUDY OF EO INTERNAL-PAIR TRANSITIONS FROM EXCITED 0^+ STATES IN $^{58,60,62}Ni$

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The recently developed magnetic plus Si(Li) - Si(Li) sum-coincidence technique[1] is employed to measure EO internal-pair-formation (IPF) branching ratios of excited 0^+ states in $^{58,60,62}Ni$. The total branching ratios of excited 0^+ states are shown in the figure. The X(EO/E2) values are obtained for a new 0_4^+ state in ^{60}Ni at 3588.0 keV, for the 0_2^+ and 0_3^+ states at 2942.3 keV and 3530.9 keV in ^{58}Ni, for the corresponding states at 2284.8 keV and 3318.3 keV in ^{60}Ni, and for the 0_2^+ state in ^{62}Ni at 2048.4 keV. The results are combined with the available lifetimes of these states to extract the monopole strengths $\rho^2(0_1^+-0_1^+)$. The results and the nature of the 0^+ states are discussed.

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ELECTROMAGNETIC DECAY OF 0_2^+ STATE IN THE DOUBLY MAGIC NUCLEUS $^{146}_{64}Gd_{82}$

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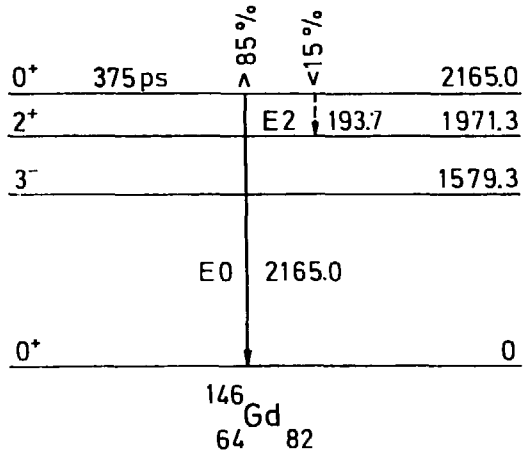
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The existence of the 0_2^+ state in ^{146}Gd at 2165.0 ± 0.4 keV has been established through observation of the $E0(0_2^+ \rightarrow 0_1^+)$ transition following the reaction $^{144}Sm(^3He,n)^{146}Gd$. A tentative assignment by Spoelstra [1] is thus confirmed. The half-life of the 2165 keV state, 375(40) ps was determined by a novel centroid method based on the Jyväskylä magnetic plus Si(Li) beta spectrometer [2]. No γ-rays were found to compete with the E0 transition; assuming a pure monopole decay for the 0_2^+ state, a value of $\rho^2 = 0.0122(13)$ is obtained for the monopole strength parameter. Decay of the 0_2^+ state in ^{146}Gd is shown in the figure.

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THE MEASUREMENT OF NUCLEAR QUANTITIES VIA ACCELERATOR MASS SPECTROMETRY *

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The highly sensitive technique of identifying and counting individual ions in an accelerator beam, recently developed for radioisotope dating,[1] can be conveniently used to determine nuclear quantities of interest when their measurement involves very low radioisotope concentrations. At Argonne, we are performing measurements of this type using a spectrometer system with the following major components: an inverted Cs-beam sputter source, the Argonne 9 MV FN tandem accelerator and an Enge split-pole magnetic spectrograph equipped with an ionization-type focal plane detector. We have measured the half-life of ^{32}Si and the cross section of the $^{26}Mg(p,n)^{26g}Al(7.2 \times 10^5$ yr) reaction near threshold.

The half-life of ^{32}Si: A $^{32}Si/Si$ ratio of $(2.82 \pm 0.50) \times 10^{-8}$ was measured from a sample material prepared through the $^{30}Si(t,p)^{32}Si$ reaction. For the same material a specific β-activity of 8250 ± 500 dpm/mg Si was measured using a liquid scintillation technique. This yields a half-life of $T_{1/2} = 96 \pm 18$ yr considerably shorter than the previously accepted value of approximately 300 years. We expect that this new value will influence results of cosmic-ray flux studies of cosmogenic ^{32}Si in terrestrial, meteoritic and lunar material.

Cross sections of the $^{26}Mg(p,n)^{26g}Al(7.2 \times 10^5$ yr) reaction: $^{26}Al/^{27}Al$ ratios in the range of 10^{-10} to 10^{-11} have been measured from irradiated and chemically processed ^{26}Mg samples yielding the following cross sections as a function of center-of-mass proton energies: 5.0 ± 0.1 MeV, 7.4 ± 2.4 mb; 5.5 ± 0.1, 37.3 ± 6.3; 6.0 ± 0.1, 28.2 ± 4.5; 6.4 ± 0.1, 42.6 ± 6.9; 6.7 ± 0.1, 65.2 ± 9.4. These values are of interest to calculate cross sections for the inverse reaction $^{26}Al(n,p)^{26}Mg$ relevant in nucleosynthesis calculations under explosive stellar conditions. The production of primordial ^{26}Al has recently gained great interest, since an excess of its decay product ^{26}Mg was found in certain inclusions of the Allende meteorite,[2] which suggests that ^{26}Al was present in early condensates of the solar system.

Measurements of nuclear quantities utilizing the sensitive technique of accelerator mass spectrometry can be applied to a number of interesting problems. For example, it can be used to study light as well as heavy-ion radiative capture reactions at thermonuclear energies. It may also be feasible to use this technique for the detection of nuclei produced through solar neutrinos in a suitable target material. At Argonne, we are planning to extend these measurements to heavier isotopes by using the new superconducting linac booster which supplies heavy ion beams of high quality both in energy and time structure suitable for a very selective isotope identification.

*Work supported by the Nuclear Science Div. of the U. S. Dept. of Energy.
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[1]For recent review articles, see for example R. A. Muller, Physics Today 32, 23 (1979); K. H. Purser, A. E. Litherland and H. E. Gove, Nucl. Instrum. Methods 162, 637 (1979).
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PARITY DEPENDENCE OF NUCLEAR LEVEL DENSITIES IN THE NUCLEAR CONTINUUM OF ^{207}Pb*

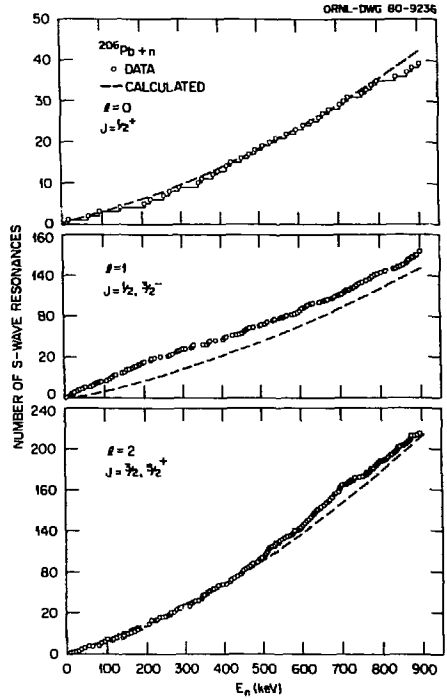
D. J. Horen, J. A. Harvey and N. W. Hill
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The availability of definitive and quantitative data with which to determine the spin and parity dependence of nuclear level densities is rather meager. We have employed high resolution neutron transmission and differential scattering measurements[1]) to investigate level densities in ^{207}Pb in the energy interval E_x = 6.738-7.638 MeV. The data have been analyzed using R-matrix codes, and approximately 400 resonances have been assigned as s-, p-, or d-wave.

The figure shows plots of the sum of the observed resonances versus neutron energy for each of these angular momentum transfers. As can be seen in the figure, the s-wave level density can be fit reasonably well over the energy range shown with a constant temperature model, i.e.,

$$\rho(E_x) = ke^{E_x/T},$$

where $E_x = S_n + E_n$, the neutron separation and incident energy, respectively, and k and T are constants. Use of the parameters found to reproduce the s-wave data and the assumption of a (2J+1) dependence for the level density formula give rise to the dashed curves for the p- and d-wave resonances. As can be seen in the figure, the calculated curve for d-waves fairly well describes the data whereas that for p-waves underesimates the level densities in this energy interval. These results show that for a given spin (i.e., J) the level density is parity dependent for ^{207}Pb (i.e., at least in the energy interval studied here). It will be interesting to see whether these results can be reproduced by detailed shell model calculations.



*Research sponsored by the Division of Nuclear Sciences, U.S. Department of Energy, under contract No. W-7405-eng-26 with the Union Carbide Corporation.

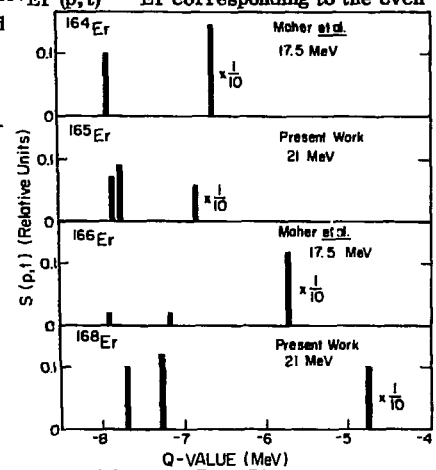
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PAIR EXCITATIONS IN Er ISOTOPES*

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In an earlier study of W(p,t) reactions,[1-3] a set of excited 0^+ states characterized by a constant (p,t) Q-value and having substantial two-neutron transfer strength was identified. It was suggested that these states arise from a group of single particle orbitals below, and decoupled from, those comprising the Fermi surface. This suggestion was confirmed by the observation of a strong L = 0 transition with the same Q-value in the ^{183}W (p,t) reaction which displayed none of the blocking of strength associated with the L = 0 transition corresponding to the even nucleus ground state transition. In an effort to see if the occurrence of such excited 0^+ states is a general phenomenon, we have studied Er(p,t) reactions with emphasis on excited L = 0 transitions. The results of this and earlier work by Maher et al.[4] are shown in the figure. In each case, excited L = 0 strength is found near Q = -7.5 MeV but does not seem to be concentrated in a single state as is the case for W. Compared to ^{170}Er(p,t) ^{168}Er the L = 0 transition in ^{167}Er (p,t) ^{165}Er corresponding to the even nucleus ground state transition is blocked by 43% -- a number which is well reproduced by microscopic calculations. The excited L = 0 strength is reduced by 30% in contrast to the W case where no blocking was observed. It seems therefore that although the occurrence of transitions such as these may be a general phenomenon, the detailed behavior is quite sensitive to the structure of each particular nucleus.



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SPIN-PARITY ASSIGNMENTS TO THE PRECURSOR STATES OF Kr-73 AND Ba-121

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We have statistically[1] analyzed the delayed proton spectra from Kr-73 and Ba-121 and theoretically computed the absolute proton intensities. The variable parameters are the spin-parity of the precursor state, $Q_\beta - B_p$ values (following the available mass relationships), and the expressions for level density due to different authors.[2,3,4,5] The beta strength function was assumed to be a constant.

The results in Kr-73 are summarized in Table 1. A comparison of the theoretical and experimental[6] values of absolute proton intensities allows a $5/2^-$ assignment to the precursor state of Kr-73, which is consistent with the $\nu(1f_{5/2})^{-1}$ shell model configuration. A similar analysis in Ba-121 has enabled us a spin-parity assignment of $11/2^-$ to the precursor state, consistent with the in-beam spectroscopy results.

TABLE 1. Absolute proton intensities due to different level density formulas in Kr-73 for $Q_\beta - B_p$ = 4.441 MeV [Liran and Zeldes] and assumed $I^\pi = 5/2^-$.

Author	Intensities
Newton[2]	4.6×10^{-3}
Gilbert and Cameron[3]	3.4×10^{-3}
Fermi gas model[4] and S. K. Kataria[5] et al	2.9×10^{-3}
Experimental value:	$(6.8 \pm 1.2) \times 10^{-3}$
Experimental $Q_\beta - B_p$:	(4.85 ± 0.3)

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SYMMETRIES OF SINGLE CLOSED-SHELL NUCLEI

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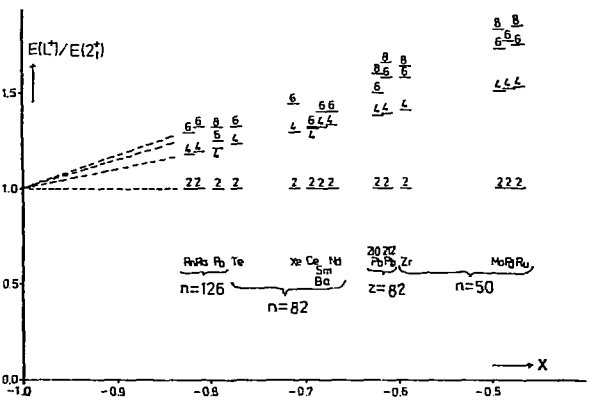
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Let us examine the experimental energies of the ground state band as a function of $X = E(4_1^+)/E(2_1^+) - 2$. When X is exactly zero, most of the experimental energies of the 6_1^+ and 8_1^+ states exhibit the expected pattern of the pure harmonic vibrator i.e. $E(6_1^+)/E(2_1^+) = 3$, $E(8_1^+)/E(2_1^+) = 4$ with $E(4_1^+)/E(2_1^+) = 2$. It is also seen that the limiting situation of the axially symmetric rotor is recovered, when X reaches to the special value of 1.33, i.e. $E(6_1^+)/E(2_1^+) = 7$, $E(8_1^+)/E(2_1^+) = 12$ with $E(4_1^+)/E(2_1^+) = 3.33$.

In the region where X is negative, considerable deviations are recognized from the pure vibrator or the pure rotor model. Since the negative X implies that $E(4_1^+)/E(2_1^+)$ is less than 2, the phonon-phonon interaction with the total angular momentum coupled to L = 4 tends to be attractive.

We pick up nuclei which have X less than -0.5 and their excitation energies are shown in the figure. The experimental energies are taken from the compilation of Sakai and Rester[1]. These nuclei apparently keep none of the SU(5),SU(3) and O(6) symmetries. It is surprising that all nuclei in the figure are those for which either of the proton or the neutron shell is closed.

All levels with the same angular momentum seem to locate roughly on straight lines which cross each other at X = -1.0. It is a point where all members of the ground state band except the ground state are degenerate. This is nothing but the typical feature of the pairing force and indicates a different type of symmetry.



The auther would like to express his sincere gratitude to Professor A.Arima for his valuable suggestions.

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SPIN ASSIGNMENT OF LEVELS WITH L_n=0 AND 1 IN ^{75}Ge

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Nuclear spectroscopic study of ^{75}Ge was performed by means of the ^{74}Ge (94%)(d,p,γ)reaction. Spin assignments were done from the angular correlation measurments by Litherland-Ferguson-Method II. Deuteron beam energy was 6.0MeV. The γrays in coincidence with emitted protons around 180° to the beam axis were measured at 30°,50°,70°,90°,and 140°. The results of the angular correlation annalysis for the levels with l_n=0 and 1,which have been determined by the study of (d,p)reaction[1],are listed in the table.

1)The levels with l_n=0

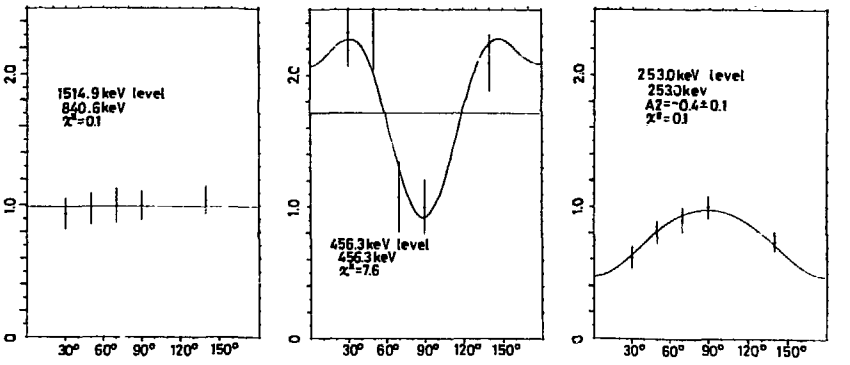
No anisotropy is observed in angular correlation functions of the deexciting γrays except the 456.3keV γray. Although the (d,p)data show that the 453±5keV level with l_n=0 exists,this work proposes a level of $J \geq 3/2$ at this position. On the other hand the 457±5keV has been assigned to be l_n=3 by (p,d)study[2]. This assignment is consistent with the result of the present study.

2)The levels with l_n=1

The γrays of 253.0keV,574.6keV,and 1136.7keV show anisotropy and the γrays of 310.3keV,885.6keV,and 819.5keV do not show anisotropy. Then the spins and parities of the levels 253.0keV,574.6keV,885.6keV,and 1136.7keV are assigned to be $3/2^-$,$3/2^-$,$1/2^-$ $(3/2^-)$,and $(3/2^-)$,respectively. These results are consistent with the study of β-decay[3] except the 1136.7keV level which is not observed in β-decay study. But the spin assignment $3/2^-$ for the 253.0keV level is in contradiction to the $1/2^-$ assignment from the (d,p)data[4].

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level(l_n=0)	γray	χ^2(W(θ)=A$_0$)	level(l_n=1)	γray	A_2(W(θ)=1+A_2P_2)	χ^2
456.3keV	203.6keV	1.6	253.0keV	253.0keV	-0.37±0.1	0.1
	456.3keV	7.6	574.6keV	574.6keV	-0.91±0.04	0.9
673.3keV	481.6keV	0.6	885.6keV	310.3keV	0.08±0.13	0.1
1514.9keV	840.6keV	0.1		885.6keV	0.02±0.12	0.1
	939.4keV	0.7	1136.7keV	819.5keV	-0.14±0.22	1.7
	1514.9keV	2.6		1136.7keV	0.52±0.29	0.1
2660.7keV	1899.3keV	0.2				



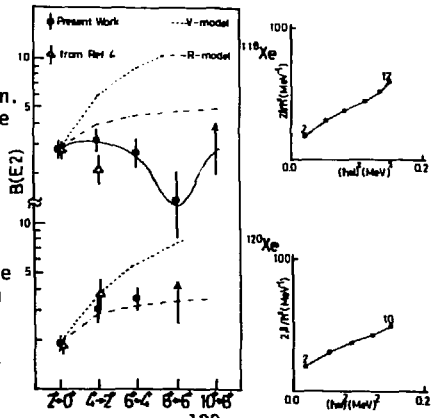
LIFETIMES OF THE YRAST STATES OF ^{118,120}Xe

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Recently, it was reported that the ratios of reduced transition probabilities, $B(E2;I - I-2)/B(E2;2^+ - 0^+)$, for the yrast cascades in the Ce isotopes, ^{130,132,134}Ce (ref.1), and the ^{126}Ba nucleus[2] deviate from the rotational and vibrational model predictions. The reductions are strongest for $10^+ - 8^+$ transitions and $8^+ - 6^+$ transition, respectively. This phenomenon was interpreted for the Ce isotopes as a result of a band mixing[3] which caused backbending in these nuclei. However, in the case of ^{126}Ba the reductions of B(E2) values seem not to correlate with the backbending[2]. It seemed worthwhile to measure the lifetimes of yrast cascades in the neighbouring nuclei ^{118,120}Xe since the lifetimes in these nuclei had been known only up to 4^+ states[4].

The experiments were performed by means of the recoil distance method using the ^{107,109}Ag(^{14}N,3nγ)^{118,120}Xe reactions at 60 MeV bombarding energy. The lifetimes and B(E2) values deduced in the present experiments are summarized in table. The B(E2) values of ^{120}Xe can be well reproduced by the rotational model up to $6^+ - 4^+$ transition. However, the $B(E2;8^+ - 6^+)$ value in ^{118}Xe is reduced substantially. The B(E2) values of $6^+ - 4^+$ and $4^+ - 2^+$ trasitions in ^{118}Xe are less than the rotational and vibrational model predictions as shown in the figure. The reduction pattern of ^{118}Xe is similar to that of ^{126}Ba (ref.2). The retardations of the E2 transitions in ^{118}Xe originate from the other reason than a band mixing since no backbending occurs in this nucleus up to spin 12^+ as shown in the figure.



^{118}Xe

Eγ(keV)	$I_i^\pi - I_f^\pi$	τ(ps)	B(E2) $e^2fm^4 \times 10^3$
337.3	$2^+ - 0^+$	65(3)	2.87(21)
472.8	$4^+ - 2^+$	10.8(18)	3.2(6)
586.4	$6^+ - 4^+$	4.6(12)	2.7(6)
676.4	$8^+ - 6^+$	4.0(15)	1.4(6)
741.5	$10^+ - 8^+$	<1.8	>2.0

^{120}Xe

Eγ(keV)	$I_i^\pi - I_f^\pi$	τ(ps)	B(E2) $e^2fm^4 \times 10^3$
321.8	$2^+ - 0^+$	122(12)	1.94(22)
473.5	$4^+ - 2^+$	11.0(12)	3.1(6)
601.1	$6^+ - 4^+$	3.0(10)	3.5(4)
701.3	$8^+ - 6^+$	<2.0	>2.4

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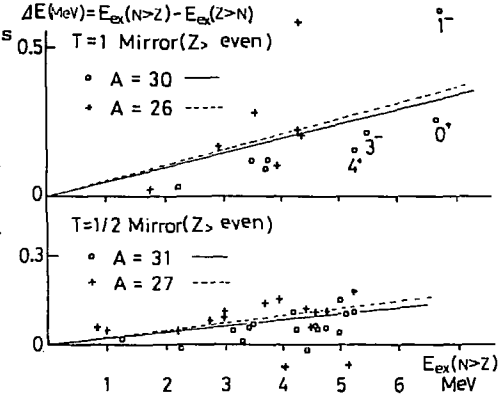
COULOMB DISPLACEMENT ENERGY OF THE EXCITED STATES IN T=1 NUCLEI

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The Coulomb displacement energies of the excited states in mirror nuclei have been studied for particle-hole states, and it was found that the BFZ model predicted fairly well the systematics of T=1/2 mirror nuclei in the 2s-1d and 1f shells. In the case of T=1 mirror nuclei,the Coulomb displacement energy should be large and more sensitive to the nature of the excited states,but we have not sufficient data yet. We tried to construct the level scheme of ^{30}S at relatively high excitation energy from the angular correlation measurement of the secondarily emitted proton in coincidence with the neutron at small angle by the $^{28}Si(\tau,n)$ reaction. The distinction of the protons to the excited states of ^{29}P was performed by the TOF signal and the n-γ separation was possible even for low energy neutrons of 300KeV.

The energies of the excited states were deduced from the proton energy and the agreement with the result of the (p,t) reaction was good up to 7.5MeV. The analysis of the angular correlation of the emitted proton in the $(\tau,n\vec{p})$ reaction using method of Litherland and Ferguson was performed and unique J^{π} assignment were given for 3 levels(5.29MeV 3^-,6.39MeV 0^+ and 6.12MeV 1^-) and probable values for other 10 levels. The correspondence of the mirror states in ^{30}Si and ^{30}S was determined from the assigned J^{π} value and relative yields of the mirror reactions $^{28}Si(\tau,n)$ and $^{28}Si(t,p)$ at small angles with the beam energies of about 10 MeV. ΔE from the present result and the data of ref.2) are shown in the figure. It is evident that the average values of the Coulomb displacement energies decrease with the excitation energy and $\Delta E=(\Delta E_{gc}/E_b)E_{ex}$ are fairly good guide lines, where E_b is the total binding energy of the Z> nucleus and ΔE_{gc} the Coulomb displacement energy of the ground states. In the case of Z> is even, the Coulomb energy is not so sensitive to the parity of the excited state but it should be necessary to take into account the effect of pairing forces between bound or unbound orbits to discuss about the fine structure.



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A CHECK ON INDIVIDUAL TERMS OF THE NUCLEAR MASS FORMULA

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The usual way to check whether a nuclear mass formula is good or not is to compare the calculated mass with experimental value. In this paper some concepts are summarized which check one or two terms in the mass formula separately:

(1) P/P' ratio – pairing energy;
(2) Jänecke ratio – symmetry energy;
(3) A-dependence of giant resonance energy – symmetry energy;
(4) IMME – Coulomb energy (isobaric multiplets);
(5) Differences of Coulomb energies – Coulomb energy;
(6) β-stability line – Coulomb energy and symmetry energy;
(7) Fissibility – Coulomb energy and surface energy.

The following nuclear mass formulae are compared with each other:

(A) Revised Weizsacker formula;
(B) Danos-Gillet formula;
(C) Myers-Swiatecki formula;
(D) Our formula.[1)]

The main results are the following:

(1) $P/P' = 1$ for (A), (B) or (C); $= 4/3$ for (D), which is in agreement with the experiment (see Ref. 1).
(2) From the Janecke ratio, the form $T(T+1)$ for the symmetry term is better than $T(T+4)$ or T^2.
(3) By the symmetry term $T(T+1)/A^{\alpha}$, with $\alpha = 0.9$, the A dependence of giant resonance can be explained extremely well.
(4) IMME, $M(A,T_Z) = a + bT_Z + cT_Z^2 + dT_Z^3$. Only for (D), $d \neq 0$.
(5) $E_C = E_C(Z+1) - E_C(Z)$. For (A) and (B), $E_C A^{1/3}/(Z+\frac{1}{2}) = \text{const.}$; for (C), $E_C A^{1/3}/(Z+\frac{1}{2})(1 - 1.689/A^{2/3}) = \text{const.}$; for (D), $E_C/Z^{2/3} = \text{const.}$, which is in good agreement with the experiment.
(6) For the β-stability line, if we compare the calculated Z^* with the experimental value Z and calculate the root mean square RMS, then for (A), RMS = 0.450; (B) =0.589; (C) =0.438; (D) =0.429.

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OCTUPOLE VIBRATIONS IN THE EVEN-MASS ISOTOPES OF MERCURY

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The elastic and inelastic scattering of ^{4}He ions from ^{198,200,202,204}Hg and ^{204,206,208}Pb has been measured by bombarding thin isotopically-enriched targets with ion beams from the ANU 14UD Pelletron accelerator. Scattered particles were detected near 180° with an annular surface-barrier detector. In addition, for ^{204,206,208}Pb and ^{204}Hg, angular distributions of elastic and inelastic scattering at 27-MeV incident energy were measured with an Enge split-pole spectrograph.

For ^{204,206,208}Pb at 27-MeV incident energy the most strongly populated level after the ground state was the well-known 3^- level near 2.6 MeV in each nucleus[1,2,3]. In the case of ^{204}Pb we find the excitation energy of this level to be 2617 ± 3 keV rather than the adopted[1]) value of 2627.1 ± 0.3 keV. With the four even-mass isotopes of mercury similar behaviour is observed; in each case, a level near 2.6-MeV excitation is more strongly fed than any other except the ground (0^+) and first-excited (2^+) states. The excitation energies in each case are given in the accompanying table. The ratio of the inelastic-scattering cross-section to the level near 2.6 MeV to the elastic-scattering cross-section is of comparable magnitude for all seven nuclei with a smooth increase from ^{198}Hg to ^{208}Pb.

These similarities indicate an essentially common structure for these states and that those observed in the even-mass mercury isotopes have, as in the lead isotopes, $J^\pi=3^-$. This conclusion is supported by the similar shapes observed for the angular distributions for inelastic scattering to these levels in ^{204}Hg and the lead isotopes. The 3^- levels near 2.6 MeV in the lead isotopes are known to have a collective nature and have been identified with octupole vibrations. The prominence in inelastic ^{4}He-scattering of the corresponding levels in the mercury isotopes strongly suggests that they too may be attributed to octupole vibrations.

Excitation energies of 3^- Levels

	^{198}Hg	^{200}Hg	^{202}Hg	^{204}Hg	^{204}Pb	^{206}Pb	^{208}Pb
Ex(keV) (Present work)	2486±3	2609±3	2709±3	2674±5	2617±3	2644±2	2612±3

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BAND STRUCTURES IN ODD-A Xe NUCLEI

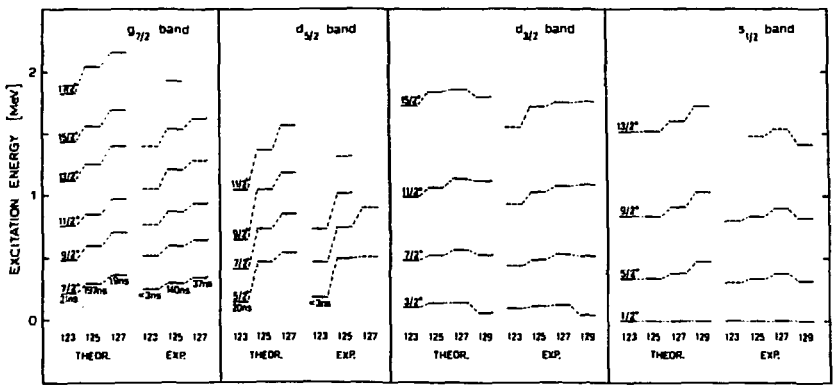
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Level structures in odd-A xenon nuclei with A = 123-129 have been studied with Te(^{3}He,xnγ)Xe reactions using in-beam γ-ray spectroscopic methods. Several different band-like structures have been identified in all these nuclei. The observed bands are based on the $s_{1/2}$, $d_{3/2}$, $d_{5/2}$, $g_{7/2}$ and $h_{11/2}$ neutron quasiparticle states which all lie close to the Fermi level in this mass region.

It has been shown[1,2] that the unique-parity $h_{11/2}$ level systems are well reproduced with the triaxial rotor model. However, our previous analysis of the level scheme of ^{125}Xe shows[2] that the positive-parity levels belong to a more spherical core shape (vibrational-like) than the $h_{11/2}$ band structure. In this work we have interpreted the positive-parity bands in terms of the core-quasiparticle coupling model[3]. The main advantage of this approach is that the particle-hole composition accords with the transitional shape of the underlying core nuclei.

The comparison of the experimental and calculated positive-parity bands in $^{123-129}$Xe is shown in the figure. All band structures and their changes from isotope to isotope are well reproduced.



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MEDIUM-SPIN STATES IN THE N=81 NUCLEUS ^{145}Gd

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The nucleus ^{146}Gd has many properties of a doubly closed nucleus[1], and therefore the level structure of the neighbouring nuclei is very interesting. The yrast levels of ^{145}Gd have been recently studied using the ^{144}Sm(α,3n) reaction[2], but only the $1/2^+$ ground state, the $3/2^+$ level at 27 keV and the $11/2^-$ isomeric state at 749 keV are known below 2.3 MeV. This is surprising because there should be about ten more levels in this energy region according to predictions of different nuclear models.

We used a ^{144}Sm(^{3}He,2n) reaction to study levels of ^{145}Gd. This reaction is suitable to search for missing medium-spin (J=5/2-15/2) states, which are strongly populated in ^{3}He-induced reactions. Methods of in-beam spectroscopy were applied, including measurements of γ-ray and conversion-electron singles spectra, γγ-coincidences and angular distributions. We observed ten new levels between the known $11/2^-$ 749 keV and $13/2^+$ 2302 keV states: the $5/2^+$ 1015 keV, $7/2^-$ 1273 keV, $7/2^+$ 1415 keV, $(3/2,5/2)^-$ 1525 keV, $9/2^-$ 1684 keV, $7/2^-$ 1810 keV, 1919 keV, 2175 keV, 2200 keV and 2259 keV levels. The known yrast levels up to the $21/2^+$ state are also populated in the ^{144}Sm(^{3}He,2n) reaction.

The lowest states in ^{145}Gd are quite pure $s_{1/2}$, $d_{3/2}$, $h_{11/2}$ and $d_{5/2}$ hole states. A weak-coupling model, where a neutron hole is coupled to the 3^- 1579 keV and 2^+ 1971 keV states in ^{146}Gd core, describes very well the other known levels. Almost all states below 2 MeV predicted by this model were observed in the present work. Our results are in agreement with the Z=64 proton-shell closure.

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STUDY OF ^{48}Ca COUPLING OF SURFACE PHONON PARTICLE HOLE

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A nucleus is a quantum system with multiple degrees of freedom. The experiments showed that for ^{48}Ca, a double closed shell nucleus, there exist not less than three 3^- levels with excitation energy below 8 Mev. In this paper, theoretical calculation is carried out based on a semi-microscopic and semi-phenomenalogical model which deals with the coupling between particle-holes and surface oscillating phonon in the light of the elementary modes of excitation. The Hamiltonian of the system can be expressed as $H = H_0 + H_{int} + H_{p-h}$

Where H_0 is the energy of particle holes and surface phonon, H_{int} is the interaction between particle holes and surface phonon, H_{p-h} is the interaction between particle and holes.

In the calculation of matrix elements Rosenfeld force with Gaussian type radial dependence are used, and the harmonic oscillitor wave functions are adopted. For the sake of comparision, we also carry out the calculations using 10 other types of two-body forces, which are suggested by Gillet.

The wave function of the system is written in the form:

$$|\Psi_n\rangle = |(\bar{j}_a j_b)_J (N,R)\, I^\pi M_I\rangle$$

Where j_a is the angular momentum of the holes; j_b is the angular momentum of the particles, R is the angular momentum of the phonon I^π is the total angular momentum for the coupling of J and R, M_I is the I^π projection.

In the calculation, potential parameter V_0 ($\sim$32.5 Mev) and β ($\sim$3) that characterizes the coupling between particle and phonon are adjusted to fit the levels in the lower excitation energy region of ^{48}Ca. The results are given in the table and show that the agreement with the experiments are quite well.

I^π	3^-(I)	2^+(II)	5^-(I)	3^-(II)	2^+(III)	4^+(I)	4^+(II)	3^-(II)	5^-(II)
experiments(Mev)	4.51	4.61	5.15	5.37	6.10	6.35	6.65	7.68	8.38
calculation (MEV)	4.56	4.73	5.65	5.37	6.00	6.00	7.19	7.68	7.70

In addition, the gamma transition probabilities are also calculated. For the transition from 3^-(4.51Mev) state to ground state, the reduced probability 6500 $e^2 f_m^6$ and lifetime 6ps (+4,-2) have been obtained experimentally, while our calculations give results 5649 $e^2 f_m^6$ and 8.46 ps respectively.

This model is valid in the description of collective degree of freedom and single particle degree of freedom for the nuclei.

THE GENERATOR COORDINATE METHOD FOR THE COUPLING BETWEEN VARIOUS MODES OF COLLECTIVE VIBRATIONS

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The study of collective motion in a certain kind of subspace using GCM has been discussed in general by Hsu(1). In this work, with the help of extending subspace we adopt GCM to treat the coupling between pairing and octopole vibrations in ^{208}Pb. The subspace is generated by applying a contineous trasformation group $g(\alpha,\bar{\alpha},\alpha_\mu)$ to the ground state:

$$g(\alpha,\bar{\alpha},\alpha_\mu)=\exp\left\{\alpha P^{+}+\bar{\alpha}P+\sum_{\mu}\alpha_\mu Q^{+}_{\mu}\right\}$$

Where P^{+},P are infinitesimal generating operators related to pairing vibration, and Q^{+}_{μ} are related to octopole vibration. The Hamiltonian is expressed as

$$H=\sum_{jm}\varepsilon_j a^{+}_{jm}a_{jm}-\frac{G}{4}\sum_{jm,j'm'}(-1)^{j-m+j'-m'}a^{+}_{jm}a^{+}_{j-m}a_{j'-m'}a_{j'm'}$$
$$-\frac{\chi_3}{2}\sum_{all\,jm}\sum_{\mu}(-1)^{\lambda-\mu}\langle j_1'm_1'|i^{\lambda}Y_{\lambda\mu}w_\lambda|j_1m_1\rangle\langle j_2'm_2'|i^{\lambda}Y_{\lambda-\mu}w_\lambda|j_2m_2\rangle a^{+}_{j_1'm_1'}a^{+}_{j_2'm_2'}a_{j_2m_2}a_{j_1m_1}$$

We start from Hill-Wheeler equation

$$\int(H_{\alpha\alpha'}-EN_{\alpha\alpha'})f(\alpha')d\alpha'=0$$

The overlap integral $N_{\alpha,\alpha'}$ is calculated using Gaussian overlap approximation. When calculating $H_{\alpha,\alpha'}$, we neglect anharmonic effect and the contributions given by the higher order Feynman diagrams. We only select those diagrams which represent the interactions between the pairing and octopole vibrations. After some manipulations(1), $H_{\alpha\alpha'}$ is transformed into the form expressed in phonon number representation, and the coupling energy is evaluated to be about 170Kev. By means of a canonical transformation(2), we finally have

$$H=E_c+E^{+}G^{+}_{+}G_{+}+E^{-}G^{+}_{-}G_{-}+\sum_{\mu}E^{\lambda}\Lambda^{+}_{\mu}\Lambda_{\mu}+\text{four operator terms}$$

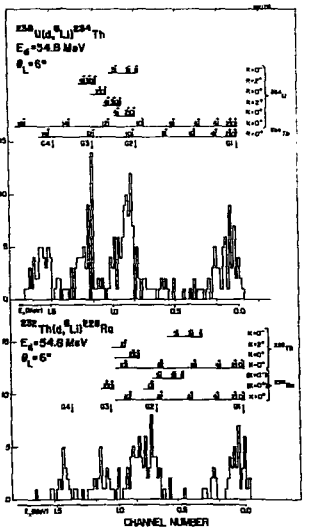
We refer to G and Λ as the physical phonon operators for pairing and octopole vibrations respectively. E_c is the energy for ground state correlation. Because of the above mentioned approximations in $N_{\alpha\alpha'}$ and $H_{\alpha\alpha'}$, we don't calculate the pairing vibration spectra in the region of ^{208}Pb, but only estimate the coupling effect on the neutron pairing vibration state (1,1) arising from extending subspace. The result shows that this effct is about -0.3Mev. It brings the level(1,1) close to the experimental level but seems unable to fully account the discrepancy(2).

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OBSERVATION OF SELECTIVE EXCITATIONS IN ACTINIDE NUCLEI VIA ALPHA-PICKUP†

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The α-cluster pickup reaction (d,^{6}Li) has been studied at E_d=55 MeV on targets of ^{232}Th and ^{238}U. The low-spin members of the ground state rotational bands in ^{228}Ra and ^{234}Th are excited. Absolute reduced α-widths obtained from finite-range distorted-waves analysis are in excellent agreement with the values deduced from α-decay life times and branching ratios. Three additional groups of states in both ^{228}Ra and ^{234}Th are strongly populated with spectroscopic strengths about equal to those of the ground state bands. It appears that the excited groups are rotational bands with band heads at E_x=700±40, 1070±60, 1390±60 keV in ^{226}Ra and at E_x=810±30, 1150±40, 1470±40 keV in ^{234}Th. The observed α-transfer to excited states is much stronger than is observed in (p,t) experiments[1] in this region where usually only one excited 0^+ state is populated with typically 15% of the ground state strength, and from (t,p) experiments[2] where excited 0^+ states are usually not seen. The α-transfer is also 5 - 10 times stronger than is indicated by the reduced hindrance factors deduced from weak α-decay branching ratios.



About 20 - 40 % of the nuclear matter density in the nuclear surface at r≈10.6 fm is associated with valence α-particles. This quantity is calculated from the distribution of α-particle centers (based on the experimental reduced widths) folded with the size of the free α-particle. The nuclear matter density at this radius is about 0.2 % of the central density, and the high α-clustering probability may be indicative for α-particle condensation of low-density nuclear matter

The interacting boson model is used to describe the systematics of excited 0^+ states in the actinide region, but intruder states are clearly present and transfer strengths are not reproduced properly. The observation of strong α-cluster pickup to excited rotational bands seems to suggest coherent contributions from both neutron and proton pair excitations which lead to strong α-like four-body correlations and/or to new types of collective excitation which favor quartet structure.

† Supported in part by the National Science Foundation Grant PHY 78-07754
†† Supported in part by the Stichting voor Fundamenteel Onderzoek (F.O.M.)

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OBSERVATION OF COMPOUND-NUCLEUS X-RAYS IN 10 AND 12 MeV p + ^{112}Sn SCATTERING†

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United-atom x-rays emitted during nuclear scattering identify the short-lived compound nucleus (CN). For proton scattering on ^{112}Sn and ^{106}Cd, such CN x-rays have been observed[1,2] and the mean lives of the excited CN deduced. Present experiments[3] at Darmstadt and Berkeley attempt to use this scheme to look for CN formation in ^{208}Pb+^{64}Ni and Ar+Th collisions.

We have studied CN x-rays in elastic and inelastic proton scattering at 7,10 and 12 MeV on ^{112}Sn. Proton-K x-ray coincidences were measured in close geometry[1], with protons detected at $130^0 \pm 30^0$, and x-rays at 90^0. Prompt CN x-rays were seen for inelastic scattering into 1.0-6.9 and 2.6-8.7 MeV excited states of ^{112}Sn at 10 and 12 MeV, respectively. Fig. 1 shows the x-ray spectra after removal of randoms,of the intense Sn x-rays, and the Compton background (2.3×10^{-5}/keV per inelastic proton, in the 0.87sr, 5mm Si(Li)). A total of 0.4 and 1.2×10^8 inelastic events were recorded. The Sb-K_α signal is 80±50 at 10 MeV, and 250±80 at 12 MeV. No CN x-rays are found at 7 MeV, and for elastic scattering at 7,10 and 12 MeV. The CN x-ray yield is converted into average CN level width Γ_{CN} by comparison to the K-vacancy decay width Γ_K (Sb)= 9.19 eV. Fig. 2 shows how the result depends on the ratio $r=P_K^{in}/P_K$ of K-shell ionization probability before absorption into the CN over probability on a full scattering trajectory. The naive choice r=0.5 yields Γ_{CN}= 16.6±15.7 eV at 13 MeV, and 19.1±11.1 eV at 15 MeV excitation of the CN ^{113}Sb.However, a preliminary semiclassical calculation[4] gives at 10 MeV r=0.75, while one estimates r=0.33 in broken-line approximation by using the monopole amplitude[5] from p+Ni at similar relative velocity v_p/v_K. Corresponding values Γ_{CN}/Γ_K are 3.21 and 0.85.

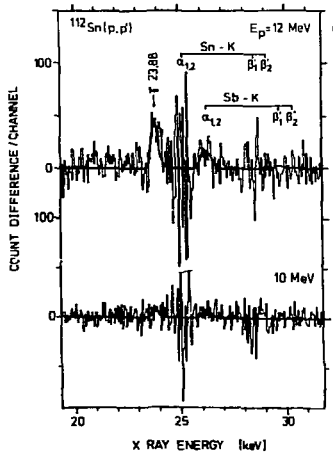


Fig. 1

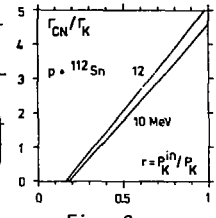


Fig. 2

The variation of Γ_{CN}/Γ_K with excitation in ^{113}Sb, considering present errors, is as expected. For ^{107}In the CN x-ray yield of Chemin et al.[2], with P_K which we have measured independently, results for r=0.5 in Γ_{CN}/Γ_K=1.0 at 13.6 MeV, and =0.2 at 15.6 MeV excitation.

We have started constructing an improved detection system with partial suppression of Compton background in the x-ray spectra.

†Supported by BMFT and DFG, Bonn, Germany

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REGULAR STRUCTURE IN BENZENE AND NUCLEI

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The Benzene molecule is usually thought of as being a "ring" structure but this is probably only a two dimensional projection of an octahedronally shaped three dimensional object. The many body force in Benzene molecules arises mainly because each point of the octahedron has four nearest neighbor points. In Benzene the entity which resides near these points is a Carbon - Hydrogen.

In the heavy nuclei I observe that the especially stable nucleus $_{82}Pb^{208}$ with the addition of six Tritons gives $_{88}Ra^{226}$ and eight gives $_{90}Th^{232}$ and further ten gives U^{238} and that a main sequence of Triton structured nuclei seems to exist from $_{50}Sn^{112}$ through $_{98}Cf^{256}$.

Also in very light nuclei the sequence of nuclei $_{1}H^{3}$, $_{2}He^{6}$, $_{3}Li^{9}$, $_{4}Be^{12}$, $_{5}B^{15}$, and $_{6}C^{18}$ ect. support the idea that in nuclei the Triton acts similiarly to the way a Carbon - Hydrogen acts in the Benzene molecule.

DETERMINATION OF NUCLEAR STABILITIES IN THE SUPER HEAVY REGION AND SOME NEW CONCEPTS

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If a set of accepted norms for a system fail to account for some fundamental characteristics, we have to look to methodologies without a similar break-down. For instance, the stability curves and graphs lose their predictive potentials when projected into the region of Super-heavies. Other accepted principles such as the nuclei having double magic numbers cease to be spherical. Also the outer Atomic system of electrons, which has otherwise not much to do with the stability of nucleides, starts playing a definite role in determining the over-all stability, as due to the high fissility of the nucleus, the outer electrons start collapsing into the nucleus, thereby preventing further Elemental formation, beyond a limit, which has been calculated to be nearabout 145Z.

The cause of these break-downs is the large fissility of the nuclei in this region. Alternative methodologies have to be followed to pin-point stable and semi-stable Elements in this region. We will touch upon these briefly.

Substantial shell corrections have to be applied to bring out the reality. There are many methods available for this, including that of Strutinsky; we may however, quote the mass formula :

$$M(N,Z) = m_n N + m_H Z - a_1\left[1 - K_v\left(\frac{N-Z}{A}\right)^2 A\right] + a_2\left[1 - K_s\left(\frac{N-Z}{A}\right)^2\right] A^{2/3} g_s + c_3 \frac{Z^2}{A} + \delta U(N,Z)$$

where gs, g_c are fissility parameters, and form δU (N,Z) the deformation parameter or the shell correction is calcuable, corresponding to the shape of the nucleus.

In order to calculate the fissility of nuclei in this region, modified H.F. corrections are projected carefully.

Then we may calculate as to how the outer electron system starts collapsing into the nucleus at nearabout 145Z. The relativistic fissility of 145Z on the single particle - shell model calculates to about 4.0. The valence electrons of 145Z are :-

$$5g^{18}\ 6f^{3}\ 7d^{2}\ 8s^{2}\ 8p_{\frac{1}{2}}^{2}$$

The relativistic fissility of the 5g orbit calculates to nearly 3.58 and of the 8p orbit to 3.90. The 8p orbit starts collapsing into the nucleus, which phenomena prevent further Elemental formation beyond nearby 145Z.

The criteria for determining the stability of nuclei in this region changes in terms of the Proton Shells characteristics and nuclear structure by numbers 4, 8, 16 and 32, keeping a stable nucleus like that of Pu_{94}^{239} as the base.

The role played by the predictive power of the Periodic Table cannot be minimised. There has been nothing to show that this role of the Periodic Table undergoes a change in this region. The universality of the Periodic Table remains unchanged.

Consequently, the stability criteria for the nuclei in this region and the role of the outer electron system vis-a-vis the fissility of the nucleus as also the positional placement in the Periodic Table, determine the stable and semi-stable Elements. The determination of such Elements in this research, were presented in some other forum of the American Physical Society.

DECAY OF ^{97}Pd AND INVESTIGATION OF LEVELS IN ODD-A Rh ISOTOPES

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The energy levels of ^{97}Rh have been investigated through the decay of ^{97}Pd. Direct γ-spectra, γ-γ and β-γ coincidences were measured on enriched ^{96}Ru targets irradiated with 20 MeV ^{3}He ions. A Q_{EC} of 4.8±0.3 MeV has been obtained. Of the 55 γ-transitions assigned to the decay of ^{97}Pd, 46 have been included in a level scheme.

The ground state of ^{97}Rh is g $9/2^+$. One would expect to observe a quintet with $5/2^+ \leq J^\pi \leq 13/2^+$ resulting from the coupling of the g $9/2^+$ quasiparticle to the 2^+ phonon state of the core at about the energy of the quadrupole excitation in neighboring doubly even nuclei. However, in the Z=43, 45 and 47 nuclei experimentally one finds the $7/2^+$ and $5/2^+$ members lying well below the energy of the 2^+ states in the adjacent even-even cores. In some cases, the $7/2^+$ state is below the $9/2^+$ state and is the ground state (e.g., ^{103}Rh and ^{103}Ag). The other three members of the quintet are usually found near the energy of the adjacent even-even core (e.g., ^{95}Tc, ^{105}Ag).

From the systemetics of the difference energy $\Delta E(7/2^+-9/2^+)$ and $\Delta E(5/2^+-9/2^+)$ for odd-A isotopes of Tc, Rh and Ag, as well the position of the first 2^+ level in neighboring e-e isotopes, the low lying $7/2^+$ and $5/2^+$ states in ^{97}Rh are assigned at 265.4-and 475.1-keV, respectively. These states are much lower than the 2^+ state in ^{96}Ru (833-keV) and ^{98}Pd (841-keV). The results of the dressed three quasi particle, 3DQP, calculations of Kuriyama et al.[1] are compared with experimental results in odd-A Rh isotopes. The general features are well reproduced especially by including the mixing effects between the 3DQP ($7/2^+$ and $5/2^+$) and one quasi-particle states (g $7/2^+$ and d $5/2^+$, respectively).

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EXPERIMENTAL AND THEORETICAL SURVEY OF THE STRUCTURE OF In NUCLIDES

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Extensive experimental studies by numerous investigators using nearly all of the techniques available to nuclear scientists have been applied to the study of the low-lying level structure of the odd-mass indium nuclides. The discovery of low-lying low-spin positive parity states in In-115 that cannot be found in the simple shell model description of a single g 9/2 or p 1/2 hole coupled to the closed shell at Z=50 has stimulated equally extensive theoretical attempts to describe the observed structural features of the In nuclides.

The principal structural features include the g 9/2 ground state and a p 1/2 isomeric hole states known for odd-mass In nuclides for which $105 \leq A \leq 129$, a quintuplet of positive parity states with $5/2 \leq J \leq 13/2$ with g $9/2^{-1}$ x 2^+ principal configuration, $3/2^-$ and $5/2^-$ states with mixed configurations, and the anomalous low-spin positive parity states. The positive parity quintuplet is known from $107 \leq A \leq 121$ and has an average energy near that of the 2^+ state in the adjacent even-even closed shell Sn nuclide. The $3/2^-$ and $5/2^-$ states lie above the $1/2^-$ isomer and appear to have both p $1/2^{-1}$ x 2^+ and p $3/2^{-1}$ or f $5/2^{-1}$ character.

The anomalous positive parity states consist of six states with $1/2 \leq J \leq 11/2$ that are known for mass 115, 117 and 119. Only the $9/2^+$ state is missing for In-121 and only the $11/2^+$ state is missing in In-113. Only $1/2^+$, $3/2^+$, and $5/2^+$ states have been identified in In-107, In-109 and In-111.

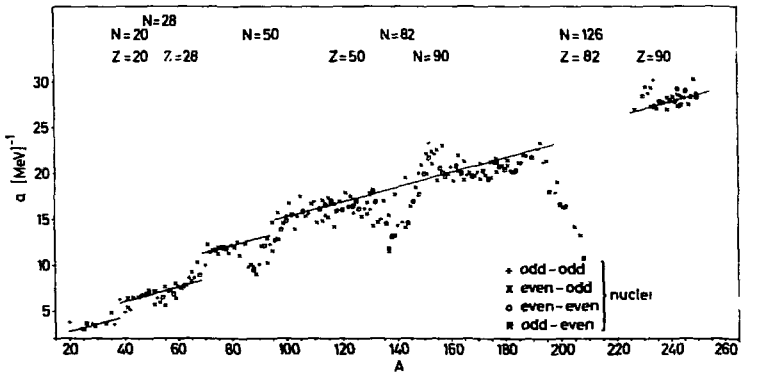
In In-115 these states may be described with nearly equivalent success as one-particle two-hole states in which the 49th proton lies in the d 5/2 or g 7/2 orbital across the Z=50 closed shell or as a highly decoupled $1/2^+[431]$ Nilsson band. The Nilsson description suffers for other nuclides from the need for unrealistically large decoupling parameters required to fit the data, and from the absence of any experimental evidence for the $13/2^+$ or $15/2^+$ states that should lie nearby. The particle hole description has the advantage of being in a basis that permits calculation of the observed mixing with the hole-core states which is particularly well known for the $5/2^+$ states. The relative positions of the $5/2^+$ and $7/2^+$ states are also seen to follow the positions of the $5/2^+$ and $7/2^+$ single particle states in the Z=51 antimony nuclides. Recent studies have also revealed additional states below 2 MeV that decay almost exclusively to the lower anamolous states, and whose positions can be described in the particle-hole calculations. New data from the decay of Sn-111 to levels of In-111 are found to be consistent with the levels in adjacent nuclides.

Pairing Energies and Single Particle State Densities Studied by means of the Level Density Systematics.

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A method to study residual interactions in nuclei is described. It is based on energy levels of excited nuclei observed at energies where the number of states is large enough to determine the level density and where the excitation energy is large compared to the depression of the groundstates caused by the pairing energy, the most important short range force. Both conditions are fulfilled for the neutron resonances observed at neutron separation energy. A level density systematics is performed based on the level density of compound resonances (newly evaluated[1]). It is interpreted by comparison to calculated values of the level density of doorwaystates resulting from the first step of the compound process [2].

The deviation of the level density parameter 'a' from a linear dependence on the atomic number A indicates two types of structures. First there are the usual shell effects with "dips (20, 28, 50, 82, 126) and bumps (90)" at specific N and Z values, reflecting changes of the level density of single particle states at the Fermi surface energy. Second there are distinct steps (three in total) of the level density parameter 'a' at certain A values which we interprete as evidence for a successively more important contribution from higher hierarchies of states in the compound nucleus formations[3].



The lines in between successive structures seen in the figure are defined by using odd-odd compound nuclei, where pairing corrections are minimised. Based on this interpretation of the level density systematics the pairing energy Δ and shell energy S are determined and possibilities of adjusting Nilsson single particle states are discussed. Using (Δ + S) together with the liquid drop model a "semi-empirical binding energy formula" can be obtained. It is hoped with this and the level density systematics to provide insight into the effects of short range forces.

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LEVEL STRUCTURE OF ^{132}Xe

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Recently Arima and Iachello[1]) have considered the even-even xenon isotopes, Z = 54, to lie in the transitional region between the rotational and vibrational limits of their IBA model. Previously Habs et al[2]) used the vibrational model of Gneuss and Greiner to describe them. In order to test the applicability of these different models we have studied the levels of ^{132}Xe populated following the β-decay of ^{132}I. We have measured the directional distribution of γ-rays from the decay of oriented ^{132}I and also γγ directional correlations of the dominant cascades.

The nuclear orientation was made by implanting the parent ^{132}Te activity in an iron foil and cooling this to 15 mK. A high degree of orientation occured and the 0^0 anisotropy values exceeded 100% for several transitions while the good statistics give precise results with an error of typically ∿3%. Directional correlation coefficients were determined for 48 of the observed transitions and the subsequent analysis provided consistent and unique spins assignments. From the dominant multipolarity of linking γ-ray transitions it was possible to determine the relative parities of levels. We have assigned unique spins to most levels up to 3 MeV and determined the multipole mixing ratios of 28 γ-rays.

The measurements failed to identify a 0_2^+ state which might be expected on a sample vibrational picture to lie at ∿1.5 MeV. Neither was there any evidence for a 3^- state at ∿2 MeV which would be expected from systematic trends. It is possible that such states might not be seen in the present work as the β-decay of ^{132}I($J^\pi = 4^+$) would not be expected to populate them directly, while feeding by γ-transitions from levels above ∿2 MeV would not be very favourable either.

We compared the energy levels predicted by the SU(5) and O(6) limits with the experimental results and found both theoretical spectra to be equally good. Neither could calculated B(E2) ratios distinguish between the SU(5) and O(6) representations. The predictions of Habs et al were also equally successful and had the merit of excluding a 0_2^+ state which was present in both of the IBA predictions. Habs et al found that ^{132}Xe is very soft in the β-direction with a very small energy difference between prolate and delate shapes and no β-like band.

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2 D Habs, H Klewe-Nebenius and K Wisshak Z Physik 267 (1979)

OPEP CONSTRAINTS ON THE DEUTERON WAVE FUNCTION†

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It is a long standing problem to deduce the percentage D state of the deuteron from measured properties such as the quadrupole moment. We have recently made some progress in this endeavour by taking into account, in addition, the rms radius. Let (u_1,w_1) and (u_2,w_2) be two solutions of the Schroedinger equation which behave asymptotically as a pure s-wave and a pure D wave. We suppose V(r) known for r>R and to have the OPEP form at large r. A general solution is then $u = N(u_1+\eta u_2)$, $w = N(w_1+\eta w_2)$ where the normalisation constant N is known (from the $^3S_1$ effective range) and we suppose η, the asymptotic D:S ratio, to be a variable parameter. The 'internal' parts of Q and $\langle r^2\rangle$ are

$$X(R,\eta) = \sqrt{50}\,Q - \int_R^\infty (uw - \frac{w^2}{\sqrt{8}})r^2\,dr \qquad Y(R,\eta) = 4\langle r\rangle^2 - \int_R^\infty dr(u^2+w^2) \ . \qquad (a)$$

We define moments

$$U_n = \int_0^R dr\ r^n u^2 \ , \quad V_n = \int_0^R dr\ r^n uw \ , \quad W_n = \int_0^R dr\ r^n w^2$$

which are unknown because we have not defined the potential for 0<r<R. However

$$V_2 - W_2/\sqrt{8} = X \qquad , \qquad U_2 + W_2 = Y \ . \qquad (b)$$

Using Schwarz's inequality, we have

$$U_2W_2 \geq X^2 + XQ_2/\sqrt{2} + W_2^2/8 \ . \qquad (c)$$

Fixing R ≃ 2 fm and varying η, we find that (b) and (c) are compatible only if $Y^2 - 4X^2 - \sqrt{2}XY > 0$, and that this occurs only for $.0260<\eta<0.292$, (R = 2 fm) or $.0264<\eta>.0278$ (R = 1.6 fm). By an extension of Klarsfeld's method[1] we find rigorous lower bounds for the percent D state $p_D > 3.5\%$ (R = 2 fm) or 4.5% (R = 1.6 fm). The numerical values quoted assume a pure OPEP force for r>R. Using a variety of 'realistic' phenomenological forces we find very little deviation from the above values. We conclude that the more restrictive limits for the case R = 1.6 fm may be adopted with confidence. There is agreement with recent measurements of $\eta = 0.263\pm.0013$[2]) and $.0259\pm.0007$[3]), but further improvement of these measurements could pose problems for the nonrelativistic potential model we have employed.

An additional assumption, which enters into the determination of p_D, is that the 'internal' part of Q, X of eq. (a), is positive. For large enough R this is certainly true, but as R decreases it may eventually fail. This provides a limit on the possibility of obtaining larger 'model independent' lower bounds on p_D.

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THE (p-n) IBA MODEL IN THE O(6) LIMIT AND THE SPECTRA OF ^{196,198,202}Hg

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The Interacting Boson Approximation (IBA)[1)] is extended to include equivalent proton and neutron bosons and the spectra of ^{196,198,202}Hg are discussed in terms of the O(6) group appropriate to this mass region.

The totally symmetric irreducible representation [N], as in the standard model, produces the ground state band and the "intruder" Majorana states, by having an excitation energy which increases with boson number N.

Current experimental data in the Hg isotopes suggests the model is a useful extension, but more detailed E2 data is required to test the model predictions - particularly in investigating F-spin[2)] breaking in Pt,Hg.

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EFFECT OF COULOMB INTERACTION ON NUCLEAR BINDING AND RADII

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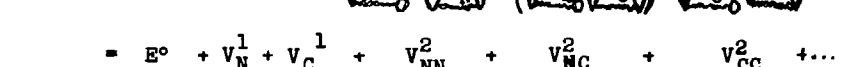
We have performed a carsful calculation of the effect of the Coulomb interaction on the binding energies and radii of ^{4}He, ^{16}O, and ^{40}Ca, using an oscillator(osc) basis.

In particular we performed parallel calculations:

(i) On the one hand using graphical techniques and incorperating the Coulomb(C) interaction on the same footing as the Nuclear(N) interaction. Thus with the Hamiltonian

$$\hat{H} = H + R^2 = H_{osc} + (V_N - U_{osc} + R^2) + V_C = H_{osc} + \hat{V}_N + V_C,$$

$$(\Psi|\hat{H}|\Psi) =$$



$$= E^\circ + V_N^1 + V_C^1 + V_{NN}^2 + V_{NC}^2 + V_{CC}^2 + \cdots$$

In this approach we have performed complete calculations (including all $2\hbar\omega$ states) to fourth order in perturbation theory for ^{4}He and ^{16}O and to second order for ^{40}Ca, by extending the component graph techniques developed in a previous paper[1]. A technical complication which arises here is due to the fact that unlike the nuclear interaction which is an isospin scalar the Coulomb interaction also has T = 1,2 components.

(ii) In a complimentary approach we set up energy matrices including all the T = 0,1 and 2 states that arise in a space incorperating excitations to $2\hbar\omega$ i.e. at most 2p-2h excitations (13 dimensional for ^{4}He, and 107 dimensional for ^{16}O). This involves increasing the dimension by about a factor 2 over the T = 0 space one needs with the nuclear interaction alone. With these energy matrices we perform energy and radius calculations to high order, which we compare to the results of approach (i) while also diagonalizing and inverting these matrices(to get linked-graph expansions in these restricted spaces[2]).

In the table are listed some results for ^{40}Ca, using the saturating Sussex interaction. These results are bigger than those quoted in ref. 3. One notes that the relative importance of V_{CC}^2 which is constant and V_{NC}^2 is sensitive to the size parameter b one uses.

^{40}Ca results for the Energy (in MeV)

b(fm)	1.5	1.6	1.7	1.8	1.9	2.0
$E^\circ + V_N^1 - \frac{3}{2}\hbar\omega$	-141.65	-200.74	-228.15	-238.85	-223.33	-220.60
V_C^1	131.87	123.63	116.36	109.89	104.11	98.90
$V_{NN}^2(2\hbar\omega)$	-78.97	-35.27	-19.13	-14.25	-15.78	-21.90
$V_{NC}^2(2\hbar\omega)$	-14.39	-7.70	-3.24	0.52	3.48	6.26
$V_{CC}^2(2\hbar\omega)$	-1.90	-1.90	-1.90	-1.90	-1.90	-1.90

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NUMBER-CONSERVING TREATMENT OF PAIRING CORRELATIONS IN ODD NUCLEI

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Very recently, an equations-of-motion method has been proposed by the present authors[1]) to treat pairing correlations in doubly-even nuclei without violating the particle-number conservation. In particular, a simple technique has been developed to overcome the problem of the spurious states arising from the use of an overcomplete set of basis vectors. We present here a straightforward extension of the method of ref.[1]) to the case of odd nuclei.

The wave function for a system with an odd number (N+1) of identical particles is written[2]) as a linear combination of states obtained by adding a particle and a hole to the states (we consider states of individual level seniorities of zero) of the neighbouring N and (N+2) doubly-even nucleus, respectively,

$$|N+1,pjm\rangle = \sum_{\beta} c_{pj\beta}(N+1)a^{\dagger}_{jm}|N,\beta\rangle + \sum_{\alpha} g_{pj\alpha}(N+1)a_{j\bar{m}}|N+2,\alpha\rangle \ .$$

Making use of the equations of motion[3]) for $a^{\dagger}_{jm}$ and $a_{j\bar{m}}$, one obtains a set of linear equations which determine the energies and spectroscopic factors for the (N+1) odd nucleus, once the solutions for the N and (N+2)-particle systems are known. The elimination of the spurious states is carried out through a procedure similar to that described in ref.[1]).

In table 1 we report the excitation energies of the seniority-one states for the Ni isotopes obtained from the first-order theory (i.e., by restricting the core states $|N,\beta\rangle$ and $|N+2,\alpha\rangle$ to the ground states). They are considerably better than the BCS ones and in very good agreement with the exact values[4]). This indicates that the present method provides an accurate treatment of states of seniority one.

TABLE 1

Excitation energies in the Ni isotopes(MeV). For the input data, see ref.[1])

j \ N+1	3(^{59}Ni)	5(^{61}Ni)	7(^{63}Ni)	9(^{65}Ni)	11(^{67}Ni)
3/2	0	0.16	0.48	0.71	1.36
5/2	0.36	0	0	0	0.50
1/2	1.07	0.63	0.43	0.03	0
9/2	3.96	3.43	3.12	2.68	2.27

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THE $0^+,2^+$ STATES IN ^{112}Cd*

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Previous studies of the even mass Cd isotopes with A=110 to 114 have shown the existence of a quintuplet of levels at the two phonon quadrupole vibration energy. The two additional states, other than the expected triplet, have been attributed to the 0^+ and 2^+ members of a quasi-rotational band based on a proton four-hole, two particle 0^+ level.[1] This interpretation is supported by the results of (^{3}He,n) studies which show large two proton transfer cross sections to the appropriate 0^+ levels in ^{110,112}Cd, and also by the observation of strong intraband B(E2) values in the quasi-rotational band of ^{110}Cd.[1]

Recent calculations by Heyde et al.[2] for even Cd and Sn nuclei have shown that inclusion of proton 2p-2h configurations coupled to the vibrational excitations, as well as the pure quadrupole vibrational excitations themselves, can generate a second $\Delta J=2$ rotational-like band structure. Indeed within this framework the levels and B(E2) branching ratios up to, and including, the two phonon quintuplet are very well described. It is clearly of interest to know what fraction of the low lying levels in these nuclei can be accounted for within this basis, so that the importance of other degrees of freedom can be estimated. An investigation of levels in ^{112}Cd has therefore been undertaken, using 2 keV average resonance neutron capture at the filter beam facility at Brookhaven National Laboratory. The process of averaging over many resonances greatly reduces the distribution in primary intensities, so that intensities (reduced by an E_γ^5 energy dependence) to levels in ^{112}Cd with $J^\pi = 0^+$ and 2^+ will fall within a narrow band, and hence all 0^+ and 2^+ levels can be identified up to the excitation energy corresponding to the sensitivity limit of the measurements.

E_x	I_γ/E_γ^5	J^π
0.0	1.00(6)	$0^+,2^+$
616.8	1.35(8)	$0^+,2^+,(1^+)$
1223.6(4)	0.62(6)	$0^+,2^+$
1311.8(3)	0.99(8)	$0^+,2^+$
1432.8(3)	0.96(9)	$0^+,2^+$
1467.8(3)	1.07(10)	$0^+,2^+$
1870.9(4)	0.83(10)	$0^+,2^+$
2121.1(7)	0.94(21)	$0^+,2^+$
2155.3(4)	1.05(13)	$0^+,2^+$
2230.7(4)	1.13(14)	$0^+,2^+$
2299.8(4)	1.26(14)	$0^+,2^+,(1^+)$
2506.2(3)	4.58(27)	$0^-,1^-,2^-$
2648.5(7)	1.02(23)	$0^+,2^+$
2668.3(4)	3.68(29)	$0^-,1^-,2^-$
2722.7(6)	1.16(25)	$0^+,2^+$
2765.1(5)	1.47(24)	$0^+,2^+,1^+$
2827.8(4)	3.33(39)	$0^-,1^-,2^-$
2832.1(7)	1.63(35)	$0^+,2^+,(1^+)$
2852.2(5)	1.41(23)	$0^+,2^+,(1^+)$
2929.9(5)	1.49(26)	$0^+,2^+,(1^+)$

Table 1: Excitation energies and spins from primary γ-rays observed in 2 keV capture.

J^π	Quadrupole Vibrational	Quasi Rotational
0^+	0.0, 1.391, 1.850	1.034, 2.709
2^+	0.582, 1.166, 1.870	1.379, 2.292
4^+	1.191, 1.877, 2.969	1.749, 2.660

Table 2: Results of 2p-2h calculation. The division of levels into two types is based on the dominant components in the wave functions of each.

The results are given in Table 1, and can be compared with the proton 2p-2h calculations in Table 2. It can be seen that although the quintuplet of states at the two phonon energy is well reproduced, above the pairing gap far more 0^+ and 2^+ levels appear than can be accounted for within the framework of this description. Further degrees of freedom are clearly necessary to describe the complete set of states, and it is also evident that care must be taken in associating specific higher lying $0^+,2^+$ states in these nuclei with the 2p-2h band structures.

* Research supported by the U.S. DOE under Contract DE-AC02-76CH00016.

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A NON-LINEAR EXTENSION OF THE QUASIPARTICLE RANDOM-PHASE APPROXIMATION

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For a long while, the quasiparticle random-phase approximation (QRPA) has been applied to the collective states in the spherical (or vibrational) nuclei. However this approximation cannot be applied to the so-called transitional nuclei, because the solution of the equation of motion under the RPA is rather unstable and often imaginary in the transitional region; the usual QRPA is not suitable for the collective motion in such a finite system as nucleus in which a gradual phase transition occurs. In the transitional nuclei, the strength of the correlation inducing the collective motion is so large that it seems quite important to take into account the non-linear effect ignored in the usual QRPA. A method to take it into account has been proposed by Sawada.[1] Now let $X_n^\dagger$ be the phonon mode, for which the equation of motion is

$$[\, H,\ X_n^\dagger \,] = \omega_n X_n^\dagger - Z_n \qquad (1)$$

where H is the total Hamiltonian and ω_n the energy eigenvalue of the mode and Z_n denotes the higher order term. In the usual RPA, we linearize Eq.(1) ignoring Z_n. The eigenmodes obtained from this equation are not exact but approximate. Therefore if one can make the effect of Z_n as small as possible by including effectively some part of Z_n into $X_n^\dagger$, one will have better eigenmodes than those in the usual RPA. The philosophy by Sawada[1] is to carry out this by introducing a kind of renormalization of single-particle energy.

To investigate the validity of the approximation of Sawada's method, we first applied it to a two-level model with T=1 pairing force (Fig.1). In comparison to the exact solution[2] the present method gives a big improvement of the usual RPA and then it seems very promising for description of gradual phase transition.

We generalized Sawada's method for the case of the QRPA; we introduced renormalizations not only of the single-quasiparticle energies but also of the coefficients of the Bogoliubov transformation. We applied this method to single-j model with P+QQ force (Fig. 2). Our conclusions are:

(1) The present method has considerable validity in the spherical and the transitional regions.

(2) In our method there appears no sudden phase transition. Therefore it is promising to be applicable to the collective motion in the transitional nuclei.

(3) Both the renormalizations of the single-quasiparticle energy and the coefficients of the Bogoliubov transformation are considerably large. Consequently, the renormalized effective interactions are rather different from the original ones.

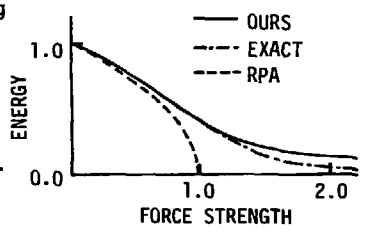


Fig. 1

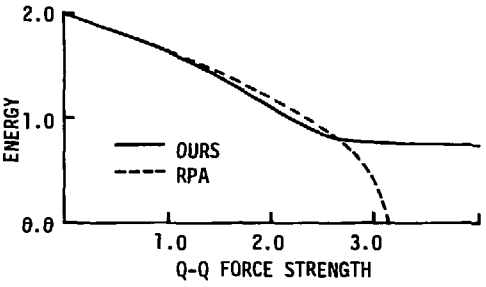


Fig. 2

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COUPLING BETWEEN PAIRING AND QUADRUPOLE DEGREES OF FREEDOM IN ^{93}Nb

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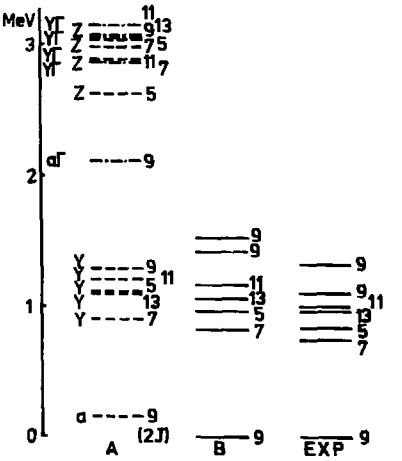
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It has been shown that the couplings between pairing vibrational modes and quadrupole correlation modes plays so important role in some even-even nuclei that the two-phonon 0^+ state and the pairing vibrational state couple with each other and the energy of the first excited 0^+ state drops down.[1] This leads us to the idea that the coupling effect must be large not only in even-even nuclei but also in adjacent odd-mass nuclei. One of the typical example is shown in Ref. [2] for the case of odd-mass Sn isotopes. Unfortunately, we did not have enough experimental data of these isotopes. Recent experimental study[3] on ^{93}Nb has shown that there are two excited $9/2^+$ states around the excitation energy corresponding to the one-phonon 2^+ state of the adjacent even-even nucleus (^{92}Zr). On the analogy of Ref. [2], one of them is supposed to be a member of the quintet made of the product states $|Y^\dagger\rangle = P|X^\dagger \otimes a^\dagger\rangle$, where $X^\dagger$ denotes the 2^+ phonon mode and $a^\dagger$ the one-quasiparticle mode ($1g_{9/2}$). The other is a strongly mixed state consisting of $|a^\dagger\Gamma^\dagger\rangle$ and $|Z^\dagger\rangle$, where $\Gamma^\dagger$ denotes the pairing vibrational mode and $Z^\dagger$ is the five-quasiparticle mode $|Z^\dagger\rangle = P|X^\dagger \otimes X^\dagger \otimes a^\dagger\rangle$. The symbol P projets to the highest seniority state.

Theoretical study on the low-lying positive parity states in this nucleus was done as follows; we first determined the modes, $a^\dagger$, $\Gamma^\dagger$ and $X^\dagger$, and their energy eigenvalues using P+QQ force model. With these modes we got energies of the states, $|a^\dagger\Gamma^\dagger\rangle$, $|Y^\dagger\rangle$, $|Y^\dagger\Gamma^\dagger\rangle$ and $|Z^\dagger\rangle$, which are shown in Column A in the figure. To calculate the coupling effect among these basis states, we diagonalized the total Hamiltonian of P+QQ force model within the space $\{ |a^\dagger\rangle, |a^\dagger\Gamma^\dagger\rangle, |Y^\dagger\rangle, |Y^\dagger\Gamma^\dagger\rangle, |Z^\dagger\rangle \}$. The results are shown in Column B, which are compared with experimental data.

Column A in the figure shows that there are no candidates which can be identified with the closely-lying two $9/2^+$ states in the experiment. In Column B, however, there appears closely-lying two $9/2^+$ states near experiment. The main component of the lower state is $|Y^\dagger\rangle$ (88%) with small mixing of $|a^\dagger\rangle$ and that of the higher one is $|a^\dagger\Gamma^\dagger\rangle$ (74%) with considerable mixing of $|Z^\dagger\rangle$. This shows that it is indispensable to take into account the coupling between $|a^\dagger\Gamma^\dagger\rangle$ and $|Z^\dagger\rangle$ for the explanation of the appearance of the two $9/2^+$ states.

It can be said that our method of calculation is very useful for analyses of low-lying collective states in medium-mass nuclei. Investigations of electromagnetic properties of ^{93}Nb and other nuclei are now in progress.



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COLLECTIVE SUBSPACE AND HAMILTON EQUATION WITH CONSTRAINTS

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The time dependent Hartree-Fock method (TDHF) has been successfully applied to the description of the large amplitude collective motions. TDHF provides much information on how to determine the collective subspace and the classical equation of motion for the collective fields. However, this does not involve the prescription of how to quantize the collective fields. On the other hand, the boson expansion method (BE) in the C-number representation has been shown to be equivalent to the full TDHF, where the necessary and sufficient set of parameters is introduced to specify the time-dependent Slater determinant. Further, BE provides the prescription of the quantization. Hence it is interesting to develop a method to determine the collective subspace in the framework of BE in the C-number representation.

We show that we can express the collective subspace as the set of points in the phase space which satisfy certain constraints. We expand the Hamiltonian obtained with the use of BE in the C-number representation around an arbitrary point $(\mathring{q},\mathring{p})$:

$$H(q,p) = H(\mathring{q},\mathring{p}) + \{\nabla_q H\big|^{\circ}(q-\mathring{q}) + \nabla_p H\big|^{\circ}(p-\mathring{p})\} + \frac{1}{2}\{\nabla_q\nabla_q, H\big|^{\circ}(q-\mathring{q})(q'-\mathring{q}') + 2\nabla_q\nabla_p H\big|^{\circ}(q-\mathring{q})(p-\mathring{p}) + \nabla_p\nabla_p, H\big|^{\circ}(p-\mathring{p})(p'-\mathring{p}')\} + \ldots,$$

where the symbol $\big|^{\circ}$ means that the derivatives are taken at the point $(\mathring{q},\mathring{p})$. When we approximate the local behavior of H by the second order expansion, .i.e., by the superposition of the plane and the quadric corresponding respectively to the first and second terms in the above expansion, the above expression can be given in the standard form

$$H(q,p) = H(\mathring{q},\mathring{p}) + (\nabla_Q H\big|^{\circ}Q + \nabla_p H\big|^{\circ}P) + \frac{1}{2}\sum_i(P_i^2 + \omega_i^2 Q_i^2)$$

where we consider the case of the positive semi-definite matrix $(\nabla_p\nabla_p, H\big|^{\circ})$ for simplicity of notations. Then we specify the collective subspace as the set of points, at which the principal axes $\{(Q_k',P_k');k=1,2,..n\}$ are involved in the plane and the axes $\{(Q_i^{\circ},P_i^{\circ});i=1,2,..m\}$ with some smallest ω_i^2 are not involved:

$$\partial H/\partial Q_k' = \partial H/\partial P_k' = 0\ ,\quad k=1,2,\ldots.n.$$

Here we must notice that the principal directions (Q',P') are defined at each point in the phase space. Under these conditions, the degrees of freedom of the system are reduced from $(m+n)$ to m and these m degrees of freedom are considered as collective.

Then the equation of motion can be expressed as the Hamilton equation with constraints which can be formally equivalent to the canonical equation without constraints when we use the Dirac bracket in place of the Poisson bracket.

Further we can quantize such constrained Hamilton equation with the use of the Dirac bracket and also the path integral method, which are popular in the modern treatment of guage theory.

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APPLICATION OF DOUBLE GEL'FAND POLYNOMIALS TO NORMALIZATION KERNELS OF CLUSTER SYSTEMS

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In nuclear many-body problems products of harmonic oscillator (h.o.) wave functions are often adopted as orthonormal basis wave functions. Their algebraically simple treatment is based on the following coupling scheme in the irreducible representation (IR) of the SU_3 group;[1]

$$[\cdots[[U_{(N_1\ 0)}(\vec{a}_1^{\dagger})U_{(N_2\ 0)}(\vec{a}_2^{\dagger})]_{(\sigma\tau)}U_{(N_3\ 0)}(\vec{a}_3^{\dagger})]_{(\sigma'\tau')}$$

$$\cdots U_{(N_n\ 0)}(\vec{a}_n^{\dagger})]_{(\lambda\mu)\kappa JM}|0\rangle\ ,$$

where $U_{(N\ 0)}(\vec{a}^{\dagger})$ is a boson monomial which generates a h.o. wave function with total quanta N. The boson polynomials in such vector-coupling scheme are an expression of $SU_3 \times SU_n$ double Gel'fand (DG) polynomials where the coupling scheme is specified by a Gel'fand pattern of the SU_n algebra associated with the Moshinsky operators.[1],[2]. By considering the DG polynomials in the complex generator coordinate space, the vector coupling expressions of the DG polynomials, in combination with other remarkable properties, give us many fruitful applications to the multiplicity-free problems of the SU_2 and SU_3 algebras and others.[2]

We applied the theory of the DG polynomials to the eigen-value problems of the normalization kernels of cluster systems. The normalization kernel is SU_3 invariant due to the SU_3 scalar property of the antisymmetrization operator when the cluster wave functions are described by the SU_3 shell model wave functions with a common h.o. constant. Since the eigenvalues are independent from the internal quantum numbers of the SU_3 IR, we can only consider the SU_3 projection instead of the angular momentum projection.[3] By assigning a complex conjugate vector for the description of the ^{12}C cluster with the SU_3 label (0,4), we could write the eigenvalues of $^{12}C+\alpha$ system in an analytical form.[4] More complicated cluster systems as $^{12}C+^{12}C$ and $^{12}C+2\alpha$ were also solved by using the 9-$(\lambda\mu)$ or 6-$(\lambda\mu)$ SU_3 coefficients, the explicit expressions of which can be derived based on the theory of the DG polynomials. The straightforward application of the $SU_3 \times SU_3$ DG polynomials was done in a four-alpha system. We can also investigate $^{20}Ne+^{8}Be$, $^{24}Mg+\alpha$ and other systems, where ^{20}Ne, ^{8}Be and ^{24}Mg are specified by SU_3 (8,0), (4,0) and (8,4), respectively. The SU_3 coherent state of ^{24}Mg is easily constructed by the use of the $SU_3 \times SU_2$ DG polynomials.

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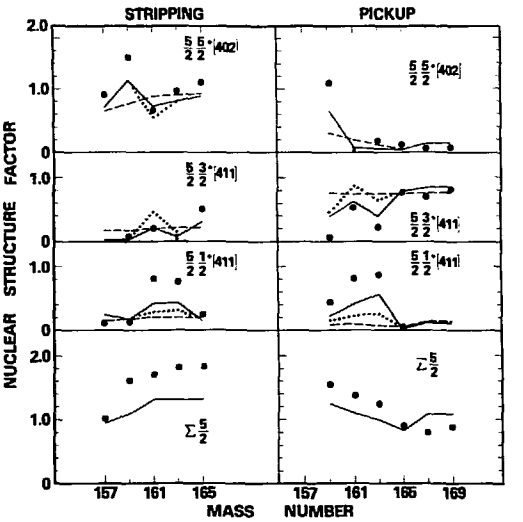
SPECTROSCOPIC EVIDENCE FOR THE UNUSUAL CORIOLIS STRENGTHS IN ^{159,161,163}Ho NUCLEI†

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Stringent tests for quasi-particle-plus-rotor models of nuclei are offered in cases where (Nilsson) orbitals from similar shells give rise to low-lying particle and hole excitations. In the holmium isotopes such a situation exists for rotational members of the $3/2^+[411]$ proton-hole state and the $1/2^+[411]$ and $5/2^+[402]$ particle states. In order to explain the perturbed energy spacings of the $3/2^+[411]$ bands in ^{161,163}Ho Funke et al[1] needed Coriolis mixing strengths which were about twice as large as the attenuated values typical in this region. Recent single-nucleon-transfer studies[2-4] also indicate unusually strong coupling. In particular there are anomalously large transfers of strength for the $3/2^+$ and $5/2^+$ members of the above bands.

This work examines these mixing phenomena in the framework of the Nilsson model with pairing and effective Coriolis strengths included. Calculations were performed both with the Coriolis matrix elements attenuated by a factor of $\alpha = 0.75$ (typical in this region) and with effective strengths chosen to best fit the energy spacings of the bands. Comparisons of the observed and calculated nuclear structure factors of the $I^\pi = 5/2^+$ members are shown in the figure. The circles are experimental values and the dashed lines are theoretical values with no mixing included. The values calculated with $\alpha = 0.75$ (dotted lines) are in poorer agreement with experiment than those obtained with the larger effective strengths chosen to fit the energy spacings (solid lines).



Moderate changes of the deformations and Nilsson parameters can not produce Coriolis strengths as large as the effective values used here, and still larger values would be needed for better agreement with the observed strengths. These discrepancies may indicate a need for a more refined handling of the pairing and/or collective parts of the Hamiltonian.

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† Work supported by NSERC of Canada.

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THE STUDY OF THE CLUSTER FEATURES OF $5 \leqslant A \leqslant 8$ NUCLEI BY USING THE TWO-PARAMETER COORDINATE METHOD

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An unified method is presented to investigate nuclear structure and composite-particle scattering by using the two-parameters (S—the distance between the centres of wells and ν—the oscillator width parameter) generator coordinate method. With this method the nuclear cluster wave function, the energy spectra, the reduced transition probabities B(EL), the rms radii $\sqrt{\langle r^2 \rangle}$ for ^{5}He, $^{5,6,7}Li$, $^{7,8}Be$ nuclei and the momentum distributions of the nuclear clusters for $^{6,7}Li$ nuclei and α-α elastic scattering phase shift are calculated. The results are in good agreement with the experimental values. Especially, the band of second 0^+ cluster structure for ^{8}Be nuclei, the resonance structure of α-α elastic scattering phase shift and the enhancements of FWHM of the momentum distributions with increase of incident energy are explained (see Figs.1-3). Finally we have discussed the Pauli spurious-state components of the obtained cluster structure wave functions.

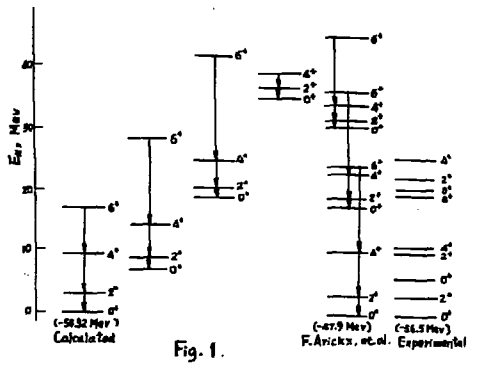


Fig. 1.

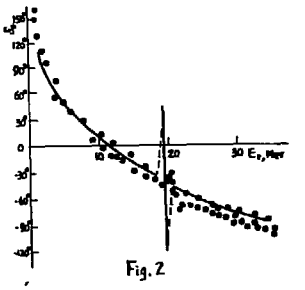


Fig. 2

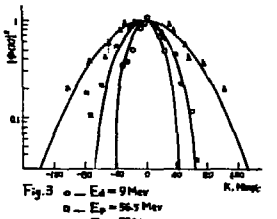


Fig. 3 ● — E_α = 9 Mev
■ — E_p = 56.5 Mev
▲ — E_p = 590 Mev

NUCLEAR VIBRATIONS WITH A ZERO RANGE INTERACTION[†]

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We use the interaction $-G(1 + xP^{\sigma})\delta(\vec{r}_1 - \vec{r}_2)$ to study nuclear vibrations. The parameter G is chosen by a self consistency condition. Results are compared with zero-range Skyrme interactions for the dipole, quadrupole and octupole modes.

We find that if a degenerate single particle spectrum is used, then after diagonalization several states do not move from the unperturbed positions. An expression was derived for the number of such states.

For the four different S,T particle-hole channels, the strength of the interaction is given by the factor $(1-4\delta_{S,o}\delta_{T,o} + 2 \times \delta_{S,o} - 2 \times \delta_{T,o})$.

If G is chosen so that the mean energy of the single particle-single hole splitting for the multipole operator $r^L Y^L$ is equal to $2\hbar\omega$ for the isoscalar quadrupole state, then the mean energy of the 2^+ vibrations comes reasonably close to $\sqrt{2}\hbar\omega$. However a corresponding condition for the octupole state leads to a collapse or near collapse of the lowest 3^- state.

The above situation is somewhat improved if the mean is not taken for operator r^3Y^3 but rather for the lowest 3^- collective state.[††]

The isoscalar E2 effective charge correction obtained with a self consistent strength G varies from about 0.5 for A=5 to one as A approaches infinity.

We note the appearance in some cases and the absence in others of pigmy resonances. With a delta interaction the collective strength is much more fragmented, than with a zero range Skyrme interaction.

[†]Supported by the National Science Foundation.
[††]George Bertsch, private communication.

ON THE RELATIONSHIP BETWEEN THE BOHR COLLECTIVE HAMILTONIAN AND THE INTERACTING BOSON MODEL†

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The interacting boson model (IBM) has been dramatically successful in providing a phenomenological description of spectroscopic data over a wide range of nuclei demonstrating collective features[1]. However, the connection between the fitted parameters of the IBM and the geometrical description has not been clarified, and this has detracted from the intuitive appeal of the IBM. We propose an intrinsic state[2] for a system with N bosons outside a closed shell state $|0\rangle$,

$$|N\ ;\ \beta\ ,\ \gamma\rangle = [s^\dagger + \beta(\cos\gamma\ d_0^\dagger + \frac{1}{\sqrt{2}}\sin\gamma(d_2^\dagger + d_{-2}^\dagger)]^N|0\rangle \qquad (1)$$

where $s^\dagger$ and $d_\mu^\dagger$ are creation operators for spin 0 and 2 bosons and μ is the magnetic projection quantum number. With this intrinsic state we can derive a differential Hamiltonian H in terms of the shape variables β, γ and the Euler angles of rotation from any boson Hamiltonian H[3]. This H will separate into rotational part and an intrinsic part. For β, γ small the Hamiltonian H reduces to the harmonic Bohr Hamiltonian. However, in general, there are important anharmonic terms including coupling between the β and γ degrees of freedom. For a boson Hamiltonian with single boson energy ε and with quadrupole interactions with strength κ where the quadrupole operator is

$$Q_\mu = s^\dagger\tilde{d}_\mu + d^\dagger_\mu s + \sqrt{\frac{7}{2}}\,\bar{\chi}\,(d^\dagger\tilde{d})^2_\mu \quad , \qquad (2)$$

the moments of inertia are

$$\mathcal{I}_k = \frac{2\hbar^2\beta^2\sin^2(\gamma - k\,\frac{2\pi}{3})}{\kappa[1+\bar{\chi}\beta\,\cos(\gamma - k\,\frac{2\pi}{3})]^2} \qquad (3)$$

which depend on the shape variables and the boson Hamiltonian. The equilibrium values of β and γ will depend on the parameters of the boson Hamiltonian. For $\kappa=0$ the equilibrium value of β is $\beta_0=0$ and γ undetermined which corresponds to a spherical vibrator. For the SO_6 limit[1] ($\varepsilon=\bar{\chi}=0$), $\beta_0=1$ and γ is undetermined which corresponds to a γ-unstable rotor. For the SU_3 limit[1] ($\varepsilon=0$, $\bar{\chi}=-1/\sqrt{2}$), $\beta_0=\sqrt{2}$ and $\gamma_0=0$, corresponding to an axial rotor.

†Work supported by the U. S. Department of Energy.
††On leave from the Weizmann Institute of Science, Rehovot, Israel.

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LIFETIMES OF STATES IN ^{196,198}Pt; APPLICATION OF INTERACTING BOSON APPROXIMATION MODEL TO DETAILED SYSTEMATICS OF THE EVEN Pt ISOTOPES+

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The even Pt nuclides are of considerable interest as they are positioned critically within the transitional Os-Hg group. The nuclear structure characteristics of these transitional nuclides have been reported to evidence[1]) the tendency of progression from a near axially symmetric rotor behaviour to a near quadrupole deformed rotor description corresponding, respectively, to the near-SU(3) and near-O(6) subgroup limiting symmetries generated within the Interacting Boson Approximation (IBA)[2,3]) group-theoretic model approach.

As the exposition of the low-lying level characteristics of ^{196,198}Pt are of particular import in this regard, we have made detailed studies of these two isotopes both experimentally and theoretically, and have further extended the theoretical treatment within the IBA framework to examine the detailed structure systematics displayed by the even Pt nuclides in the nuclide sequence $^{190-198}$Pt.

The mean lives of the low-lying excited states in ^{196,198}Pt up to and including the 6^+_1 levels were experimentally measured using the recoil-distance method (RDM). These states were populated via multiple-Coulomb excitation employing 220-MeV ^{58}Ni ion beams provided by the Australian National University 14UD Pelletron tandem accelerator and the measurements were carried out in coincidence with backscattered projectiles. The measured mean lives of the states, the branching ratios of their de-excitation transitions, and the inferred B(E2) values for these transitions between levels were determined.

These specific findings, and the observed structure systematics obtained from the combination of the present results with those of prior workers for the lighter even Pt isotopes ($^{190-198}$Pt), are critically compared with our calculations employing the IBA model as a basis; good concurrence is found. Comparisons are also made with alternative model prescriptions and fits, including that of the Boson Expansion Model[4]).

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MICROSCOPIC THEORY OF THE INTERACTION BOSON MODEL VIA THE SCHWINGER BOSON REPRESENTATION

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The IBM introduced phenomenologically has been highly successful, but its microscopic foundation remained to be explored. The s- and d-boson each carrying a nucleon quantun number n=2 are not just superpositions of particle-particle pairs, but accompanied by particle-hole pairs.

The SU(6) trancated quandrupole-phonon model of Janssen, Jolos and Donau[1] is successful in constructing a collective Hamiltonian, in terms of SU(6) generator, but their basic operators in terms of quasi-particles do not carry a definite nucleon quantum number. It is shown here that basic operators X^+ , X_S with definite nucleon quantum number n=2 and n=-2 can be constructed, which togather with their commutators $[X_S$, $X^+]$ form the generators of a closed algebra.

$$X^+_\nu = \frac{1}{2}\sum_{\alpha\beta} X^\nu_{\alpha\beta}\, a^+_\alpha a^+_\beta$$

$$X^\nu_{\alpha\beta} = x_{j_\alpha j_\beta} \langle j_\alpha m_\alpha j_\beta m_\beta | J M\rangle$$

$$[X_\nu, X^+_S] = \delta_{\nu s} + \sum_{\alpha\beta} (x^s x^\nu)_{\alpha\beta}\, a^+_\alpha a_\beta$$

a^+_α , a_α are the fermion creation and annibilation operators, $x_{j_\alpha j_\beta}$ are superposition coefficients, r≡n,J,M , n being further quantum number needed to specify the paired state.

$x^\nu_{\alpha\beta}$'s satisfy the following orthogonality relations,

$$\sum_{\alpha\beta} X^\nu_{\alpha\beta} X^s_{\alpha\beta} = 2\,\delta_{\nu s}$$

$$\sum_{\nu} X^\nu_{\alpha\beta} X^\nu_{\alpha'\beta'} = \delta_{\alpha\alpha'}\delta_{\beta\beta'} - \delta_{\alpha\beta'}\delta_{\alpha'\beta}$$

Under the assumption that only J=2 collective states are retained, the basic operators $X^+_{2\mu}$, $X_{2\nu}$ and $[X_{2\nu}\ X^+_{2\mu}]$ form the generators of SU(6) algebra and can be mapped into boson representation of the Holstein-Primakoff type i.e. $X^+_{2\mu}$ and $X_{2\nu}$ are mapped respectively into $B^+_{2\mu}\sqrt{\hat{N}-\hat{N}}$, and $\sqrt{\hat{N}-\hat{N}}\ B_{2\nu}$ where $\hat{N}=\sum_\sigma B^+_{2\sigma} B_{2\sigma}$ and N is the maxima number of bosons contained in a given nucleus. The appearence of square root in the H.P. representation which leads to infinite boson expansion can be removed if one enlarges the boson space by introducing an extra monopole boson A, such that the total no. of bosons euqal the no. of quadrupole bosons plus the no. of monopole bosons. The matrix elements in the H.P. boson space and in the enlarged boson space must be equal. This leads naturally to the Schwinger boson-representation, which is a finite boson representation and in which the hermitian property of the operators mapped is preserved.

In this way starting from a nuclear Hamiltonian in the fermion space, a collective Hamiltonian of the IBM type can be constructed under the above assumptions, with all parameters expressed in terms of single particle energies and effective nucleon-nucleon interactions.

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Linear Response RPA Calculations for Open-Shell Nuclei

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We present herein a procedure which enables the application of Linear Response RPA method to open-shell nuclei. An essential feature of this procedure[1]) is the introduction of occupation parameters $\theta_{n\ell j}$ in the early stage of determining the HF single-particle basis and subsequently in calculating the RPA unperturbed Green function of the linear response method.[2]) Unlike other models which are capable to treat open-shell nuclei the present procedure accounts for the entire spectrum of the HF single-particle hamiltonian. The model has been used to calculate the characteristics of collective states in the Ca isotopes, ^{12}C, ^{16}O and ^{18}O. Our main findings for the isotopic dependence of multipole giant resonances (GMR) of Ca isotopes are as follows: (1) Smooth variation with the mass. (2) More structured resonances due to opening the $f_{7/2}$ shell. (3) Energy centroid do not follow the simple $A^{-1/3}$ rules. Comparison of calculated GMR in open-shell $^{12}C(\theta(1s_{\frac{1}{2}}) = 1,\ \theta(1p_{3/2}) = 0.804,\ \theta(1p_{\frac{1}{2}}) = 0.392)$ [3]) with those of a closed shell ^{12}C shows: (1) A shift of transition strength towards higher energies accompanied by broadening of the GMR. (2) Enhanced collectivity reflected in a significant increase of the energy weighted sum rule. (3) A new structure on the tail of the isovector giant resonance in complete agreement with experiment. Similar results were obtained for ^{16}O and ^{18}O. In particular our results account for the so-called pigmy resonances in ^{18}O.

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ON AN APPROXIMATION TO DYSON'S FINITE BOSON EXPANSION FOR THE NUCLEAR MANY-BODY PROBLEM

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It is shown that Dyson's finite boson expansion[1] in second order is not equivalent to the Jancovici-Schiff approximation[2]. The equation with H_L^+ is used as starting point in our boson description. Here H_L^+ is the hermitian conjugate of the transcribed Hamiltonian in Dyson's finite boson approximation. It is then transformed into an equation of the RPA type with a reduced H^{40}-term(We will call it DRPA). The boson wave-functions in boson space are eventually transformed back into the Fermion space by a Jancovici-Schiff substitution. The energies can be improved considerably by taking the expectation value of H with the approximate wave-functions thus obtained.

Some of the exact solutions of a simple soluble model are compared with the RPA and the present approximation. It is shown that the present approximation is better than the RPA.

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THE DYSON BOSON REPRESENTATION AND THE INTERACTING BOSON MODEL

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The nuclear Hamiltonian H is first transformed into the Dyson boson representation H_D by means of the relation: [1]

$$(\xi_\mu \xi_\nu)_D = b_{\nu\mu}$$

$$(\xi^+_\mu \xi_\nu)_D = \sum_{\nu'} b^+_{\mu\nu'} b_{\nu\nu'}$$

$$(\xi^+_\mu \xi^+_\nu)_D = b^+_{\mu\nu} - \sum_{\sigma\tau} b^+_{\mu\sigma} b^+_{\nu\tau} b_{\sigma\tau}$$

where ξ^+_μ, ξ_ν are the fermion creation and annihilation operators. and $b^+_{\mu\nu}$, $b_{\mu\nu}$ the Dyson ideal boson creation and annihilation operators. Let $H_D(0)$ be the part of H_D which is quadratic in $b^+_{\mu\nu}$, $b_{\mu\nu}$. When this is diagonalized, one gets the phonon creation operators $Q^+_{\nu JM}$ defined in terms of the coupled ideal Bosons $b^+_{\alpha\beta}(JM)$.

$$Q^+_{\nu JM} = \sum_{(\alpha\beta)} X_{(\alpha\beta)}(\nu J)\, b^+_{(\alpha\beta)}(JM)$$

$$b^+_{\alpha\beta}(JM) = (1+\delta_{\alpha\beta})^{-1/2} \sum_{m_\alpha, m_\beta} b^+_{\alpha m_\alpha, \beta m_\beta} \langle j_\alpha m_\alpha\, j_\beta m_\beta | JM \rangle$$

$$\left[\hat{b}_{(\alpha\beta)}(J'M'), b^+_{\alpha\beta}(JM)\right] = \delta_{\alpha\beta',\alpha\beta}\, \delta_{JJ'}\, \delta_{MM'}$$

$$[\hat{Q}_{\nu'J'M'}, Q^+_{\nu JM}] = \delta_{\nu\nu'}\, \delta_{JJ'}\, \delta_{MM'}$$

$$[\hat{Q}^+_{\nu'J'M'}, Q^+_{\nu JM}] = 0$$

where $\hat{b}$ and $\hat{Q}$ are the time reverses of b and Q, $(\alpha\beta)$ indicates an ordered pair of indices $\alpha\beta$. $X_{(\alpha\beta)}(\nu J)$ is the transformation coefficient which bring $H_D^{(0)}$ into diagonal form.

$$H_D^{(0)} = \text{const.} + \sum_{\nu JM} Q^+_{\nu JM} Q_{\nu JM} \hbar\omega_{\nu J}$$

where ν includes both collective as well as non-collective states. Using the reverse transformation

$$b^+_{\alpha m_\alpha, \beta m_\beta} = (1+\delta_{\alpha\beta})^{1/2} \sum_{JM} \langle j_\alpha m_\alpha\, j_\beta m_\beta | JM \rangle \left(\sum_\nu X_{\alpha\beta}(\nu J)\, Q^+_{\nu JM} \right)$$

one can express H_D in terms of the phonon operator $Q^+_{\nu JM}$. When only the most collective J=0 & J=2 states are retained, one gets a hamiltonian h_D of the IBM type, in which the parameters are determined from the single particle energies and the effective nucleon-nucleon interactions.

The eigen-functions of h_D in boson space can be trasformed back into wave functions in fermion space. Let $\Phi(s^+, d^+)$ be the engenfunction of h_D with engenvalue E. $\Phi(s^+, d^+)$ can be expressed interms of $b^+_{\mu\nu}$ i.e. $\Phi(s^+, d^+) = \Psi(b^+_{\mu\nu})$. It is shown that $U^+\Psi(b^+_{\mu\nu})|0\rangle = \Psi(b^+_{\mu\nu} \to \xi^+_\mu \xi^+_\nu)|0\rangle$ is also an eigenfunction of H belong to the same eigenvalue E

$$H\, \Psi(\xi^+_\mu \xi^+_\nu)|0\rangle \cong E\, \Psi(\xi^+_\mu \xi^+_\nu)|0\rangle$$

Here U is Usui transformation operator [2]

$$U = \langle 0 | \exp\left(\tfrac{1}{2} \sum_{\mu\nu} b^+_{\mu\nu} \xi_\nu \xi_\mu\right) | 0 \rangle$$

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THE NUCLEAR FIELD THEORY AND BOSON STATES IN NUCLEI +

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The nuclear field theory(NFT) which was first proposed by Mottleson [1] provides a theoretical scheme to describe nuclei with both fermion and boson degrees of freedom. Early works considered only the lowest order NFT diagrams(LNFT) since it is extremely difficult to sum up infinite order NFT diagrams. Of course, it is very difficult to check the importance of the high order diagrams. Besides, within the framework of the LNFT, one cannot obtain the NFT wavefunctions and correctly pick out the non-spurious states. From this point of view, it is rather difficult to present convincing arguements that the NFT is an exact fermion theory especially when there seems to be too many degrees of freedom that could violate the Pauli Principle.

In this work, we develop the NFT from two point of views. They are:

(a) an exact summing method for the NFT diagrams;
(b) a method to obtain the NFT wavefunctions.

This theory is first examined by comparing it with the shell model results of four nucleons moving in a single j shell. It turns out that all the exact (i.e. shell model) results can be reproduced for any interactions and for any j value. Furthermore identical results are obtained for any expectation values or transition matrix elements of any physical quantities by using both the NFT and shell model wavefunctions, thus establishing the equivalence of these two seemingly different wavefunctions. This demonstrates that the NFT is an exact theory for a fermion system. Since the NFT contains the boson degrees of freedom precisely, it is therefore well suited to study the boson behavior of a fermion system. For example, it may be utilized to understand the Interacting Boson Model (IBM) [2] on a microscopic level.

For the single j shell case, we have studied the probabilities of boson states in nuclei via the NFT wavefunctions. The result seems to suggest that the nuclear force prefers to maximize the boson probabilities. For the low lying states, the S and D bosons are shown to be most important. Of course, more realistic calculations by using the NFT are called for if one were to firmly establish these points as well as to make concrete connection between the NFT and the IBM.

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IBFA STUDIES IN THE ODD XENON ISOTOPES*

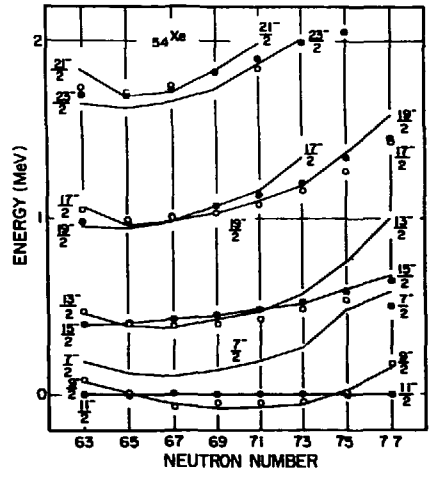
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We have studied the systematic behavior of the negative parity states in the odd Xenon isotopes in terms of the Interacting Boson-Fermion Approximation (IBFA). These states are based on the coupling of an $h_{11/2}$ neutron (hole) to the even Xenon cores, and since they have negative parity, they do not mix with other single particle configurations.

The IBFA hamiltonian can be written as the sum of the boson and fermion hamiltonians and a boson-fermion interaction: $H = H_B + H_F + V_{BF}$. The boson hamiltonian, H_B, has been discussed at great length [1] so we shall not dwell on it here. The fermion hamiltonian is taken to be $H_F = \Sigma_j \epsilon_j \hat{n}_j$, where for this simple case of a single j-shell, we have chosen $\epsilon_j = 0$. It has been suggested by Iachello and Scholten [2] that a good approximation to the boson-fermion interaction is:
$V_{BF} = A[(d^+\tilde{d})^{(0)} \times (a_j^+\tilde{a}_j)^{(0)}]^{(0)} + \Gamma Q_B \cdot q_f + \Lambda : [(a_j^+\tilde{d})^{(j)} \times (d^+\tilde{a}_j)^{(j)}]^{(0)} :$, where $Q_B = (s^+\tilde{d} + d^+s)^{(2)} + \chi (d^+\tilde{d})^{(2)}$, $q_f = (a_j^+\tilde{a}_j)^{(2)}$, and the normal ordering has been introduced in the last term to eliminate the commutator of $\tilde{d}$ and d^+.

In applying the IBFA to the odd Xenon isotopes, we took H_B from a previous calculation of the even Xenon cores [3] and chose χ to be the average of χ_ν and χ_π. This leaves three parameters, A, Γ, and Λ to be fitted to the experimental data. The results of this fit are shown in the figure. The energy of the $11^-/2$ state has been taken as zero. We find good agreement between our results (lines) and the experimental levels (dots), suggesting that the choice for V_{BF} is appropriate.



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INTRINSIC LIE GROUP AND NUCLEAR COLLECTIVE ROTATION ABOUT INTRINSIC AXES

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For any element R(b) of a Lie group G, one can define, as in the case of finite groups,[1] a corresponding operator $\overline{R}(b)$ in the group space Lg by the following equation:

$$\overline{R}(b)R(a) = R(a)R(b), \text{ for any } R(a) \in Lg \tag{1}$$

in other words, the operator $\overline{R}(b)$ applied to a basis R(a) in Lg changes R(a) into another basis R(a)R(b). It is easy to prove that the set of operators $\overline{R}(b)$ forms a group, the intrinsic Lie group $\overline{G}$, which has the properties:

1. The group $\overline{G}$ and G are commuting, $[R(a), \overline{R}(b)] = 0$.
2. The group $\overline{G}$ and G are anti-isomorphic.

Let X_ρ and $\overline{X}_\rho$ be the infinitesimal operators of G and $\overline{G}$. Corresponding to the above two properties, one has

1. $[X_\tau, \overline{X}_\rho] = 0$ (2)
2. $[X_\tau, X_\rho] = C^\sigma_{\tau\rho} X_\sigma, [\overline{X}_\tau, \overline{X}_\rho] = -C^\sigma_{\tau\rho} \overline{X}_\sigma$ (3)

From definition (1), one gets

$$\overline{R}(b) = R(a)R(b)R^{-1}(a) \tag{4}$$

It should be emphasized that neither (1) nor (4) is an identity relation; it merely shows that $\overline{R}(b)$ is equivalent to $R(a)R(b)R^{-1}(a)$ when it acts on the element R(a) of G. While acting on another element R(c), it will be equivalent to $R(c)R(b)R^{-1}(c)$. Corresponding to (4), one has

$$\overline{X}_\rho = R(a)X_\rho R^{-1}(a) = \sum_\sigma D^{(\nu_0)}_{\sigma\rho}(a) X_\sigma \tag{5}$$

where $D^{(\nu_0)}$ is the adjoint representation spanned by $\{X_\rho\}$.

Applying eq. (1) to the special case of the group SO(3), it can be proven that the infinitesimal operators $\overline{J}_x$, $\overline{J}_y$, $\overline{J}_z$ of the intrinsics group $\overline{SO}(3)$, are just the three components of the angular momentum in the intrinsic coordinate system. Therefore, eq. (2)-(4) become the well known formulae in the Bohr-Mottelson model of nuclear collective rotation. The physical meaning of eq. (4) is now very clear; where parameters $a = (\alpha, \beta, \gamma)$ are the orientation angles of the intrinsic frame with respect to the fixed frame and R(a) represents a transformation operator which brings the fixed frame to the intrinsic frame.

We abstract the concept of the intrinsic group from the concrete physical problem and then turn back to use it in describing nuclear collective rotation about the intrinsic axes. Some puzzling features of eq. (2)-(5) now become transparent. So it may be said that we have tailored an appropriate mathematical formalism for the description of nuclear rotation about the intrinsic axes.

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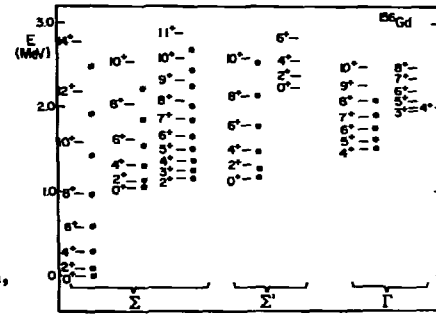
INTRUDER STATES IN THE INTERACTING BOSON MODEL

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In the framework of the interacting boson model, we have performed detailed calculations on the nucleus ^{156}Gd, about which a considerable amount of experimental information is available. Of special interest in this nucleus are a hexadecupole band ($K^{\pi}=4^{+}$) and a low-lying ($E = 1.168$ MeV) 0^{+} states and its associated band up to 10^{+}. This second low-lying $K^{\pi}=0^{+}$ band, not predicted in any collective calculation, is also commonly observed in various other mass regions. A few examples are the Ru and Pd isotopes, the Zr region and the Sn isotopes.

These low-lying 0^{+} states could arise for several reasons. For example, they could come from a subshell closure in the valence shell, as that occuring at proton number 64 in the 50-82 shell. Another possible origin could be the breaking of major shells through two-particle two-hole excitations, as in the case of the Sn isotopes. It should be noticed that in the boson description of the latter type of excitation, the number of bosons is not conserved and this constitutes a fundamental difference between the two possible explanations.



In a phenomenological approach, we have studied these intruder states together with the hexadecupole states, by introducing s' and d' bosons and g bosons [1] and using the Hamiltonian: $H = H_{sd} + \epsilon_{s'}s'^{+}s' + \epsilon_{d'}d'^{+}d' + \kappa Q\cdot Q' + \kappa_{g}[Q \times (g^{+}\tilde{g})^{(2)}]^{(0)} + \Lambda:[(g^{+}\tilde{d})^{(4)} \times (d^{+}\tilde{g})^{(4)}]^{(0)}$: where Q is the quadrupole operator of the s and d bosons and Q' of the s' and d' bosons. The results of the calculations, together with the experimental levels (dots), are shown in the figure. Σ' refers to states arising from s' and d' bosons, whereas Γ refers to the hexadecupole bands. [1]

However, in order to obtain a more detailed description of the nucleus under consideration, it is necessary to include interaction between the Σ, Σ', and Γ bands and to study electromagnetic transition properties. This work is in progress.

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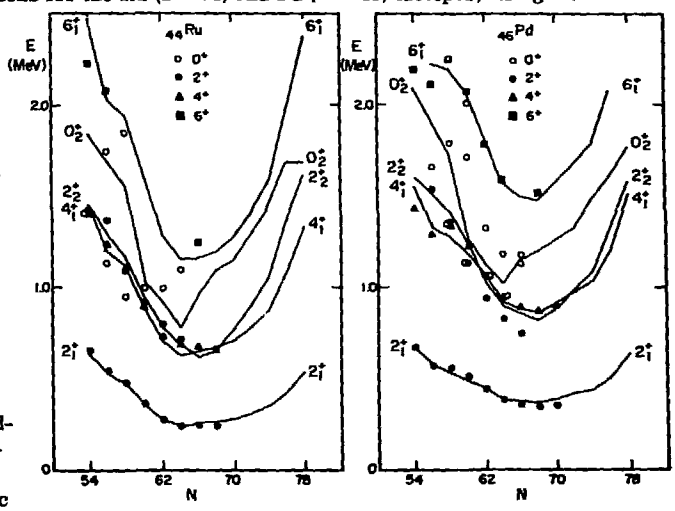
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THE Ru AND Pd ISOTOPES IN THE PROTON-NEUTRON INTERACTING BOSON MODEL

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In the framework of the proton-neutron interacting boson model, we have performed calculations for the Ru (Z = 44) and Pd (Z = 46) isotopes, using the Hamiltonian of ref. [1]. The energy spectra, resulting from these calculations, are shown in the figures. Parameters appearing in the Hamiltonian are allowed to vary in the usual way, i.e., only parameters depending on neutron number vary in a chain of isotopes and only parameters depending on proton number can be different for two isotonic Ru and Pd nuclei. The general behavior of the parameters ϵ, κ, χ_ν, and χ_π is in accordance with previous calculations done in other mass regions. Also calculations have been performed for nuclei not known at present. For those nuclei, we took the parameters of the Xe and Ba isotopes. [2]



In many Ru and Pd isotopes more than one excited 0^+ state is observed experimentally, one of which is not reproduced by theory. These states constitute possible indication for the existence of new excitation modes (s' and/or d' bosons) in addition to the sd boson Hamiltonian. These ideas are currently under investigation.

In conclusion, we remark that also electromagnetic properties have been calculated (E2, M1 transitions, quadrupole moments), which are available on request.

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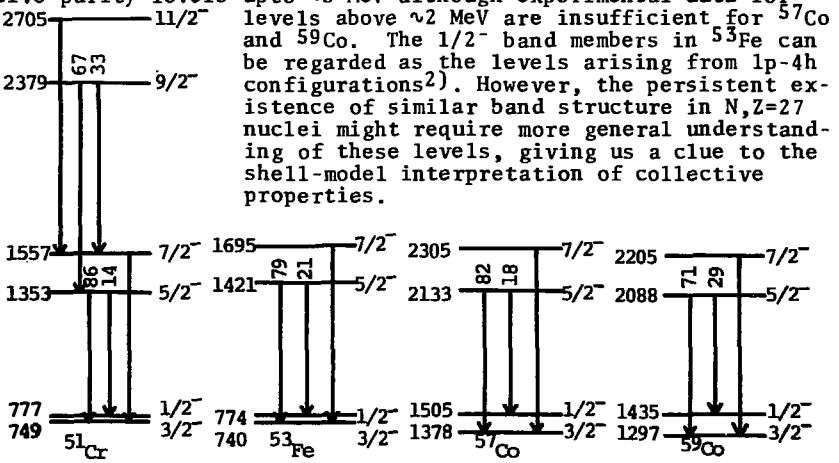
LOW-LYING $K^{\pi}=1/2^-$ BANDS IN N,Z=27 NUCLEI

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Recently low-lying $K^{\pi}=1/2^-$ bands have been identified[1] in N=27 nuclei, ^{51}Cr and ^{53}Fe. The most striking is the fact that all the negative-parity levels below ∿3 MeV can be classified into two groups: those with dominant spherical $(f_{7/2})^n$ configurations and those which belong to the $1/2^-$ bands. These band members are characterized by strong in-band E2 transitions and very weak transitions to the $(f_{7/2})^n$ states. The B(E2) values for the in-band transitions suggest $\beta \approx 0.3$.

The inspection of the previous experimental data for ^{57}Co suggests similar structure also in this Z=27 nucleus. Hence we have further investigated the levels in ^{59}Co via the ^{56}Fe(α,pγ)^{59}Co reaction. A 9.5 MeV α beam from the T.I.T. Van de Graaff was used. Proton-γ angular correlations and γ-γ coincidence measurements using an annular Si detector placed at 180° and two Ge(Li) detectors have revealed the possible existence of the $1/2^-$ band members at 1435($1/2^-$), 1297($3/2^-$), 2088($5/2^-$) and 2205($7/2^-$) keV. In the figure is shown a comparison of the $1/2^-$ band members in various nuclei. Shell-model or intermediate-coupling model calculations for Co isotopes have not been able to reproduce these levels, while they seem to account for the rest of the negative-parity levels upto ∿3 MeV although experimental data for levels above ∿2 MeV are insufficient for ^{57}Co and ^{59}Co. The $1/2^-$ band members in ^{53}Fe can be regarded as the levels arising from 1p-4h configurations[2]. However, the persistent existence of similar band structure in N,Z=27 nuclei might require more general understanding of these levels, giving us a clue to the shell-model interpretation of collective properties.



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SEMI-INFINITE NUCLEAR MATTER AND THE INCOMPRESSIBILITY OF FINITE NUCLEI*

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If the energy per nucleon e of a finite nucleus is expressed in terms of a simplified droplet model, the incompressibility K_A of this nucleus, defined by

$$K_A = \left(R^2 \frac{d^2e}{dR^2}\right)_{R_{eq.}} \qquad (1)$$

can be parametrized according to

$$K_A = K_\infty + K_{sf} A^{-1/3} + \left(K_{ss} + K_{ss} A^{-1/3}\right)\left(\frac{N-Z}{A}\right)^2 + K_{coul} \frac{Z^2}{A^{4/3}} \qquad (2)$$

BGG[1] have made RPA calculations of K_A for different nuclei with the Skyrme-Orsay force S3 and with the Gogny force, and have fitted their results to Eq. (2).

Here we use the model of semi-infinite nuclear matter to calculate the surface compressibility K_{sf} for these same two forces. We have[3]

$$K_{sf} = 4\pi r_0^2 \left\{ 22\,\sigma(n_0) + 9 n_0^2 \ddot{\sigma}(n_0) + \frac{54\sigma(n_0)}{K_\infty} n_0^3 \dddot{e}_\infty(n_0) \right\} \qquad (3)$$

where σ is the surface energy per unit area, n_0 the saturation density of infinite nuclear matter, e_∞ its energy, and dots denote derivatives with respect to the nuclear-matter density. Hartree-Fock calculations of $\sigma(n_0)$ for the two forces have already been published [2], but $\ddot{\sigma}(n_0)$ implicitly involves calculating semi-infinite matter with limiting interior densities different from the saturation value n_0, so that because of the resulting pressure, stability of the surface can be achieved only by applying an external constraint.

We show how this can be done in a unique way (in so doing we obtain a rigorous proof of the "$\ddot{\sigma}(n_0) = 0$ theorem"), and find

$$\ddot{\sigma}(n_0) \simeq -\frac{K_\infty}{18 n_0} t_0 \qquad (4)$$

where t_0 is the surface thickness of semi-infinite nuclear matter at saturation. Using the results of Ref. 2 we then find for K_{sf}:

S3: -458 MeV(-568) Gogny: -296 MeV(-315)

where the figures in parentheses are those of BGG[1]

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NUCLEAR MATTER PROPERTIES INCLUDING MESONIC AND ISOBAR DEGREES OF FREEDOM AND USING CONTINUOUS SINGLE PARTICLE POTENTIALS

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The effects of mesonic and isobar degrees of freedom are studied in nuclear matter. For the study of the mesonic degrees of freedom the meson-exchange model for the NN-interaction is used within the framework of old fashioned perturbation theory. Further the excitation of nucleons to $\Delta(1236)$-isobars is taken into account using π- and ρ-exchange at the $N\Delta$-vertices[1]. Both effects considered in this work are repulsive and add up to a total effect in the order of +10 MeV at nuclear matter density with a strong density dependence[2].

The nuclear matter calculations are performed in the framework of Brückner theory applying a selfconsistent single particle potential. When a standart version for the single particle potential, i.e. there is a gap between particle and hole states, is used the repulsion adds up to +12 Mev; with a continuous single particle potential we get an effect of + 9 MeV. In the latter case a considerable improvement of the saturation density is achieved being much closer to the empirical value then former results.

The repulsive effects gained in these considerations are a welcome feature for the following reason: There is empirical evidence that the tensor part of the nuclear force is rather weak[3,4]. A tensor force causing a D-state probability of the deuteron (P_D) of 4 - 5 % seems to have about the right size. On the other hand we know, that a NN-potential with a P_D around 4.5% saturates nuclear matter at an energy per particle of about -23 MeV (empirical value $\approx$-16 MeV) in a lowest order Brückner calculation. That means, when one wants a consistent description of the nuclear tensor force and of nuclear matter one needs extra repulsive effects in nuclear matter.

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Equation of State in the Density Range 10^{14} - 10^{15} gmcm^{-3}

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We have considered an interacting system of baryons B, including nucleons N and their first excitations the N(1234), and pions. The system is charged neutral and in equilibrium with respect to

$$B \rightarrow \pi + B'$$

Any free pions are assumed to Bose condensate and hence the pion field operators are replaced by their expectation values. The N-N* and N*- N* potentials are the π- and ρ- potentials of Arenhövel[1], the N-N interaction is the Reid potential modified to avoid overcounting of π- and ρ-exchange. The π-B Hamiltonian is chosen to be chirally invariant, apart from a small isoscalar symmetry breaking term, compatible with PCAC. The B-B Hamiltonian is treated by the method of lowest order constrained variational calculations[2] and the B-B correlations, N* width and π propagator are treated self-consistently. The system is unstable against pion condensation at densities $\gtrsim 2 \times 10^{14}$ gmcm^{-3}. A standard Maxwell construction yields a density discontinuity from $\sim 1.5 \times 10^{14}$ gmcm^{-3} to 5×10^{14} gmcm^{-3} across the phase boundary. This phase boundary straddles the normal nuclear matter saturation density and has considerable significance for the masses of stable neutron star configurations. While we expect coulomb and surface considerations to inhibit the condensation in finite nuclei, we are close enough to the transition that relatively low energy probes might be expected to detect the associated quantum fluctuations.

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NUCLEON EMISSION INDUCED BY HIGH ENERGY HADRONS IN PASSING THROUGH NUCLEAR MATTER

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Fast nucleons, of kinetic energies from nearly 20 to nearly 400 MeV, are copiously emitted in high energy hadron-nucleus collisions, as we can conclude from the usually observed in experiments intensive emission of the protons. The events are registered in which the hadron induces such emission in colliding with the atomic nucleus without causing multiparticle creation, even if the hadron is of the kinetic energy high enough to be able to produce many particles as well.

Accurate analysis of the characteristics of emitted protons indicates that high energy hadrons cause monotonously fast nucleon emission in passing through nuclear matter. The emission starts from some vessel-shape spatial region situated along the hadron course; the number of emitted nucleons is proportional to the path length of the hadron inside the target-nucleus, it equals the number of nucleons met in a neighbourhood to this path. It seems to be mostly probable that this emission goes on via some two or more nucleon intermediate systems; it follows from the average energy value of the emitted protons and from the irregularities observed in the proton energy spectra. The nucleon emission intensity distribution is determined by the geometry of the target-nucleus, exactly speaking - by its dimensions and the radial nucleon density distribution in it.

Accepting that the multiparticle creation acts go on via some intermediate states which behave themselves inside nuclear matter as any high energy hadron does and decay into usually observed created particles after having left the target-nucleus, the formula describing well the nucleon multiplicity distribution in high energy hadron-nucleus collisions has been derived; it has been tested by experiment within wide energy interval - from nearly 3 to nearly 400 GeV.

Probably, a mechanism of this nucleon emission is such that the projectile hadron generates mesons in nuclear matter, monotonously along its path, of such energies at which they are absorbed simply by two or more nucleons; the nucleon systems formed in such a way, being of energies small enough to be able to move inside nuclear matter without causing fast nucleon emission in ones turn, decay into observed protons and usually nonvisible neutrons after having left the target-nucleus.

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NARROW Σ AND Ξ HYPERNUCLEAR STATES

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Recently, narrow Σ-hypernuclear states ($\Gamma \lesssim 10$MeV) were observed[1] at CERN in $(K^-,\pi^\pm)$ 0° production at 720 MeV/c on ^{7}Li, ^{9}Be and ^{12}C targets. The existence of narrow Σ states was unexpected, since crude nuclear matter estimates had predicted widths of Γ>20MeV. In the present work, we have studied mechanisms for the quenching of Σ and Ξ widths in finite nuclei. Some preliminary results have already been published[2]. Our conclusion is that the spin-isospin dependence of low-energy ΣN→ΛN conversion leads to substantial quenching of Σ widths for particular states in light hypernuclei. As an example, in the (K,π) reaction on ^{12}C at 0°, the excitation of 0^+ and 1^- hypernuclear states dominates the spectrum. We find that the width of the 1^- Σ-states is not significantly changed relative to the nuclear matter estimate, whereas the width of the coherent substitutional $(\Lambda p_{3/2} \otimes n\, p_{3/2}^{-1})0^+$ state with isospin I=3/2 is quenched by more than a factor of two. Similar results are obtained for $^7_\Sigma$Li, $^9_\Sigma$Be and $^{16}_\Sigma$O: the narrowest Σ states correspond to substitutional states $(1p)_N^+(1p)_\Sigma$ of maximum isospin. In $^{16}_\Sigma$O, if the Σ-nucleus spin-orbit potential is comparable to that of the nucleon, we predict a single narrow 0^+, I=3/2 state, whereas if the Σ spin-orbit potential is weak, we expect two somewhat broader 0^+, I=3/2 excitations spaced by about 6MeV. We are extending our earlier calculations[2] to other light systems such as $^4_\Sigma$He, $^{13}_\Sigma$C, $^{17,18}_\Sigma$O; for $^{13}_\Sigma$C and $^{17}_\Sigma$O, the nuclear core is spin-isospin saturated, and the predicted Σ-widths are larger than for $^{12}_\Sigma$C and $^{16}_\Sigma$O. In light systems, the Σ width can serve as a delicate probe of the spin-isospin structure of hypernuclear wave functions.

We have also estimated the production cross sections and widths for doubly strange Ξ hypernuclei, produced via the (K^-,K^+) or (K^-,K°) reactions[3]. Because of the large momentum transfer, even at 0°, these processes preferentially populate high spin Ξ states. The width of certain Ξ configurations is predicted to be small; Ξ widths are intrinsically smaller than Σ widths, and the spin-isospin dependence of the $\Xi\bar{p}\to\Lambda\Lambda$ conversion process (I=0, $^1S_0$ only near threshold) also leads to quenching effects.

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IRREDUCIBLE REPRESENTATIONS OF THE LIE ALGEBRA SU(n) AND THE GRADED LIE ALGEBRA SU(n/1)

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The infinitesimal generators of the algebra SU(n) can be written as

(a) the infinitesimal generators of the group SU(n-1)

(b) a scalar operator Q of SU(n-1)

(c) a set of irreducible tensor operators $V(\beta)$ of rank [1] of SU(n) and their hermitian adjoint operators $V^{+}(\beta)$

By means of the commutation relations of these operators all the irreducible representations of the group SU(n) can be calculated. The matrices corresponding to these operators in the irreducible representation $\Gamma_n=[m_{1n}\, m_{2n}\cdots m_{nn}]$ are

$$\left\langle \begin{matrix}\Gamma_n\\ \gamma_n'\end{matrix}\middle| Q \middle|\begin{matrix}\Gamma_n\\ \gamma_n\end{matrix}\right\rangle = \left\{\frac{n-1}{n}\sum_p m_{pn}-\sum_q m_{qn-1}\right\},$$

$$\left\langle \begin{matrix}\Gamma_n\\ \gamma_n'\end{matrix}\middle| V(\beta) \middle|\begin{matrix}\Gamma_n\\ \gamma_n\end{matrix}\right\rangle = \left\langle \begin{matrix}\Gamma_n\\ \Gamma_{n-1}'\end{matrix}\middle\| V \middle\|\begin{matrix}\Gamma_n\\ \Gamma_{n-1}\end{matrix}\right\rangle \left\langle \begin{matrix}\Gamma_{n-1} & 1\\ \gamma_{n-1} & \beta\end{matrix}\middle|\begin{matrix}\Gamma_{n-1}'\\ \gamma_{n-1}'\end{matrix}\right\rangle .$$

where γ_n', γ_n are the quantum numbers needed to specify the basis vectors and $\left\langle \begin{matrix}\Gamma_{n-1} & 1\\ \gamma_{n-1} & \beta\end{matrix}\middle|\begin{matrix}\Gamma_{n-1}'\\ \gamma_{n-1}'\end{matrix}\right\rangle$ are the reduction coefficients of the group SU(n-1). The reduced matrices $\left\langle \begin{matrix}\Gamma_n\\ \Gamma_{n-1}'\end{matrix}\middle\| V \middle\|\begin{matrix}\Gamma_n\\ \Gamma_{n-1}\end{matrix}\right\rangle$ can be written as

$$\left\langle \begin{matrix}\Gamma_n\\ \Gamma_{n-1}(i)\end{matrix}\middle\| V \middle\|\begin{matrix}\Gamma_n\\ \Gamma_{n-1}\end{matrix}\right\rangle = \left\{\prod_p (x_{pn}-x_{in-1}-1)\Big/\prod_q (x_{qn-1}-x_{in-1}-1)\right\}^{1/2},$$

where

$$\Gamma_n(\pm i)=[m_{1n}\, m_{2n}\cdots m_{in}\pm 1\cdots m_{nn}], \qquad x_{pn}=m_{pn}+(n-p).$$

The scalar factors of the reduction coefficient of the group SU(n) can be written as

$$\left\langle \begin{matrix}\Gamma_n & 1\\ \Gamma_{n-1} & 0\end{matrix}\middle|\begin{matrix}\Gamma_n(k)\\ \Gamma_{n-1}\end{matrix}\right\rangle = \left\{\prod_q (x_{kn}-x_{qn-1})\Big/\prod_{p\neq k}(x_{kn}-x_{pn})\right\}^{1/2},$$

$$\left\langle \begin{matrix}\Gamma_n & 1\\ \Gamma_{n-1}(-i) & 1\end{matrix}\middle|\begin{matrix}\Gamma_n(k)\\ \Gamma_{n-1}\end{matrix}\right\rangle = \frac{1}{x_{kn}-x_{in-1}}\left\langle \begin{matrix}\Gamma_n\\ \Gamma_{n-1}\end{matrix}\middle\| V \middle\|\begin{matrix}\Gamma_n\\ \Gamma_{n-1}(-i)\end{matrix}\right\rangle \left\langle \begin{matrix}\Gamma_n & 1\\ \Gamma_{n-1} & 0\end{matrix}\middle|\begin{matrix}\Gamma_n(k)\\ \Gamma_{n-1}\end{matrix}\right\rangle .$$

The Lie algebra of SU(n/1) is SU(n)×U(1), thus its even elements are given by the generators of SU(n) and a scalar operator D of SU(n). Its odd elements consist of a set of irreducible tensor operators $U(\beta)$ of rank [1] of SU(n) and another set of operators $T^{+}(\beta)$ whose hermitian adjoint are also irreducible tensor operators of rank [1] .

In the same manner we can obtain all the irreducible representations of SU(n/1).

THEORY OF NUCLEAR SINGLE PARTICLE POTENTIAL

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The single particle (sp) potential $u_{\alpha\beta} = M_{\alpha\beta}(\varepsilon_\beta)$ [or $M_{\alpha\beta}(\varepsilon_\alpha)$] defined in terms of the mass operator $M_{\alpha\beta}(\omega)$ is studied in detail. First it is proven that although u is non-hermitian, the energy eigenvalues ε_γ of the sp Hamiltonian $h = t+u$ are all real and satisfy rigorously the relation

$$\varepsilon_\gamma = \pm\left[E_\gamma(A\pm1) - E_0(A)\right],$$

where $E_0(A)$ denotes the exact ground state energy of a closed shell nucleus (A), $E(A\pm1)$ are exact energy eigenvalues of its neighbouring nuclei of mass number $A\pm1$, and the upper (lower) sign holds if γ refers to a particle (hole) state. Then the principle of maximal cancellation of perturbation diagrams is analysed by a new and non-perturbative method, which shows that u is indeed a good choice and its cancellation property can be expressed analytically in the form

$$\mathcal{M}_{\alpha\beta}(\varepsilon_\beta) = 0,$$

where $\mathcal{M}_{\alpha\beta}(\omega)$ is the reducible mass operator. This relation not only tells what terms can be cancelled but also gives us a deeper insight into the property of the remaining terms. An exact expression for the sp Green function $G_{\alpha\beta}(t=t_1-t_2)$ is derived and its approximation discussed. One sees that u indeed facilitates the calculation of $G_{\alpha\beta}(t)$ and thus the sp propagator renormalization. Further, it is shown that the line-weighting (or amplitude renormalization) factor $A_{\alpha\beta}$ can be written exactly as follows:

$$A_{\alpha\alpha} = 1 - \mathcal{M}'_{\alpha\alpha}(\varepsilon_\alpha), \qquad A_{\alpha\beta} = \mathcal{M}_{\alpha\beta}(\varepsilon_\alpha)G^0_\beta(\varepsilon_\alpha) \qquad (\alpha\neq\beta).$$

By means of the above formula, a method for calculating $A_{\alpha\beta}$ is suggested. One obtains, for instance,

$$A_{\alpha\alpha} = \left[1 - M'_{\alpha\alpha}(\varepsilon_\alpha) - \sum_{\gamma(\neq\alpha)} x_{\alpha\gamma}G^0_\gamma(\varepsilon_\alpha)M'_{\gamma\alpha}(\varepsilon_\alpha)\right]^{-1},$$

which is reduced to the wellknown Brandow formula, if one neglects the non-diagonal elements and introduces for $M_{\alpha\alpha}(\omega)$ the approximation

$$M_{\alpha\alpha}(\omega) \simeq \sum_h G_B(\alpha h,\alpha h;\omega+\varepsilon_h)A_{hh},$$

where G_B is Brueckner's G-matrix.

K-SHELL INTERNAL CONVERSION OF THE 35.5 KeV TRANSITION IN ^{125}Te

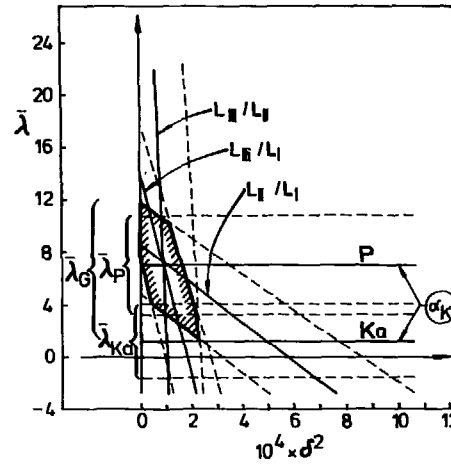
C.Protop and C.Ciortea

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The K-shell internal conversion of the 35.5 KeV transition in ^{125}Te has been measured by XPG method. In order to select the K X-rays following the K-conversion in the transition of interest from the entire K X-ray photopeak we measured the low energy photon spectrum in coincidence with the 601 KeV gamma transition feeding the 35.3 KeV level in ^{125}Sb decay. The KX/γ(35.5 KeV) relative efficiency has been measured by means of ^{109}Cd, ^{137}Cs and ^{241}Am calibrated sources. Taking the fluorescence yield ω=0.873 $\pm$ 0.017 we obtained α_K = 10.9 $\pm$ 0.6.

A quadrupole admixture and penetration process analysis in linear (δ^2, $\bar{\lambda}$) plot of the present α_K value, that from ref.[1] and L-subshell ratios from ref. [2] with Hager and Seltzer's coefficients is given in the figure. Since α_K is here quite independent of quadrupole admixture , we can obtain three values for $\bar{\lambda}$. These values together with the experimental value of the reduced matrix element of the M1 gamma operator provide three values for the moduli of the reduced matrix element of the penetration operator, denoted by P(M1): $P(M1)_P$ = 2.8 $\pm$ 1.7, $P(M1)_{Ka}$ = 0.48 $\pm$ 0.96 and $P(M1)_G$ = $2.9 \pm \frac{1.7}{2.5}$ in eħ/2Mc units.

The calculated value of P(M1) with Kisslinger and Sorensen's wave functions [3] and g_S = -3.826, g_R = Z/A is $P(M1)_{K-S}$ = 1.68 eħ/2Mc. This lies between the two experimental P(M1) values derived from α_K measurements. The L-subshell ratios give a higher P(M1) and a smaller E2 transition probability (deduced from the corresponding δ^2) as compared with K-S estimations, i.e. the states involved in the transition are less collective than predicted.



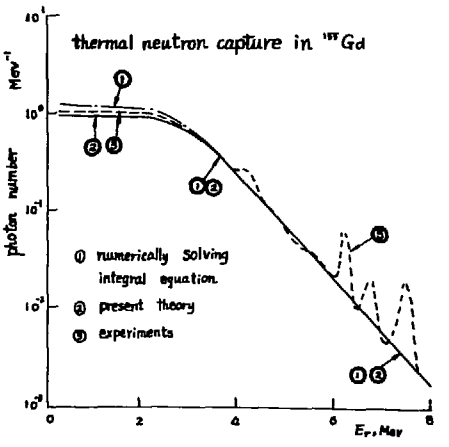
1. E.Karttunen, H.U.Freund, R.W.Fink, Nucl.Phys.A131 (1969) 343
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A VARIATIONAL PERTURBATION METHOD FOR THE CALCULATION OF NEUTRON INDUCED γ-RAY SPECTRA

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A variational perturbation method is proposed to calculate the γ-ray spectra following neutron-induced nuclear reaction on the basis of statistical theory. The essential point of this method is to introduce a functional A which variational value is just the required γ-ray spectra. When an approximate solution is inserted into the functional A, one can get an approximate γ spectra, which has higher precision than the inserted one. This method is applied to obtain an analytical expression for the γ-ray spectra, and to relate the semi-empirical Howenton-Perkins formalism (R parameter method) with the statistical theory. It can also be used to study the sensitivity of the calculated γ-ray spectra to the selection of transitive function. Based on the perturbation theory. for two different zero-order transitive funtions their corresponding γ-ray spectra are obtained. As an example, the calculated results for γ-ray spectra induced by thermal neutron capture in ^{155}Gd are compared with the results obtained by numerically solving an integral equation and with the experiments. It has been shown that the variational perturbation method is useful provided a proper zero-order transitive function is chosen (for example the second function given in this paper).



TRIPLE ANGULAR CORRELATION STUDIES

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Extension of double angular to triple angular correlation when all the three radiations are detected is important in many ways for the radiation from radioactive decay. Besides the additional information of decay scheme, this method of triple correlation studies can be of advantage over double correlation in the following way: elimination or reduction of unwanted double cascade, back scattering contribution in gamma-gamma angular correlation, permutation of spin assignment to excited states, angular correlation of cascades of gamma-radiations if the gamma-rays can not be resolved, phases of amplitude mixing ratios in gamma transition, octupole transition as a mixture in dipole and quadrupole, doublet in gamma-ray energy levels, β-particle parameters etc. Many test cases studied are reported for the radiation from the decay of Ru^{103}, Rh^{106}, Ag^{110m}, Sb^{124}, Ba^{125}, Pr^{144}, Ir^{192}.

The geometries of the mounting of the three detectors can be done in many ways. The useful geometries are (a) when all the three detectors are in one plane (b) two are in one plane and third perpendicular to the plane. Solid angle correction for these geometries are calculated in order to find the triple angular correlation coefficient. There coefficients are calculated considering the spins of the excited, matrix elements and radiation parameters involved in the cascade.

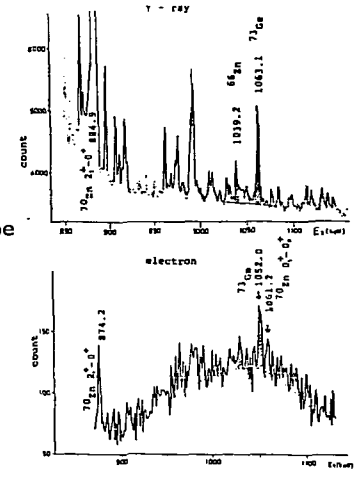
With the development of highly versatile electronic circuits and detectors, many other triple angular correlation studies are suggested for the studies of nuclear structures.

EO TRANSITION PROBABILITY FOR THE 0^+-0^+TRANSITION IN ^{70}Zn

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The EO matrix elements are sensitive to the fine details of the nuclear wave functions since it is related to the change in the mean square radius between initial and final states. The EO transition from the lst 0_1^+(1070.7 Kev) state to the 0_2^+.(gnd.) state of ^{70}Zn was studied by Reisberg et.al.by ^{70}Zn(P,P') with 67% enriched target in which the peak of the EO electrons was not observed due to the β^- background activity.[1] An upper limit $|\rho(EO)|$ = 0.05 was reported. In this work we have investigated the EO transition by means of ^{70}Zn(α,α') reaction with 8.5 Mev α beam to suppresse the background activity. A combination of a solenoide and a cooled Si(Li) detector was used as an electron spectrometer. The spectrum was taken by the Si(Li) while the solenoide was used as a window. The efficiency and the energy scale were determined by ^{152}Eu,^{207}Bi and conversion electrons of inbeam measurement on ^{70}Zn target. The effeciency was 2.0×10^{-2} for the conversion electron of 874.2 Kev 2^+-0_2^+ transition in ^{70}Zn. The resolution was ~3 Kev. The γ-rays were measured by a Ge(Li) detector. The spectrum of γ-rays and electrons are shown in figure with same energy scale.In the electron spectrum abscissa is shifted by K-electron binding energy in the figure. A peak at 1061.2 Kev corresponds with the EO, 0_2^+-0_1^+ transition in ^{70}Zn. The energy of γ-ray 0^+-2_1^+(884.9 Kev, Eγ=185.9 Kev) in ^{70}Zn is close to that of $3/2^-$ - gnd. state (Eγ=184.6 Kev) in ^{67}Zn and the crossection of 0_2^+.(^{70}Zn) is much smaller than that of $3/2^-$ in ^{67}Zn . We used 67 % and 99 % enriched ^{70}Zn target to determine the intensity of 185.9 Kev γ-ray. Subtracting the effect of L-conversion line of 1063 Kev γ-ray from the 1061.2 Kev peak area, the branching ratio $E0(0^+-0^+)/E2(0_2^+-2^+)$ was obtained to be $3.1 \pm 0.6 \times 10^{-3}$. With the available life time τ = 5.36 ± 0.29, ns for the 0^+, the matrix element $|\rho(EO)|$ was obtained to be 0.051 ± 0.015 [1,2]. The present value of $|\rho(EO)|$ in ^{70}Zn is depressed compared with those of neighbouring nuclei, 0.09 for ^{70}Ge, 0.095 for ^{72}Ge and 0.176 for ^{72}Se.



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Identification of a New 75 S Isomer in ^{160}Tm†

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Existence of low lying isomers in many of the neutron deficient Tm isotopes prompted us to investigate isomerism in ^{160}Tm. The decay of 9.2 m ^{160}Tm (g.s., $J^{\pi}=1^{-}$) has already been studied by Strusny et al [1]. They recorded all their measurements 20 m after the formation of radioactive ^{160}Tm and did not report any shorter lived activity associated with ^{160}Tm. In our experiments, 57 MeV proton beams from the McGill University Synchrocyclotron were used to produce ^{160}Tm isotope through the reaction $^{164}Er(p,5n)$. The following spectroscopic measurements were carried out immediately after the source formation: γ-ray time sequential spectra, γγ-coincidences (using Ge(Li)-Ge(Li) system), X-ray and low energy γ-ray measurements, and conversion electron measurements (using Si(Li) detector and mini-orange magnetic filter system).

The decay curves for two prominent transitions in ^{160}Er i.e. 125 keV ($2_1^+ \rightarrow 0^+$) and 264 keV ($4_1^+ \rightarrow 2_1^+$) were both found to clearly display two half-lives: 74 S and 8.7 m. A third transition of 376 keV which is well known (from in-beam measurements) to be a $6_1^+ \rightarrow 4_1^+$ transition in ^{160}Er decayed with a single half-life of 76 S. Coincidence data and X-ray spectra helped, further, to confirm the assignment of this short-lived activity to ^{160}Tm. The decay curve for Tm L-X-rays revealed a component corresponding to 75 S half-life, although K-X-rays did not show any such component. An average value for the half-life of this isomer is determined to be 75 ± 1 S. The following γ-rays with energies (relative photon intensities) as shown were assigned to 75 S ^{160}Tm decay:
125.8(72), 264.1(100), 375.8*(27), 597.6(2.9), 738.7*(12), 840.8*(3.8), 861.4(12.4), 882.0(2.5), 926.7*(6.7), 1008.2(2.3), 1104.1(5.3), 1115.8*(5.0), 1186.1*(4.2), and 1249.4(6.5).
Transitions marked with * were not observed in decay of 9m ^{160}Tm. Uncertainties on energies are 0.1 keV below 1 MeV and 0.3 keV above this energy. Relative photon intensities are accurate to about 10%.
The following excited levels in ^{160}Er are proposed on the basis of the above measurements: 125.8(2^+), 389.9(4^+), 765.7*(6^+), 987.4(3^+), 1008.0(2^+), 1128.6*(4^+), 1230.3*(4), 1316.6*, 1375.2(3^+), 1505.7*, 1576.0*. Levels marked with * were not reported by Strusny et al [1].

From decay curves, we estimate that nearly 80% of the decay proceeds via isomeric transitions in ^{160}Tm while the remaining 20% goes through electron-capture and β^+ to levels in ^{160}Er. A search was made for isomeric transitions through conversion electron and low energy γ-ray studies (threshold for γ-ray detection was about 5 keV and that for electron detection about 20 keV). These data did not reveal any lines decaying with a half-life of 75 S. Combining this information with the knowledge that Tm K-X-rays did not contain a short-lived component, it may be interpreted that the 75 S isomer is located less than about 100 keV above the ^{160}Tm g.s. A spin assignment of 5 for this isomeric state would be consistent with log ft values for decay to the 389.9 keV ($J^{\pi} = 4^+$) and 765.7 keV ($J^{\pi} = 6^+$) levels in ^{160}Er.

† This work was supported by NSERC of Canada.

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ELECTROMAGNETIC PROPERTIES OF EXCITED LEVELS IN ^{49}Ti

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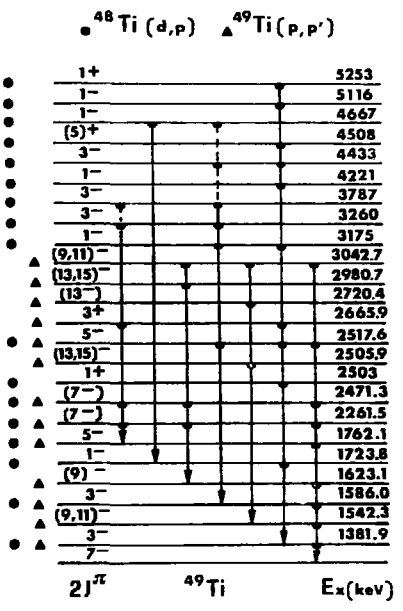
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Levels in ^{49}Ti were populated via ^{49}Ti(p,p'γ) and ^{48}Ti(d,pγ) reactions, at 6 MeV beam energy. Enriched targets of ^{49}Ti (~1 mg/cm^2 thick) and natural targets of ^{48}Ti (~40 μg/cm^2) were used. Measurements were performed at the CN Van de Graaf accelerator of Laboratori Nazionali di Legnaro.

Proton - gamma coincidences were recorded in both cases. The information on the decay scheme provided by the two reactions are somewhat complementary since the (d,p) reaction excites preferentially low spin states up to E_x~5.5 MeV, while the (p,p') reaction excites also high spin states up to E_x~3 MeV.

The figure summarizes the information obtained on the decay scheme. Some tentative J^π assignments, deduced from the observed decay properties, are reported in parenthesis.

The (p,p'γ) reaction was also used to measure the lifetimes of various levels, by observing the shift of γ-peaks centroids as the Ge(Li) was rotated from +90° to -90° to the beam direction, with the Si detector fixed at +90°. Lifetimes were deduced from the observed attenuated Dopplershifts by the standard Blaugrund-type analysis. Preliminary values are reported in the table, where the quoted errors include a ±15% uncertainty in the electronic energy loss.



Level energy (keV)	Mean life (fs)
1623	44±7
1762	33±9
2261	136±30
2517	>8000
2665	> 210
2720	49±35
3042	< 15

Finally, the 1542 keV level was Coulomb excited by α-particles' bombardment (E_α= 5.2 ÷ 5.8 MeV). In the same experiment no Coulomb excitation was detected of the 1586 keV level. The deduced B(E2)↑ values for the corresponding transitions from the ground state are 98±10 and <5.5 e^{2}fm^4, respectively.

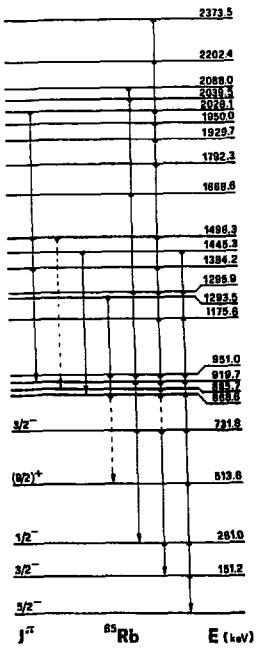
‡Present address: Cyclotron Laboratory, Michigan State University, East Lansing, 48824 Michigan.

GAMMA DECAY PROPERTIES OF ^{85}Rb

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The level scheme of ^{85}Rb has been investigated by the ^{84}Kr(p,γ) reaction with the 3 MeV proton beam of the KN3000 accelerator of INFN in Florence. A gas target of natural Krypton has been used in a target cell separated from the beam line by means of a thin Nickel foil. Through γ-γ coincidence measurements the gamma decay of the levels at 1496.3, 1792.3, 1950.0, 2202.4 and 2373.5 keV has been observed and levels at 1668.6, 1929.7, 2028.1, 2039.5 and 2088.0 keV have been identified. Moreover the level at 1295 keV, which has been reported[1] as decaying both to the $9/2^+$ level at 513.6 keV and the $3/2^-$ first excited state, has been found to be a doublet at 1293.5 and 1295.9 keV. In our experiment only the level at 1295.9 keV is in fact populated, while the one at 1293.5 keV is strongly populated in ^{82}Se(^{6}Li,3nγ) and ^{82}Se(^{7}Li,4nγ) experiment[2].



Meanlives of various levels have been measured with the method of Doppler Shift Attenuation in gas, with pressures varying from 0.2 to 22 bar. The full Doppler shift for the various lines ranged from 130 to 1500 eV. Analysis of experimental data is in progress. A preliminary result of $1.0\pm.2$ ns for the meanlife of the 151.2 keV level compares well with previous electronic measurements, while the value of 30 ± 10 ps obtained for the meanlife of the 281.0 keV level is significantly shorter than the value of 450 ps reported in a Coulomb excitation experiment[3]. This discrepancy appears to be mainly due to the value adopted in ref. 3 for the branching ratio of the 129.8and 281.0 keV γ-rays deexciting the 281.0 keV level.

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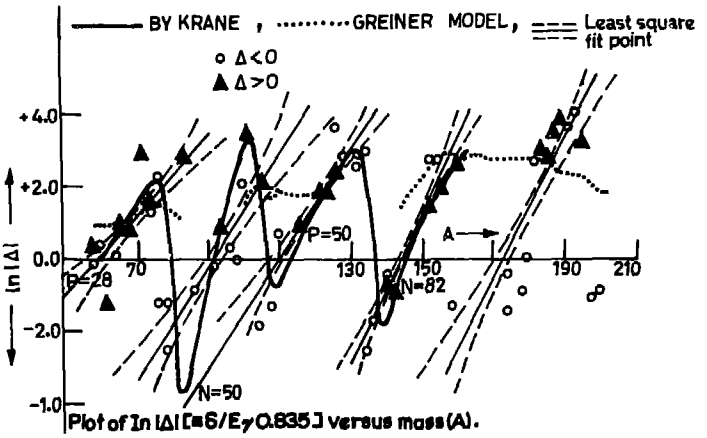
1)E. Barnard et al., Z. Physik 260 (1973) 197; R.P. Torti et al., Phys. Rev. C6 (1972) 1686.
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ANALYSIS OF VARIATION OF THE EXPERIMENTAL E_2/M_1 MIXING RATIO FOR $2^{+'} \rightarrow 2^+$ TRANSITION AND ITS BROAD FEATURES.

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Transition probabilities and mixing ratios are important to understand nuclear structure. $E_2/M_1 = \delta$, mixing ratio for $2^{+'} \rightarrow 2^+$ transition in even-even nuclei are compared with single particle shell model and collective model of Davydov and Filipov. It is found that the experimental values are close to the collective model estimate. The experimental values E_2/M_1 mixing ratio are obtained from the angular correlation data. In order to understand the magnitude as well as phases of E_2/M_1 mixing ratio, the angular correlation coefficients A_2(expt.) and A_4(expt.) for almost all the nuclei have been reanalyzed to calculate with phase by the method of Arns and Weidenbeck and of Coleman. The values are plotted with mass number and atomic number. The plot In $|\Delta|$ ($\Delta = \delta/E_\gamma 0.835$) where E_γ is the energy gamma-transition versus A, suggests that nuclei can be divided in five groups by drawing straight lines.



Plot of In |Δ| [=δ/Eγ0.835] versus mass(A).

The slope of these lines are calculated. These lines cut the A-axis at P-28, N-50, P-50 and N-100-114 indicating magic number. The magic behaviour at N 100-114 can be argued on the basis of deformation parameter in Nilsson diagram. The phase of δ i.e. + or - do find a system in N-Z plane. The second excited state $2^{+'}$ may be just above 2^+, of above 4^+ or 6^+ or 8^+ excited state. 0^+ state may lie between 2^+ and $2^{+'}$. The analysis of δ with phase for this consideration reveals a typical classification which may help in microscopic calculations for nuclear structure studies.

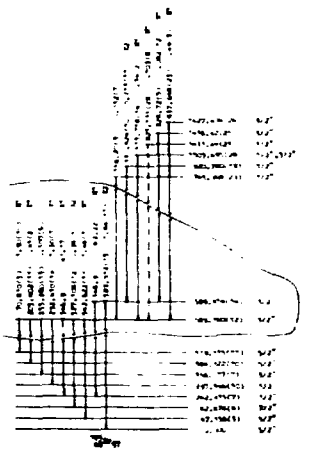
$3/2^{-}-3/2^{+}$,150 eV LEVEL DOUBLET AT THE ENERGY OF 590 keV IN ^{165}Er

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The existence in ^{165}Er of 590 keV doublet of levels with different parity was first pointed out in ref.[1]. Marguier and Chery[2] proposed that the spins and parities for levels 589.8 keV are $3/2^{+}$ and 589.9 keV - $1/2^{-}$ or $3/2^{-}$.

In the course of investigation of the ^{165}Tm decay, on the basis of more exact data on the energies and intensities of transitions, multipolarity determinations and on the results of e-γ-coincidence we have improve the decay scheme of ^{165}Tm. The results on the level doublet at the energy of 590 keV are presented in the Figure. It has been found unambiguously that both levels have the same spin 3/2 and that the lower level of the doublet has positive parity, when the upper one has negative parity. The levels of doublet are spaced (154±13) eV apart. More precise and complete data about the population and depopulation intensities of these levels have been obtained. The total intensities of transitions are given in the percent per decay. The complete results of our investigations of ^{165}Tm decay will be published later.



One can observe lately a certain interest to experiments connected with investigations of parity violation in the electromagnetic interaction. The potential which violates the parity in nuclear transitions at low energies is very small, (10^{-6}-10^{-7}). Owing to this the experiments of these type are possible in a rather limited number of cases, which are convenient from methodic point of view. Besides, in studying the γ-quanta circular polarization asymmetry which indicates on the parity violation it would have been usefull if the interacting states are as close to each other as possible.

In the considered case the energy distance between the opposite parity level enables to suppose the increase of parity nonconservation effect ($\gtrsim 50$ times) with respect to the known cases[3].

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Study of Kurath Sum Rule in ^{28}Si by Statistical Theory *

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The isovector magnetic dipole operator is

$$M1(T=1) = \sqrt{\frac{3}{16\pi}} \sum_i \{-\ell_i \vec{\tau}_i + (g_n - g_p)\, \vec{s}_i \vec{\tau}_i\} \qquad (1)$$

and the Kurath approximation [1] to the linear-energy-weighted sum rule (LEWSR) for such excitations from the ground state is, in ds-shell nuclei,

$$S_{EW}^{Ku} = 4.286\ (2\, n_{5/2} - 3\, n_{3/2})\ \mu_o^2\ \text{MeV} \qquad (2)$$

where $n_{5/2}$ and $n_{3/2}$ are the ground state occupancies of the orbits $d_{5/2}$ and $d_{3/2}$ respectively. We evaluate this for ^{28}Si using three sets of occupancies. From the extreme single-particle model (j-j coupling) one gets 103 μ_o^2 MeV. This goes down to 47 μ_o^2 MeV when occupancies are obtained (by the spectral distribution method [2]) from a Brown-Kuo Hamiltonian. The value is 49 μ_o^2 MeV if experimental occupancies [3] are used. However, the total LEWSR is experimentally determined [4] (by the known isovector M1 strengths) to be at least 77 μ_o^2 MeV, indicating substantial contributions from the two-body part of the Hamiltonian. A part of the two-body contribution can be included in a unitary sum rule [5], but this increases the value to 59 μ_o^2 MeV only. We therefore calculate the LEWSR with the full (1+2)-body Brown-Kuo Hamiltonian using the spectral distribution methods. The value is 127 μ_o^2 MeV (of which the spin-flip part, obtained by neglecting the $\vec{\ell}\,\vec{\tau}$ term in eqn. (1) is 70 μ_o^2 MeV - this means that the spin-flip part accounts for about 74% of the isovector magnetic dipole operator), compared to the experimental value of at least 77 μ_o^2 MeV. The experimental measurements include transitions to a few low lying states only, and hence are expected to be somewhat lower than the theoretical result.

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* supported in part by the National Science Foundation

THE EFFECTIVE CHARGE FOR THE $h_{11/2}$ SUBSHELL DEDUCED FROM THE E2 TRANSITION PROBABILITY IN ^{130}Sn

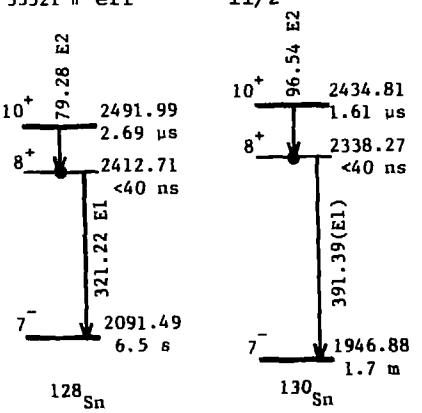
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Studies of even nuclei in the region around double shell closures are often very profitable and can give considerable information on the properties of single particle states which is difficult to obtain from studies of odd-mass nuclei. Examples regarding the ^{132}Sn region are given in refs[1,2]. The present work, comprising a study of ^{130}Sn and a continued investigation of ^{128}Sn from the decays of In isotopes, obtained at the OSIRIS on-line mass separator facility, has resulted in the identification of several two particle excitations in ^{130}Sn. A conspicuous feature of the level schemes of ^{128,130}Sn is the occurrence of a μs isomer in both nuclei at about 2.4 MeV excitation energy. Each isomer is deexcited to the 7^- level via a cascade of an E2 and an E1 transition, see the figure. Available systematics of nuclear structure in this mass region as well as arguments based on the shell model, strongly suggest that each of the isomeric E2 transitions can be interpreted as the $10^+ \rightarrow 8^+$ transition within the $(h_{11/2})^2$ neutron hole multiplets in ^{128,130}Sn. The 10^+ and 8^+ neutron hole states in ^{130}Sn can be assumed to be very pure. One is therefore able to deduce the neutron effective charge from the relation

$$B(E2;h_{11/2}^{-2})_{10} \rightarrow (h_{11/2}^{-2})_8) = \frac{2025}{35321\,\pi} e_{eff}^2 \left(\langle r^2 \rangle h_{11/2}\right)^2$$

A value of $e_{eff}/e = 0.85 \pm 0.04$ results from the measured transition probability, using 33 fm^2 for the radial matrix element[1]. The value is only slightly smaller than the $e_{ff}/e = 0.96$ obtained for the $i_{13/2}$ neutrons in ^{206}Pb.



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LONGITUDINAL POLARIZATION OF ^{12}B IN MUON CAPTURE

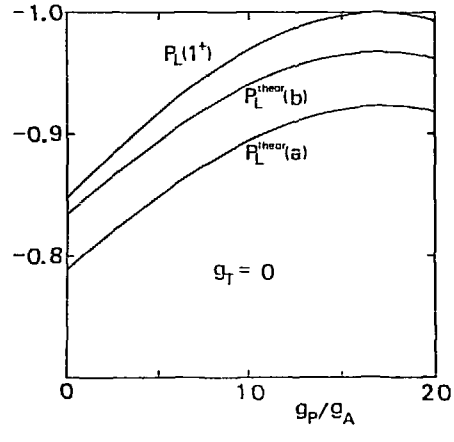
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The nuclear system of A=12 is one of the most suitable examples for studying in detail the structure of the weak nucleon currents, since this system supplies us the mirror beta decays of large Q values and the muon capture of a large momentum transfer. In this connection, our theory group has been investigating this system in its various aspects continuously. Here we report our latest work on muon capture in ^{12}C.

It is known that the partial capture rates are dependent on the oscillator strength parameter even if we fix the configurations of the nuclear states. On the other hand, the average polarization of the recoil nucleus is insensitive to the detail of the radial wave functions of nuclear states. It is, however, noticed that the observed value of the average polarization includes the effects of the average polarizations of the excited states through gamma cascade transitions. We made this correction to analyze the experimental data given by Louvain-Saclay-ETH group, and obtained[1] $(g_P-g_T)/g_A = 10.3 \pm 2.7$.

Since an experiment on the longitudinal polarization of ^{12}B in the muon capture in ^{12}C was published,[2] we made a general expression for this quantity for the muon capture in spinless nucleus, including the contribution from excited states. It is confirmed that the longitudinal polarization is insensitive to nuclear structure, by numerical analysis of the muon capture in ^{12}C. Contribution from excited states of 2^+, 2^-, and 1^- plays an important role to determine the induced pseudoscalar and induced tensor form factors. The calculated values are summarized in the figure where the upper curve $P_L(1^+)$ indicates the longitudinal polarization of the ground state of ^{12}B, which is directly excited by muon capture. The other two include the contributions from all 2^+, 2^-, and 1^- states and the 1^- state only, respectively, for the cases (a) and (b). Experimentally,[2] $P_L = -0.83 \pm 0.21$ which covers the whole scale in this figure, and hence we can not restrict g_P at this moment. To do this, we need more accurate data on the capture rates W leading to the 2^+ and 2^- states with experimental uncertainties ΔW less than 0.2×10^3 sec^{-1} and those on the longitudinal polarization P_L with ΔP_L less than 0.03.



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DELAYED PROTON EMISSION OF A NEW NUCLIDE ^{59}Zn

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The nuclide ^{59}Zn is a member of the T_z=-1, A=4n-1 series. Its decay is expected to lead predominantly to the ground state of its mirror, ^{59}Cu, by superallowed β-transition. Because only a small fraction of decays is then associated with β-delayed γ-rays, the observation of ^{59}Zn by γ-ray studies is difficult in the presence of other short lived nuclides. However, the proton binding energy of ^{59}Cu is relatively low, 3.42 MeV, while its Q_{β^-} value is predicted to be -8.76 MeV [1]. A detectable fraction of β-decays should therefore populate proton unbound levels and result in delayed proton emission.

^{59}Zn precursor nuclei were produced by the ^{58}Ni(^{3}He,2n)^{59}Zn reaction. A stack of four 0.5 mg/cm^2 Ni target foils were bombarded by 25 MeV ^{3}He ions. The recoil atoms were transported with NaCl loaded He jet to a tape transport system and collected on an aluminized tape. Simultaneous gamma-ray and particle spectra were measured in a detector configuration described in ref. 2.

The delayed proton spectra revealed some 15 distinct proton groups in the energy range 0.9 MeV<E_p<2.9 MeV. The half-life of the proton activity was measured to be 210±20 ms. A value of (3±1) 10^{-3} was obtained for the total proton branching in the β-decay of ^{59}Zn. The observed proton groups have been associated with excited levels of ^{59}Cu known from (p,γ)-resonance reaction studies.

In addition to β-delayed protons also two β-delayed gamma rays of 491 keV and 914 keV were observed and associated with the decay of ^{59}Zn. Gamma rays with these energies are known to lead from the first two excited states with J^π=1/2$^-$ and 5/2$^-$ to the J^π=3/2$^-$ ground state of ^{59}Cu. The log ft values of the β-transitions leading to the ground state, and the 491 keV and 914 keV states were found to be 3.6, 4.8 and 5.1, respectively.

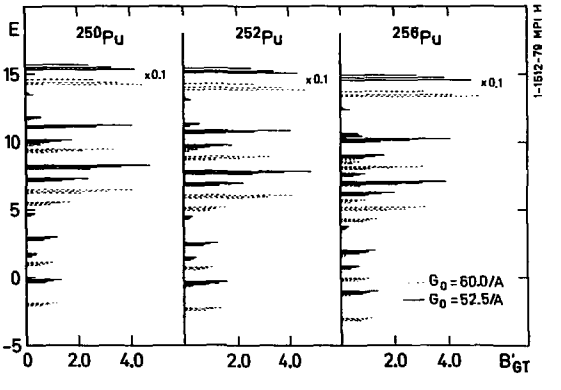
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THE BETA STRENGTH FUNCTION FOR THE GT β^- DECAY OF ^{250,252,256}Np

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Calculations of the beta strength function S_{β^-} are performed for the GT β^- decay of ^{250,252,256}Np in a Brown-Bolsterli model with a Gamow-Teller residual interaction (see ref. [1]). The figure shows the results for a Lane potential of G_0 = 52.5 MeV, G_1 = 2/3 G_0 (the dotted lines correspond to G_0 = 60.0 MeV). The main features of the calculated S_{β^-} are: At energies ∿15 MeV from the ground state of the parent nucleus lies the main maximum of the GT strength. The states at that excitation energy form the Gamow-Teller giant resonance (GTGR). The transition probability into the GTGR corresponds to log ft ≈1.7. The strength energetically accessible in the daughter nucleus by β^- decay is due to back spin flip transitions with a log ft ≈ 3.1. The essential point of the results is that the back spin flip states lie *beyond* the fission barriers in ^{250,252,256}Pu which leads to large β-delayed fission rates and thus explains the odd-even reversal found[2] in the mass yield of thermonuclear explosions with a realistic beta strength function. In a similar way the structure in S_β will affect all calculations for the synthesis of heavy and superheavy nuclides by astrophysical processes like the r or n process and the production ratios for chronometric pairs[3,4].



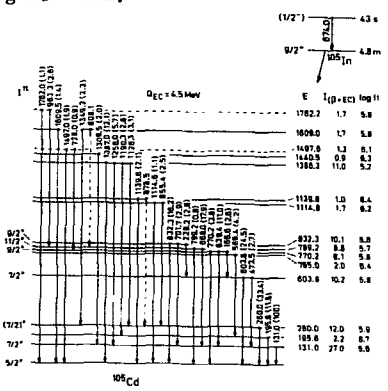
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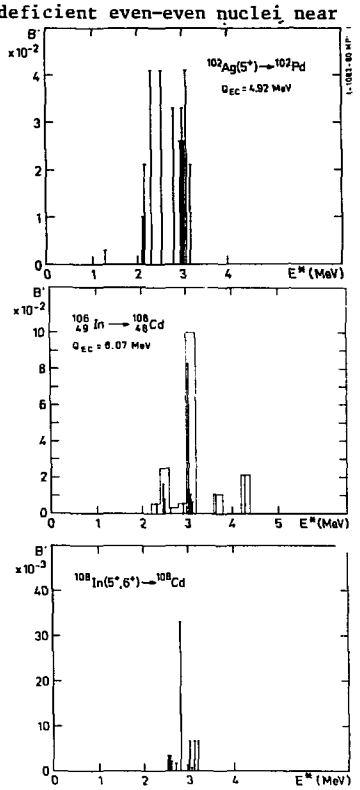
INVESTIGATION OF THE β^+ DECAY OF ^{105,106,108}In AND ^{100,102}Ag

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Low-lying high spin states in the nuclei ^{105}In($9/2^+$), ^{106}In(6^+), ^{108}In(5^+,6^+), ^{100}Ag(5^+), ^{102}Ag(5^+) were selectively populated by ^{90}Zr(^{19}F,xnγ), ^{92}Mo(^{19}F,2pnγ), ^{92}Mo(^{12}C,pxnγ), ^{90}Zr(^{19}F,α3nγ) at E_{lab} = 72 and 66 MeV and their β^+ decay was studied by observing the γ rays following the β decay with an Anticompton γ spectrometer. This investigation was undertaken in continuation of nuclear structure studies in neutron-deficient even-even nuclei near Z = 50 [1]) and of work on the β-strength distribution and its consequences for astrophysical problems[2]). Many new γ transitions were found, the level schemes of ^{100,102}Pd, ^{105,106,108}Cd completed and log ft values determined; from the latter, spins of the β-decaying states and of levels in the daughter nuclei were deduced[3]). Figure 1 (l.) shows the results for ^{105}In, Figure 2 (r.) the measured β strength functions for ^{102}Ag and ^{106,108}In. The result for ^{105}In may be compared with the prediction of ref. [4]). Only the lower parts of the GT strength distribution as calculated by ref. [5]) are probably observed, except for ^{102}Ag where the total strength seen around 2.5 MeV amounts to log ft = 4.2.





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ON THE β^- BRANCHING FROM $^{75}Ge^m$

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The energy levels of ^{75}As have been studied in a wide variety of nuclear reactions with ^{75}As and ^{74}Ge targets as well as in the decay of ^{75}Ge and ^{75}Se and $^{75}Ge^m$. There has been evidence for β^- decay of the $7/2^+$ isomeric level of ^{75}Ge to the 400.6 keV [1] level of ^{75}As which is not consistent with preliminary observations that led to the present experiment.

The γ- transitions exhbiting the 48.2 s half life of $^{75}Ge^m$ produced in the reaction ^{74}Ge (n,γ) are investigated with natural and highly enriched targets bombarded by thermal neutrons. The γ- ray spectrum was examined from 6 keV up to 1.8 MeV energy range with silicon X-ray and Ge(Li) γ-ray detector respectively, using a multiscale data acquisition and analysing system. The γ-ray spectrum was taken with a 99.99% enriched, chemically purified ^{74}Ge target, irradiated at High Flux Reactor at LLL. The γ-ray intensities were corrected for absorption in 1/16" lead which was placed between the source and the detector to improve the detection of higher energy, weak γ-radiations, compared to the intense 139.8 keV (IT) γ-rays.

The energies, relative intensities, and the measured half lives of short lived transitions assignable to the decay of $^{75}Ge^m$ are given in Table 1. The intensities are normalized to $100\%/(1+\alpha^{E3}_{tot})$ for the 140 keV isomeric transition.

Table 1. γ-rays assigned to the decay of $^{75}Ge^m$

E_γ(keV)	Photon Intensity, %	$t_{1/2}$(s)	P_{level} $\frac{\Sigma I_\gamma}{I_{tot}}$ in percent	log ft
24.2		42.0±5		
140.0	39.2	48.2±0.2		
280.1	0.019	50.3±2		
304.5	0.0021	51.0±9	0.021	6.5

As seen all 24, 279,304 keV γ-rays decay with a compatible life time to that of 139.8 keV and no 400 keV short lived γ-ray is observed. This indicates a direct β^- transition to the level of 279 keV($5/2^-$).

The intensity balance confirms β^- feeding to 304 keV level as well; in particular no 48 s component was found in the 264.7 keV transition indicating that the latter was not populated by a short lived transition of 136 keV from the deexcitation of supposedly β^- fed 400.6 keV level as previously reported.

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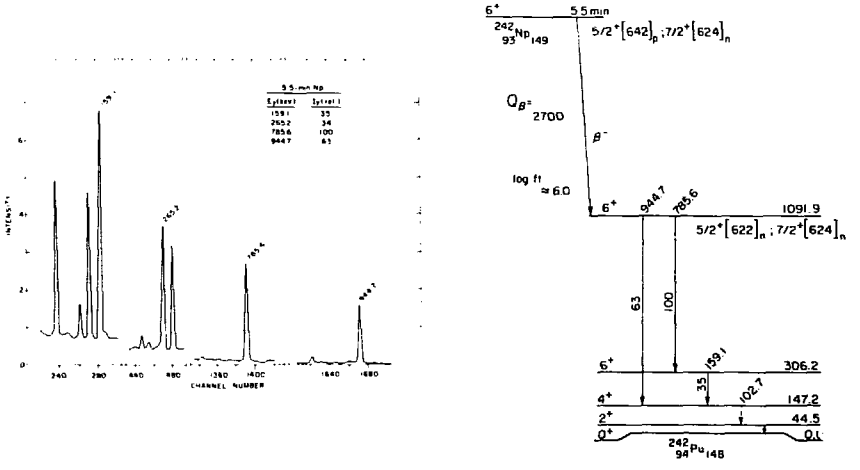
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DECAY OF NEW HIGH-SPIN ISOMER: 5.5-min $^{242}Np^{\dagger}$

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Discovery of 16.8-min ^{242}U and its 2.2-min ^{242}Np daughter ($I^{\pi} = 1^{+}$) was recently reported.[1] By analogy with the two known isomeric states of ^{240}Np a high spin isomer was also expected for ^{242}Np. Therefore targets of ^{244}Pu were irradiated with neutrons up to 200 MeV at the Brookhaven Medium Energy Intense Neutron facility (MEIN); then neptunium activities were rapidly isolated by means of thorough chemical separations. In addition to many peaks in the γ-ray spectrum assigned to known isotopes of neptunium (mainly ^{239}Np, ^{240}Np, and ^{241}Np) at least four new lines were clearly observed and they decayed with $T_{\frac{1}{2}} = 5.5 \pm 0.2$ min. Portions of this spectrum are shown (left Figure). The proposed decay scheme (right Figure) shows not only the $K = 0^{+}$ ground state rotational band with $I = 2^{+}$, 4^{+}, and 6^{+} levels of ^{242}Pu but also the lowest two-neutron level (at 1091.9 keV) with $K = 6^{+}$ and the configuration $5/2^{+}[622]_n$; $7/2^{+}[624]_n$. Because of strong K-forbiddeness for γ-ray decay ($\Delta K = 6$) this level is expected to have a lifetime as long as 10^{-3} to 10^{-4} sec. Analyses of log ft values in the β decay of both ^{242}Np isomers (2.2 min and 5.5 min) lead to assignments of $I^{\pi} = 1^{+}$ and $I^{\pi} = 6^{+}$, respectively, both belonging to the same configuration: $5/2^{+}[642]_p$; $7/2^{+}[624]_n$.



†Research supported by the U.S. Department of Energy.

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DECAY OF 14.1-h ^{240}U and 7.22-min $^{240}Np^{m}$ †

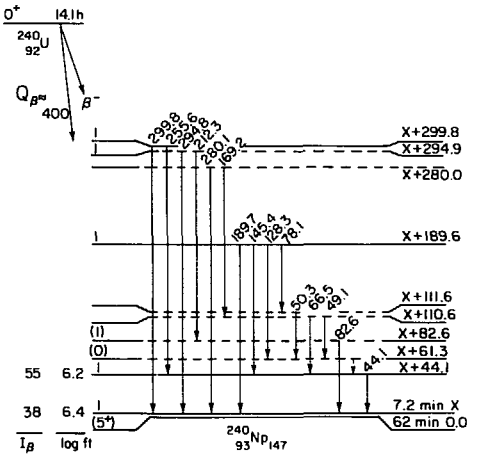
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Previous work[1] on 14.1-h ^{240}U showed that it decays by β-ray emission (E_{max} = 0.36 MeV) to the low spin isomer 7.2-min $^{240}Np^{m}$. Since copious γ-ray emission (E_γ up to 2 MeV) follows decay of the daughter $^{240}Np^{m}$, any low intensity γ rays from the parent ^{240}U may be easily masked. In the present study ^{240}U was obtained as the α-decay product from 200 mg of highly enriched ^{244}Pu. The uranium was separated and adsorbed on an anion exchange column; its γ radiation was measured with a Ge(Li) detector while the Np daughter activity was being eluted and flushed away continuously with acetic acid. Thus the γ-ray spectrum of ^{240}U was obtained almost free of radiation from $^{240}Np^{m}$, and a substantial number of new γ rays were revealed. These are listed in the table; the intensities, I_γ, are given as γ rays per 100 disintegrations. A few of the transitions had been erroneously attributed before[1] to decay of $^{240}Np^{m}$. Most of the γ rays are accommodated into the proposed (tentative) decay scheme.

Detailed study of the purified $^{240}Np^{m}$ daughter activity showed: $T_{1/2}$ = 7.22 ± 0.02 min; absolute intensity of the 554.6-keV γ ray is (20.6 ± 0.5)%; E_γ and I_γ values for about 70 transitions agree very well with earlier work[1]; 29 additional transitions were found; ten new levels are indicated for ^{240}Pu. It was deduced that the 7.22-min Np isomeric state has I = 1 with possible configurations $5/2^{+}[642]_p$; $5/2^{+}[622]_n$, $K = 0^{+}$ or $5/2^{-}[523]_p$; $5/2^{+}[622]_n$, $K = 0^{-}$.

E_γ		I_γ	
44.1	1	1.05	5
49.1	2	0.007	2
50.3	2	0.005	1
66.5	1	0.154	5
78.1	2	0.004	1
82.6	1	0.014	1
128.3	1	0.087	2
145.4	1	0.081	2
167.3	2	0.008	1
169.2	1	0.115	8
189.7	1	0.24	1
203.9	2	0.005	1
212.3	5	0.0015	3
255.6	2	0.0040	3
280.1	1	0.016	1
294.8	3	0.0019	4
299.8	2	0.013	1



† Research supported by the U.S. Department of Energy.

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CONTRIBUTION OF 2ND ORDER FORBIDDEN MATRIX ELEMENTS IN ALLOWED BETA TRANSITIONS:

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Finite value of angular correlation coefficient by beta-gamma angular correlation is well established by experimental findings. The contribution of higher order forbidden matrix elements is therefore to be considered. Considering the conservation of parities of the excited states, ~~the contribution of~~ 2nd order forbidden matrix elements are $\langle i\alpha.r\rangle$, $\langle r^2\rangle$, $\langle(\vec{\sigma}.r\rangle)\, r\rangle$, $\langle i\gamma_5\, r\rangle$ and $\langle\alpha \times r\rangle$. may contribute. Introduction of these matrix elements for the interpretation automatically required two considerations. (1) momentum type matrix elements thereby conservation of vector currents (2) nuclear structure factor. Therefore introduction of these two variables in the result and also enhancement and retardation of the terms are considered and plotted. The beta decay from the following nuclei are taken for these studies. :

Cs^{134}, Eu^{154}, Sb^{124}, Ag^{110m}, Co^{60}, Co^{58}, Co^{56}, Na^{22}, Eu^{152} Mn^{56}, and Na^{24}.

It is found that the conservation of vector current theory of Gell-Mann is to be considered to explain the finite value of angular correlation coefficients.

SYSTEMATICS OF LOG FT VALUES IN β-DECAY+

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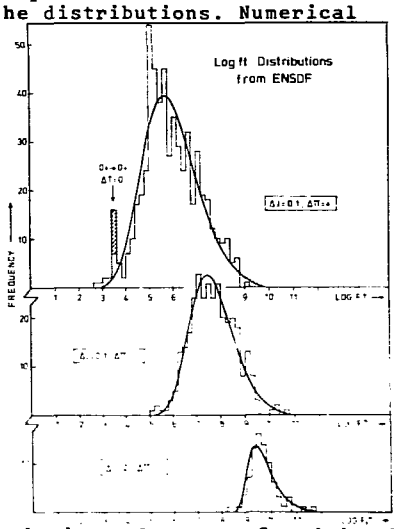
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Since the last systematic study of log ft values in beta decay for use in the assignment of spins and parities to nuclear levels appeared several years ago[1], a wealth of new experimental information has become available, justifying a reexamination of the currently accepted rules. We have extracted over 1400 log ft values between states of known spin and parity from the Evaluated Nuclear Structure Data File (ENSDF) and classified these according to their degrees of forbiddenness. From these values we rejected (1) transitions for which the $J\pi$ involved were deduced from log ft arguments, (2) transitions for which the level feeding was known to less than 50% precision, and (3) very weak transitions with a feeding of less than 0.1%, since the latter were often found to be unreliable. Since the log ft distributions in the strongly deformed rare earth region, and in particular for the even-mass nuclei, differed considerably from those in the non-deformed regions, the even-mass nuclei with A=152-182 were excluded from the present analysis. The resulting log ft distributions are shown in fig.1. Chi-square type curves were fitted to the distributions by scaling and comparison of calculated and observed 3rd moments (skewness) of the distributions. Numerical results are given in Table 1.

Table 1

Transition ($\Delta J\pi$)	0,1+	0,1-	2-
Number of logft values	564	325	77
Degrees of freedom	30	30	7
Mean	6.0	7.7	9.6§
σ	1.2	0.9	0.6§
5% limit	4.2	6.3	8.9§
50% limit	5.9	7.6	9.8§
95% limit	8.1	9.3	10.7§

§ $\log f_1 t$ values



No significant violations of the existing rules were found in this study. Despite the presence of various hindering mechanisms it has been demonstrated that log ft values belonging to certain categories of forbiddenness group together in reasonably narrow intervals.

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+ Supported by the Bundesministerium für Forschung und Technologie

DIRECT MEASUREMENTS OF THE A_1-PARAMETER IN β-DECAY

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Most of the information on the A_1 parameter in β-transitions up-to-now has been obtained from β-γ (CP) measurements. This technique is restricted to the study of β-transitions feeding excited levels : a relatively small number of transitions has been studied, however repeated by many groups and leading to some large discrepancies. Direct β-anisotropy measurements using oriented nuclei have been perforemd rarely and often lead also to large discrepancies due to uncertain scattering corrections.

We have demonstrated that using a combination of ion implanted sources, continuous low temperature orientation (with ^{3}He-^{4}He refrigeration) and the use of energy selective electron detectors, it is possible to determine A_1 parameters accurately without resorting to various scattering corrections. To prove the validity of the technique, tests have been performed on several pure G.T. transitions[1], which show complete agreement with the theoretical value, in the assumption of complete parity violation : hence more stringent restrictions on the value of G_A can be obtaind from these measurements than hitherto possible.

Here we report applications to the determination of the y-parameter (Fermi/Gammow-Teller ratio) in some isospin-forbidden $J \to J$ transitions. As test we first studied the mixed transitions in ^{58}Co for which we obtain y = -0.012(9) compared to the average of a large number of β-γ (CP) measurements y =-0.003(4), as evaluated by S. Raman et al[2]. For another well-studied transition in ^{52}Mn we obtain y = -0.11 (2) in disagreement with the value of the compilation of ref.[2], y = -0.03(2), but in agreement with the value of another NO experiment[3], y = -0.131(24). This leads to a much larger isospin impurity than previously accepted ; hence it makes ^{52}Mn a good candidate to search for a complex phase in the F/GT ratio, which could be explained as a manifestation of T-violation, using e.g. β-γ correlation on oriented ^{52}Mn[4].

* Bevoegd Verklaard Navorser N.F.W.O.

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A NEW MEASUREMENT OF THE MUON CAPTURE RATE IN LIQUID HYDROGEN

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Using the pulsed structure of the Saclay Linac, we have been able to compare the μ^+ and μ^- lifetimes in liquid hydrogen with a high accuracy and to deduce the capture rate. This technique avoids the well known limitations inherent to the absolute yield measurement of the 5 MeV capture neutrons. The $\mu^-(\mu^+)$ flux is stopped during the 3 μs beam burst in a cooper (high Z) spherical target filled with 8 liters of deuterium-free (protium) ultra pure liquid hydrogen. The decay $e^-(e^+)$ are observed in a gate following the beam burst by 6 plastic scintillator-telescopes. From the present data we get :

$$\tau_{\mu^+} = 2197.18 \pm .12 \text{ ns}$$
$$\tau_{\mu^-} = 2194.90 \pm .07 \text{ ns.}$$

Including the world average $\tau_{\mu^+} = 2197.134 \pm .077$ ns we find for the capture rate in liquid hydrogen :

$$\lambda_c = 459 \pm 21 \text{ s}^{-1}$$

where corrections for the effect of binding of the μ^- and a small deuterium contamination have been applied.

The interpretation of λ_c in terms of ortho-(λ_{om}) and para-(λ_{pm}, λ_{om}) capture rates, relevant for the pμp molecule requires the exact knowledge of the initial state of pμp during measurement. This molecule is formed in the ortho (I = 1) state and it has been assumed until now that the transition rate (λ_{op}) to the para (I =0) state is negligible compared to the μ decay rate λ_0. Such a transition is most easily observed in the capture neutrons time distribution. For this purpose we detect the low energy neutrons in a set of 6 liquid scintillators, using the technique of pulse shape discrimination to reject the intense photon background. We have found that the neutron yield decreases faster than the electron one. This effect is interpreted as an ortho-para transition at a rate $\lambda_{op} = (5.0 \pm 2.0) \times 10^4 \text{ s}^{-1}$. λ_{om} is then found larger than λ_c by an amount of $90 \pm 35 \text{ s}^{-1}$. Improved data on this transition effect will be available at the time of the conference.

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ALPHA DECAY HALF LIVES FOR HEAVY AND SUPERHEAVY NUCLEI

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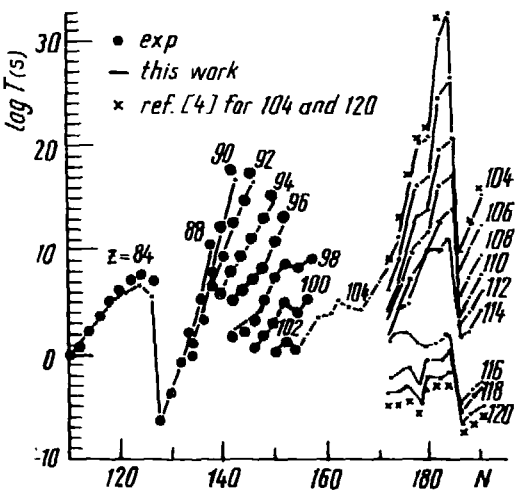
We suggested previously[1] that alpha decay is a fission process with mass and charge-density asymmetries, which are possible due to strong shell effects. In this way it was obtained good agreement of theoretical half-lives with experimental ones for 68 alpha emitters ranging from Z = 84 to 102. The purpose of this work is to extend the computations to the region of heavy and superheavy nuclei (Z = 104 - 120).

The macroscopic energy was computed in the framework of Myers-Swiatecki liquid drop model[2] extended to systems with different charge densities[3]. The Q-values used for correction energy were taken from ref.[4].

A zero point vibration energy of 0.4 MeV was used to compute the alpha half-lives. One can see on the figure, that nuclei with proton numbers Z in excess of 114, decay particularly faster. N is the number of neutrons.

For some isotopes of the elements 104, 106, and 108, we predict lower half lives than in ref.[4] but in general the present results are more optimistic (about an order of magnitude larger) for superheavies.

Although we can see very pronounced shell effects for even-even double magic daughter nuclei. When fission and beta decay modes are also taken into account, the nucleus ^{294}110 has the longest calculated total half life.



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ALPHA-DECAY : ASYMMETRIC SPONTANEOUS FISSION

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Spontaneous fission-character of α-decay first revealed in the picture of α-decay due to Basu[1]) and finally confirmed[2]) with Bohr-Wheeler fission theory perhaps lends a new direction and purpose to the study of α-decay phenomenon. Studies into this new aspect have been successfully carried out for even-even and even Z-odd N α-emitters. Present report is a comparative study of fission-character of odd Z-even N α-emitters in the light of B-W fission theory and the present theory of α-decay.

Log $T_{\frac{1}{2}}$(α-decay) vs. Z^2/A plot (fig.1) exhibits clearly fission-character of α-decay of the nuclei under study. In each of Bi and At series, while Z^2/A values in N>126 arm are lower than those in N≤126 arm, corresponding $T_{\frac{1}{2}}$ values in the former are also lower than those in the latter. This is anomalous being contrary to the true import of the fissility parameter increasing values of which should cause decreasing $T_{\frac{1}{2}}$ values of nuclei in the same series. This anomaly is obviously due to failure of Z^2/A to take into account

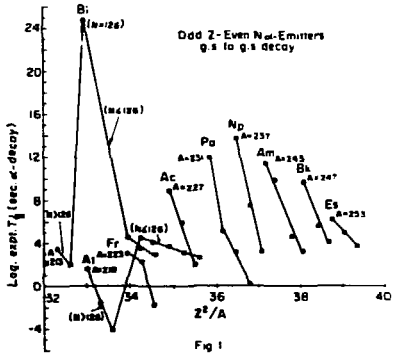


Fig 1

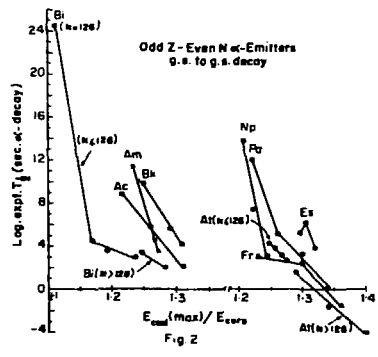


Fig. 2

two different structure-effects on either side of N=126 influencing α-decay process. Log $T_{\frac{1}{2}}$(α-decay) vs. $E_{coul}(max)/E_{core}$ (fissility parameter for α-decay in this theory) plot (fig.2) also shows fission-character of α-decay of these nuclei with the anomaly well explained. Clearly in this fig. lower $T_{\frac{1}{2}}$ values in N>126 arms are due to values of this ratio higher than those in N≤126 arms with higher $T_{\frac{1}{2}}$ values. This is in keeping with the advocated mechanism of α-decay[1]) that excess of coulomb repulsive energy $E_{coul}(max)$ emerging between transforming α-cluster and core over attractive core-interaction E_{core} is the cause of α-decay. This ratio unlike Z^2/A is evidently capable of taking into account right amount of E_{coul} (max) and E_{core} operative specifically in the α-decay mode of each nucleus. α-decay radius, daughter radius and daughter radius constant of these nuclei calculated in this picture lie in the ranges of 9.5-7.3 fm., 7.5-5.8 fm and 1.8-1.0 fm., respectively.

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A NEW THEORY OF ALPHA-DECAY

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Gamow theory of α-decay and its variants are constrained by its basic postulate of pre-existence of α-particles to consider α-formation and α-emission as two independent processes. But, as pointed out by Bethe and Frenkel soon after neutron discovery, an α-particle is formed out of two neutrons and two protons in the process of emission from the α-emitter. α-Formation and α-emission are, in other words, one and the same process.

This comment provides the motivation for an ab initio investigation into the fundamental intra-nuclear process of α-formation and α-emission without any assumption or approximation, whatsoever.

To evolve a picture of α-decay from the role of an α-cluster in the decay-process, a mass-relation[1] is derived to calculate the correct α-clustering energy (E^{α}_{Cl}) of and attractive core-interaction (E_{core}) on the last 2n-2p sub-system inside the nucleus.

Last 2n-2p sub-system in the low density surface-region is then demonstrated to be the constituents of the α-particle emitted by an α-emitter in its r.s. decay. As this sub-system in the cluster-state E^{α}_{Cl} is forced by its inherent tendency aided by the α-instability of the nucleus to switch over to a perfect α-particle (with binding energy $B(\alpha)$), the amount of evolved energy $=E^{\alpha}_{Cl}-B(\alpha)$ is found just equal to the top of the coulomb-barrier $E_{coul}(max)$. The nascent α-particle, therefore, finds itself atop the barrier and hence outside the daughter nucleus without tunneling. Though emitted from atop $E_{coul}(max)$, the α-particle has only the observed kinetic energy because of the background attractive E_{core}. α-formation and α-emission thus come out to be one and the same process. The condition $E^{\alpha}_{Cl}-B(\alpha) = E_{coul}(max)$ yields an expression for α-decay radius and also for α-pre-formation probability which give values of these two parameters in nice agreement with experimental data.

α-instability of the α-emitter is then identified with a preferential auto-coulomb excitation $E_{coul}(max)$ between the α-cluster and the core which, in competition with the attractive E_{core}, is demonstrated to be the cause of α-formation and α-emission. E_{core} obviously acts as a barrier to this process.

The picture of α-decay thus evolved has been detailed in ref.[2].

This picture, in short, reveals the following essential features. (1) An α-particle is constituted of last two neutrons and last two protons in the process of emission rather than pre-existing as a permanent entity inside the nucleus prior to emission. (2) α-emission takes place over the so-called coulomb-barrier rather than tunneling through it. (3) Coulomb repulsive energy emerging between the transforming α-cluster and virtual daughter is rather the cause of α-decay than a barrier to it. These features, in direct contradiction with Gamow theory, suggest that α-decay should be a case of spontaneous fission. It has, indeed, been demonstrated[3] with Bohr-Wheeler theory of fission that α-decay is a distinct case of highly asymmetric spontaneous fission.

The present report is intended to describe essential features of this new theory of α-decay vis-a-vis those of other existing models.

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In-Beam α-, γ-Spectroscopic Study on ^{214}Rn

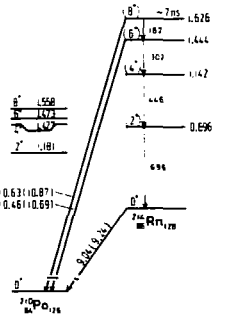
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Stimulated by the observation of α-particles deexciting 8^+ isomers in N=128 isotones, ^{216}Ra(ref. 1) and ^{212}Po(ref. 2), α- and γ-rays from excited states in ^{214}Rn have been studied using in-beam spectroscopic techniques.

An enriched target ^{208}Pb of ∿1 mg/cm^2 was irradiated with 79 MeV ^{12}C beam from the IPCR cyclotron. The discrete α- and γ-rays following the ^{208}Pb(^{12}C,αxn)$^{216-x}$Rn reaction were measured in coincidence with evaporated α-particles which were detected by a counter telescope of Si detectors (ΔE; 450 mm^2 x 50 μm, E; 450 mm^2 x 2000 μm). New α-lines of 10.46 ± 0.03 and 10.63 ± 0.03 MeV were observed and attributed to decays of the excited states in ^{214}Rn. Their intensities were obtained as 2.2 ± 0.5 and 4.3 ± 0.7, respectively, normalizing the intensity of known ground state α-decay in ^{214}Rn(9.04 MeV) to be 100. Four γ-rays of 182, 302, 446 and 696 keV were assigned to the (8^+)-(6^+)-(4^+)-(2^+)-0^+ cascade transitions in ^{214}Rn. A half-life of (8^+) state was determined to be 7.3 ± 1.5 nsec utilizing a delayed coincidence between the evaporated α-particles and these γ-rays. The resulted level scheme of ^{214}Rn is shown in figure where the α-energies in parentheses are those corrected for recoil and screening effects. Reduced α-decay widths (γ_α^2) calculated after Rasmussen's paper[3] and B(E2; 8→6) values for N=128 isotones are summarized in table.

	γ_α^2(keV)	B(E2;8→6) e^{2}fm^4
^{212}Po(ref. 2)	5.0 ± 1.2	630 ± 150
^{214}Rn	3.2 ± 0.6	322 ± 64
^{216}Ra(ref. 1)	0.48 ± 0.05	152 ± 17



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α-DECAY SYSTEMATICS IN THE LEAD REGION

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This report is part of a survey [1] of nuclear level properties in the lead region.

For even-mass Po, Rn, Ra, and Th isotopes, the probability of α-decay as a function of Eα consists of two separate branches for neutron numbers $N < 126$ and $N > 126$. The hindrance factors (HF) for other α-groups is defined relative to these 0^+ to 0^+ α-transitions. These hindrance factors exhibit remarkable regularities in the lead region.

In odd-mass nuclides in the mass range 191-213, HF for all the 50 known favored transitions are in the range 1.1-1.6 (except for four $p_{1/2}$ state decays, where the range is 1.4-2.2). The decay probability to other single-particle states is characteristic of each configuration. Data involving two or more nuclides are available for the α-decays of $\nu 3p_{1/2}$, $\nu 2f_{5/2}$, $\nu 2g_{9/2}$, and $\pi 1h_{9/2}$ configurations. For example, all four nuclides with a $g_{9/2} \rightarrow p_{1/2}$ decay (^{211}Po, ^{213}Rn, ^{215}Ra, and ^{217}Th) have HF = 100 within 10%-25% accuracy.

In odd-odd nuclides in the mass range 190-214, all 20 known favored transitions have HF-values in the range 1.5-5.0. α-groups connecting different shell-model configurations are known for the following states: $(\pi 1h_{9/2})(\nu 2g_{9/2})1^-,9^-$; $(\pi 1h_{9/2})(\nu 3p_{1/2})5^+$; and $(\pi 1h_{9/2})(\nu 2f_{5/2})5^+,6^+$. The strongest unfavored transition in each decay is usually a no spin-flip transition. In most cases, the L-values for such transitions are the same as for the corresponding odd-mass nuclides. In these cases, the HF-values are higher for the odd-odd nuclides by factors of 1-7 (for relatively pure configurations the range is 1-3). For example, the ^{212}At isomer $(\pi 1h_{9/2})(\nu 2g_{9/2})9^-$ α-group to ^{208}Bi $(\pi 1h_{9/2})(\nu 3p_{3/2})6^+$ has HF = 29, compared to HF = 17 ± 2 for the corresponding odd-mass $(2g_{9/2}) \rightarrow (3p_{3/2})$ α-decays.

With the onset of deformation for $A > 213$, the large difference between favored and hindered transitions diminishes. For each α-decay in this transition region, several α-groups with HF in the range 3-10 typically occur.

The longest lived nuclide in the lead region is the 3×10^6-y ^{210}Bi 9^- isomer. Both the proton and the neutron closed shells are crossed in this α-decay, resulting in HF-values of $\approx 10^5$.

The remarkable regularities of α-decay in the lead region enable us to make numerous predictions about half-lives, α-decay branchings, and α-group intensities to known levels in the daughter nuclei. These systematics can also be used for assigning spins and parities, and may provide a clue to the purity of the shell-model configurations.

The data pertaining to α-decay to more complex states, such as weak coupling multiplets, are rather sketchy, and no systematic features can be perceived to date.

†Research sponsored by the Division of Basic Sciences, US Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation.

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ALPHA RADIOACTIVE ISOTOPES PRODUCED IN INTERACTIONS OF 86 MeV/u ^{12}C ON MEDIUM AND HEAVY TARGETS

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Alpha radioactive nuclei were produced by reactions of various targets with 86 MeV/u ^{12}C from the CERN synchrocyclotron. The basic principle for product collection was the following : Recoil nuclei escaping from a solid target were rapidly (10^{-7} sec) thermalized in a gas (N_2). Experimentally it has been shown that even after thermalization at the end of their recoil paths these ions are not electricelly neutralized. One then takes advantage of this charge to collect them by an electric field on the surface of a solid state detector.

We have measured relative values for the cumulative yields of residual nuclei with α-branching ratios greater than 1 % and half-lives greater than 0.5 sec. In some cases independant and/or absolute yields could be obtained. For example, in Fig. 1, is shown the recoil range distributions for several nuclides (N=85) which are 25-30 nucleons lighter than the target. Their mean recoil energies are about 1/4 of the energy corresponding to total transfer of the linear momentum. Furthermore the recoil energies are rather different for these neighboring nuclei and increase with the number of lost nucleons.

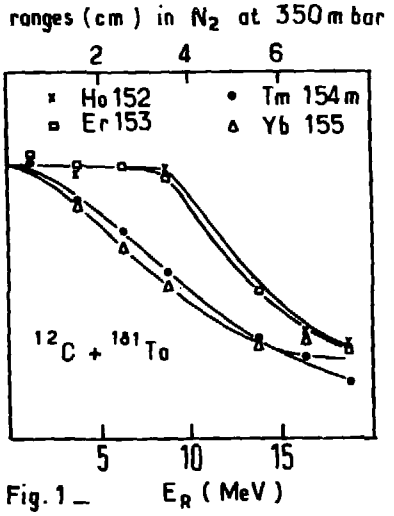


Fig. 1 _

Absolute cross sections have been measured for ^{151}Dy produced from targets of ^{nat}Sm, ^{181}Ta, ^{197}Au and ^{nat}Pb. In Fig. 2 we show the observed cross section as a function of the charge difference between target and product. It seems that 30-60 nucleons can be lost giving final products with very similar cross sections. Nevertheless, production is also observed for some nuclides with Z greater than that of the target. Their cross sections are in the range of 10-100 μb. This is the case for ^{149}Tb and ^{151}Dy produced from Sm or for $^{206-208}At$ from Pb. The recoil energies of these products of high Z are very small.

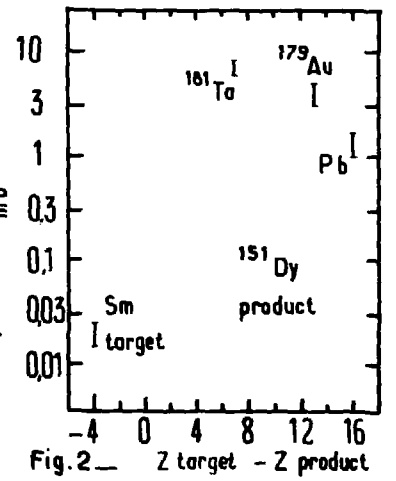


Fig. 2 _

This first view of heavy-ion reactions in this energy range indicates behavior closer to that for relativistic energies than for the heavily studied range of $\lesssim$ 10 MeV/u.

RELATIVE α-DECAY RATES IN THE Pb-REGION

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The Nuclear Field Theory (NFT) method was applied to the calculation of the spectrum and α-decay of nuclei in the Pb-region: ^{212}At, ^{212}Po, ^{212}Bi and ^{212}Rn. These nuclei with four nucleons outside the ^{208}Pb core were described as a two-boson system.

The amplitude of α-decay can be written in the form $\gamma_L = G_1 + G_2$, where $G_1 + G_2$ corresponds to different graphs contributing to the α-particle formation amplitude inside the nucleus. (See e.g. Fig. 1 for the α-decay of ^{212}At.) In the semiclassical approximation the α-decay constant is given by $\lambda_L = 2\gamma_L^2 \hbar^{-2} P_L$, where P_L is the Coulomb penetration factor. In our calculations of G_1 and G_2 all possible configuration mixings were automatically taken into account, changing substantially the previous shell-model calculations [1]. The radial dependence of γ_L and P_L is shown in figure 2 [transition ^{212}At(1^-) → ^{208}Bi(7^+) + α]. The tremendous dependence of γ_L on r is somewhat compensated by the corresponding dependence of P_L on r. The α-decay constant plotted as a function of R has a maximum around 7.5 - 8.0 fm.

The relative α-decay rates for different α-transitions in ^{212}At, ^{212}Po, ^{212}Bi and ^{212}Rn were calculated. The results are in reasonable agreement with experimental data.

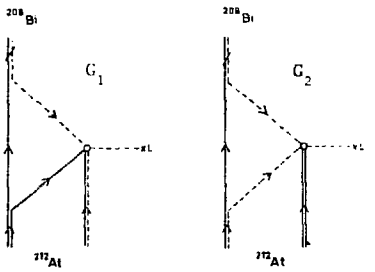


Fig. 1 Graphical representation of the amplitude of probability of α-decay. The α-particle is formed through (a) neutron-proton correlations (states in ^{210}Bi), proton-proton correlations (states in ^{210}Po). Full lines - protons, dashed lines - neutrons.

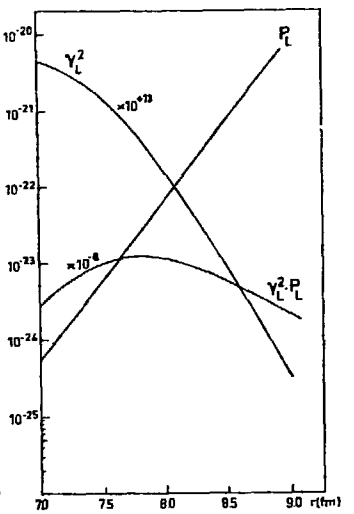


Fig. 2

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THE Z2 DEPENDENCE IN DSAM AT LOW ION RECOIL VELOCITY

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There is a considerable amount of experimental data showing the effect of the so called Z_2-oscillations of the nuclear lifetimes measured by DSAM, in the velocity region $v/c \sim 1\%$, where the electronic stopping is dominant. For lower recoil velocities $v/c \sim 0.1\%$, where the nuclear collisions are the dominant mechanism of the ion energy loss, the studies are not so abundant.

This work presents part of a series of DSA measurements on ^{28}Si ions, with an initial velocity $v=0.14\%c$, recoiling into six different backing materials. Thin targets ($\lesssim 4\mu g/cm^2$) of ^{27}Al evaporated onto these backings were used. The 4.62 MeV state of ^{28}Si, populated by the $E_p=767$ KeV $^{27}Al(p,\gamma)$ resonance, was chosen for this study. The lifetime values were derived from the analysis of the 2.84Mev γ-ray to the 1st excited state recorded at 0° with an Ortec 110cc Ge(Li) detector and an energy scale of about 0.45 Kev/channel.

Using the Monte Carlo technique [1], the classical LSS potential with the Bohr radius, and the Wilson, Haggmark and Biersack (WHB) potencial[2] correponding to the "average screening function" were considered for the nuclear stopping. The electronic contribution is small and the LSS estimate was assumed correct.

The results in the table show that both potentials predict a lifetime smaller than the adopted value, (63±3) fs, which is an average of DSA measurements[3]. Although the extracted value of the lifetime generally decreases with increasing Z_2, the departure from a smooth dependence is just statistically significant. Detailed measurements on intermediate backings are required to establish the genuine character of these "oscillations".

Table 1. DSAM Lifetime results (fs) for the ^{28}Si 4.62 Mev level, obtained with different stopping materials

Backing (Z_2)	C (6)	Al (13)	Cu (29)	Zr (40)	Ta (73)	U (92)
LSS potential	49±3	45±3	36±3	51±3	46±3	31±3
WHB potential	57±4	60±3	46±3	55±3	52±3	39±4

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LEVEL STRUCTURE OF ^{182}W+

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The ^{182}W nucleus lies in the strongly deformed region of the transitional nuclei. A large number of level structure studies have been done[1-3] in order to verify experimentally the theoretical predictions for the nucleus based on various nuclear models. Since there exists a large number of inconsistancies regarding the intensities of various gamma transitions in the level scheme of ^{182}W as well as the directional correlation measurements on various cascades in ^{182}W, the present study for this nucleus has been undertaken from the β^-decay of ^{182}Ta.

The relative intensities of 33 gamma transitions in the decay of ^{182}Ta have been precisely measured (error 2% for intense gamma rays) using 64.1 cc Ge(Li) detector. The weak gamma transitions of energy 110.4, 351.05 and 1180.7 keV have been confirmed from coincidence measurements using Ge(Li)-NaI (Tl) fast-slow coincidence set-up (2τ=6nsec)[4].

The gamma-gamma directional correlation measurements have been carried out on 11 cascades using a 64.1 cc Ge(Li)-3"x3" NaI(Tl) detector fast-slow coincidence set-up described above. The 1181-229 and 116-1257 keV cascades have been done for the first time. Based on these measurements, spin 2^+ has been assigned to 1510 keV level in ^{182}W. The multipole admixtures in 10 gamma transitions have been found as given in the following table:

Transition energy(keV)	Multipole admixture	Transition energy(keV)	Multipole admixture
116	E1+(1.0±0.5) % M2	264	M1+(95.75±3.75)%E2
152	E1+(2.5$\pm^{3.0}_{2.0}$) % M2	1113	E2
156	E1+(0.4±0.4) % M2	1121	M1+(99± $\frac{1}{9}$) % E2
179	M1+(61.5±5.5)% E2	1181	M1+(80.0±6.5)% E2
222	E1+(0.25±0.25)%M2	1231	M1+(88.5$\pm^{2.0}_{5.0}$)% E2

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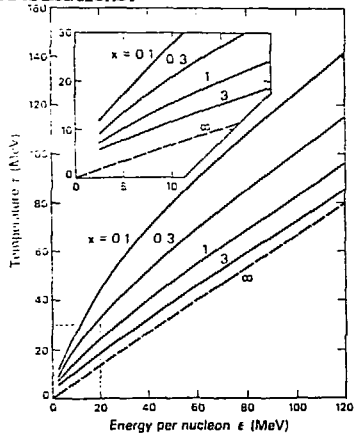
+ Work supported by National Bureau of Standards, Washington D.C., U.S.A.,

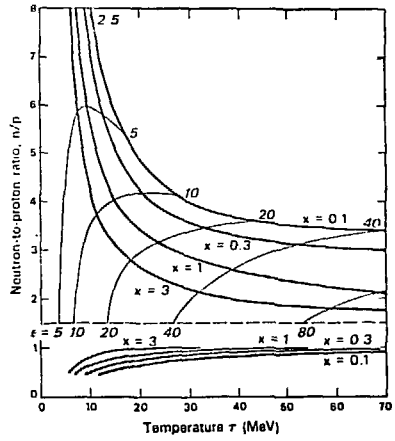
STATISTICAL MODEL FOR INTERMEDIATE-ENERGY NUCLEAR COLLISIONS*

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We have developed a statistical model for multi-fragment final states in nuclear collisions with bombarding energies E/A < 200 MeV. A portion of the system formed with energy per nucleon ε and isospin polarization I = (N-Z)/A is assumed to decay according to the available non-relativistic phase-space. The conservation of energy, nucleon number, and charge is most conveniently imposed by considering the grand canonical ensemble and introducing appropriate Lagrange multipliers. This results in a "fragment gas" at nuclear density ρ_0/χ, where $\rho_0 = 0.17$ fm^{-3} is the nucleon density of ordinary nuclei and χ is a parameter of order unity. The ground and all known particle-stable excited states of fragments with A $\leq$ 16 are included explicitly in the internal fragment partition functions, while those for A > 16 are approximated in a Fermi-gas model. For given values of ε, I, and χ, we calculate the temperature and the fragment mass and charge distributions.





The figures show some instructive results: the temperature τ for a given ε (fig. 1) is always greater than that of free nucleons ($=2/3\varepsilon$) because composite fragments effectively eliminate some translational degrees of freedom. The ratio of produced free neutrons to free protons (fig. 2) increases dramatically with I, since all light composite fragments have N $\approx$ Z.

Although our model has no dynamical assumptions, it can nevertheless correlate and predict many experimental observables in terms of only 3 parameters (ε, I, and χ), which can be determined from experiment. Any dynamical mechanisms which may be invoked to explain intermediate energy collisions can therefore be judged against these "background" predictions.

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**Alfred P. Sloan Foundation Fellow, supported in part by the NSF, Grants [PHY76-83685, PHY77-21602].

MOMENTUM PROJECTION METHODS IN NUCLEUS-NUCLEUS SCATTERING

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Until recently, microscopic calculations in nucleus-nucleus scattering were mainly based on generator-coordinate or equivalent methods which depended crucially on the factorization of the center-of-mass motion in the individual cluster states. Since, in general, this factorization property is only valid for OSM ground states, calculations with these methods were restricted to the elastic scattering of two fragments in their ground states, or at best to direct reactions between channels of this type, and more complex inelastic processes (e.g. particle hole excitations in one of the fragments) could not be treated. To overcome these difficulties we have suggested that channel states be constructed via momentum-projection techniques [1]. If $C_n^+(0,\vec{k})$ is a creation operator for a nuclear (ground or excited) state, displaced by $\vec{k}$ in momentum space, and if $\Pi_{\vec{k}}$ is the projection operator onto sharp momentum $\vec{k}$, then the state

$$D_n^+(\vec{k})\,|0\rangle = \Pi_{\vec{k}} \cdot C_n^+(0,\vec{k})\,|0\rangle$$

respects both translational and Galilean invariance [2]. Hence the two cluster channel state $D^+_{1,n_1}(\vec{k}) \cdot D^+_{2,n_2}(-\vec{k})\,|0\rangle$ has the typical resonating-group form with asymptotic relative momentum $\vec{k}$. If the unprojected fragment states $C^+_{i,n_i}|0\rangle$ are chosen as Slater determinants, the two-cluster states are still superpositions of Slater determinants and hence Wick's theorem can be applied in calculating energy and norm kernels, irrespective of whether or not c.m. motion factorizes in the intrinsic states. Although the technicalities are slightly more complicated than with the generator-coordinate methods, the approach nevertheless appears to be superior to formulations using the Peierls-Yoccoz double projection technique, at least for practical calculations of nucleus-nucleus scattering.

We have applied this method to calculate transition kernels between the elastic α-α-channel and channels with one 1p-1h excited α particle. Hamiltonian kernels of this type - which cannot be calculated in the usual generator-coordinate or resonating-group methods - have been used to compute a microscopic effective potential, including absorption, for α-α scattering [3].

Also, compound states and channels with more than two clusters can be described naturally with these momentum-projection techniques. The method should therefore open the possibility of describing microscopically several classes of inelastic processes in nucleus-nucleus scattering that were inaccessible until now to a genuine microscopic treatment.

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TWO-PARTICLE TRANSFER REACTION AND THE PARTICLE-NUMBER-CONSERVATION (PNC) APPROACH OF PAIRING CORRELATION

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Two-particle transfer reaction is a sensitive tool for studying pairing correlation in nuclei. Recently, the cross-sections of (t,p) and (p,t) reactions on even tungsten isotopes were analyzed in detail by Betts and Mortensen (Ref.1). They indicated some remarkable inconsistencies between the experimental data and the pair rotation (PR) or pair vibration (PV) modes.

However, from the point of view of the PNC approach, the PR and PV modes are two extreme cases (Ref.2,3). The quantum number labelling a PR band is not a good one, while the anharmonic effect in the PV model is very large. In this work, the PNC approach is used to account for the gross features of the two-particle transfer reactions. The calculated results are shown in the table.

It is seen that, the variation of the calculated branching ratio is consistent with that of the experimental values. Especially, for (t,p) reactions, the anomalous increase of $^{180}W(t,p)^{182}W$ has been reproduced correctly. This is due to the single particle energy gap at N=108. There is an exceptation in the case of $^{186}W(p,t)^{184}W$, the estimated branching ratio is too small. In fact, the spins of the g.s. in $^{185,187}W$ are both $[512]3/2^-$, which illustrates that the single particle levels intersect at N≃112, but in the present paper the single particle levels are fixed for all even tungsten isotopes.

Table. Branching ratio of the two-particle transfer reactions to the first excited 0^+ states and the g.s. of even W nuclei.

Daughter nucleus	(p,t) reaction		(t,p) reaction	
	Cal.[a]	Exp.[b]	Cal.[a]	Exp.[b]
^{176}W	0.09	0.09	0.03	
^{180}W	0.18	0.09	0.05	
^{182}W	0.10	0.15	0.2	0.5
^{184}W	0.0002	0.08	0.0006	0.01
^{186}W	0.000002		0.00001	<0.007

a) The single particle levels are taken from Ref.1, Fig.2d ($\varepsilon=0.2$). The strength of the pair correlation $G=0.55/A$. The truncated energy used in the diagonalization of the Hamiltonian is taken to be $11\hbar\omega_0$. The transition matrix elements that a pair of neutrons removed from or added to the different Nilsson orbits are assumed to be a constant.

b) Ref.1.

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A DYNAMICAL MODEL FOR FAST FISSION PHENOMENA AND CHARGE EQUILIBRATION

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Recently two interesting experimental developments have been done in heavy ion physics at bombarding energies smaller than 10 MeV/A :

1. Experiments on medium systems (like for instance the Ar + Ho system[1]) have shown indications about an intermediate mechanism between deep inelastic and compound nucleus formation[1]). This phenomenon seems to be strongly correlated with the disappearance of the effective barrier against fission due to angular momentum. The properties of the fast fission fragments are identical to those resulting from the fission of the compound nucleus except for one point : the FWHM of their mass distribution is different and, at least for the studied cases, is larger than the one of the fission fragments. A simple model has been introduced which allows to qualitatively understand such changes[2]).

2. The charge equilibration degree of freedom which is connected to the correlation between the neutrons and the protons in the deep inelastic fragments has been shown to be a very fast mode[3]). The FWHM of the isobaric distributions seems to indicate, for some cases, the existence of quantum fluctuations[4]).

We have developed a dynamical dissipative collective model which treats explicitly the relative motion of the two ions, the mass asymmetry and the charge equilibration degrees of freedom. The statistical fluctuations of the collective degrees together with their mean values are taken into account according to the Hofmann Siemens theory using a Fokker Planck equation in phase space[5]). As far as charge equilibration is concerned, because quantum effects are in some cases important, a quantum master equation is used[6]). Furthermore it is assumed that during the collision there is a gradual transition between a sudden interaction potential (which governs the entrance channel) and a phenomenological adiabatic potential (which governs the exit channel). This leads to interesting features concerning the energy loss which becomes in good agreement with the experimental one. In addition to the usual properties of deep inelastic reactions, this model is able to calculate the evolution of the isobaric distributions as a function of the energy loss. Furthermore the cross-section for fast fission phenomena, together with an evaluation of the FWHM of the corresponding mass distribution can be done.

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NUCLEAR SCATTERING AND FREDHOLM DETERMINANTS IN THE COMPLEX k PLANE[+]

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A nonlocal potential provides a method of presenting the physics of a many-body situation in the context of a two particle interaction. For this reason, nonlocal potentials necessarily arise when discussing nucleon-nucleus scattering. A nonlocal potential is also required for including effects of antisymmetrization, for describing compound elastic scattering, or for investigating other aspects of scattering in which more than two particles enter into the dynamics of the interaction. The theory of nonlocal potentials underlies the structure of many of the standard calculations of nuclear theory. It is, for example, particularly relevant to resonating group calculations. In these calculations emphasis is placed upon effects of antisymmetrization and the extra nodes in the relative (scattering) wavefunction which are necessary to produce the orthogonality required by Pauli exclusion of filled states.

Because a nonlocal potential casts the many-body problem into a two-body formalism, a nonlocal potential can usually be replaced by an energy dependent equivalent local potential[1]. The fact that such a potential may exhibit a fairly small energy dependence accounts for the successes of local potential models in a large number of many-body circumstances. However, resonances such as compound nuclear resonances are more narrow than allowed by a short-range attractive local potential[2]. Reproducing such resonances with an equivalent local potential requires that potential to be rapidly varying.

For these reasons, in this work we discuss an analysis of the phenomenology possible to a nonlocal potential with an eye to the relationship between this phenomenology and a microscopic picture of nucleon-nucleus interactions. The strikingly different behavior possible to nonlocal potentials can be traced to the structure of the Fredholm determinants associated with integral equations for scattering by a nonlocal potential. The Fredholm determinants referred to are $D^+(k)$, the determinant for the integral equation for the physical solution, and $D(k)$, the determinant for the integral equation for the regular solution[3].

For a local potential, $D^+(k)$ contains the scattering information, while $D(k)$ is unity. For a nonlocal potential $D(k)$ is a function of the wavenumber. If for a nonlocal potential these determinants exhibit behavior in the complex plane similar to that of $D^+(k)$ and $D(k)$ for local potentials, then replacement of the nonlocal potential by an equivalent local potential becomes feasible. On the other hand, extra nodes, continuum bound states and spurious states are possible only when nonlocality is present. The behavior in the complex k plane of $D^+(k)$ and $D(k)$ necessary for the existence of such effects is quite different from that displayed by a local potential.

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ON THE COUPLED-REACTION-CHANNEL METHODS

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Coupled-reaction-channel (CRC) equations in integral form can be directly derived from the set of Lippmann-Schwinger (LS) equations labelled by two-cluster partitions b, which provides a unique solution to the N-body scattering problem [1]. Let $\Psi^+_{\alpha i} = \delta_{b\alpha}\Phi_{\alpha i} + G_b V^b \Psi^+_{\alpha i}$ be the set of two-cluster labelled LS equations, with $\Psi^+_{\alpha i}$ the total scattering state, $\Phi_{\alpha i}$ the incoming state, G_b and V^b the two-cluster partition resolvents and residual interactions, respectively. Inserting the usual CRC expansion $\Psi^+_{\alpha i} = \sum_{c,k} X^+_{\alpha i,ck}\psi_{ck}$ for $\Psi^+_{\alpha i}$ (where ψ_{ck} describes the intrinsic states of the fragments in the channel ck), we get the CRC equations

$$X^+_{\alpha i,bj} = \delta_{bj,\alpha i}\varphi_{\alpha i} + g_{bj}\sum_{c,k}\langle\psi_{bj}|V^b|\psi_{ck}X^+_{\alpha i,ck}\rangle - \sum_{c,k}\langle\psi_{bj}|\psi_{ck}X^+_{\alpha i,ck}\rangle\bar{\delta}_{cb} \qquad (1)$$

with $\varphi_{\alpha i}$ the relative motion part of $\Phi_{\alpha i}$, g_{bj} the channel effective propagator coming from the action of G_b on ψ_{bj}; the braket $\langle\ |\ \rangle$ denotes internal coordinate integrations with the channel radius $\vec{r}_b$ being kept fixed. Of course eqs. (1) can be interpreted as equations with distorted quantities, because the LS starting point still holds (and preserves the same structure) in the distorted-wave formalism [2].

Since, as usual in the CRC method, the same expansion has been inserted into each LS equation, non-orthogonality terms appear. Once the LS equations are transformed according to modern N-body procedures and as many expansions are introduced as the two-cluster partitions are, we are left with CRC equations without any non-orthogonality term (compare with refs [3,4]). Each unknown labelled by a two-cluster partition b has to be expanded into the relevant intrinsic states ψ_{bj}. Thus combining exact few-body treatments with the CRC technique we get in integral form

$$\chi^{+F}_{\alpha i,bj} = \delta_{bj,\alpha i}\varphi_{\alpha i} + g_{bj}\sum_{c\neq a}\sum_{k}\langle\psi_{bj}|V_b|\psi_{ck}\chi^{+F}_{\alpha i,ck}\rangle \qquad (2)$$

$$\chi^{+KLT}_{\alpha i,(b)j} = \delta_{bj,\alpha i}\varphi_{\alpha i} + g_{bj}\sum_{k}\langle\psi_{bj}|V^b|\psi_{b'k}\chi^{+KLT}_{\alpha i,(b')k}\rangle \qquad (3)$$

$$\chi^{+S}_{\alpha i,(\beta)j} = \delta_{bj,\alpha i}\varphi_{\alpha i} + g_{bj}\sum_{\tau}\sum_{k}\langle\psi_{bj}|\mathcal{V}_{\beta\tau}|\psi_{ck}\chi^{+S}_{\alpha i,(\tau)k}\rangle \qquad (4)$$

when we start from the three-body Faddeev equations, the Kouri-Levin-Tobocman equations (with the channel permuting array choice) and the N-body Sandhas equations (with artificial indices in the unknowns), respectively. Here $\chi^+_{\alpha i,\eta j} = \langle\psi_{bj}|\Psi^+_{\eta,\alpha i}\rangle$ with $\eta = b,(b),(\beta)$; V_b is the interaction internal to b; b' is the partition which immediately follows or precedes b in a given sequence of the two-cluster partitions; β denotes a chain of partitions obtained by sequential fragmentation and $\mathcal{V}_{\beta\tau}$ are N-body exchange potentials [5].

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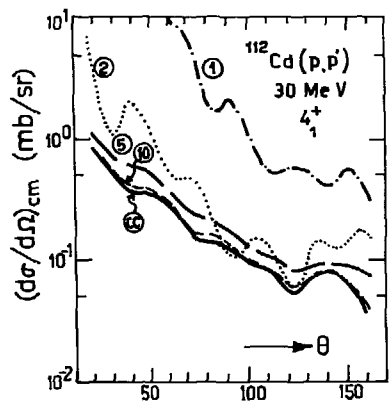
A METHOD TO APPROXIMATE COUPLED CHANNELS

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We consider two approximations to simplify the coupled channel problem for scattering: a) the adiabatic or energy-sudden (ES) approximation, based on the neglect of internal energy differences, b) the centrifugal-sudden (CS) approximation, based on the neglect of differences between centrifugal potentials for coupled channels. In the combined ES+CS approximation, for instance, the original set of coupled equations is completely decoupled in a suitable representation. An actual calculation of the vibrational excitation of ^{112}Cd by 30 MeV protons (curve1) shows, however, a considerable deviation relative to the CC curve. The discrepancies for the ES approximation alone are often much smaller.

Such discrepancies led us to look for a method for finding corrections to the approximations. Consider the ES approximation from the classical point of view: if the internal motion of the scatterer is not slow enough to permit it to be considered as "frozen" during the entire collision, it may still be slow enough to permit frozen internal coordinates for shorter time intervals. Inspired by this observation, in the stationary description of quantum scattering we correspondingly subdivide the r-axis in a number of limited radial intervals. Within each interval we apply the ES and/or CS approximation. At the interval boundaries we transform the solution as follows. For each of the channels we define a pair of ES/CS basis waves in the interaction region, leaving out the coupling. We determine the matrix transforming the coefficients of these waves from one side of an interval to the other, using the ES/CS approximation including coupling. This matrix is then taken over in the exact case, but to transform the coefficients of "exact" basis waves. The latter are assumed to take into account properly the amplitude and phase changes due to "diagonal" propagation within the channels.



Calculations in a simple two-channel model [1]) have shown promising results. In the accompanying figure we show realistic results for a 4^+ two-phonon level, indicated with the various numbers of intervals. The results converge to the CC curve, as is to be expected. The computation time for this preliminary, unoptimized calculation, roughly proportional to the number of intervals, is a factor of 3 to 4 lower than for a conventional CC calculation.

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SEARCH FOR ANALOGUE RESONANCES IN ^{57}Co (II)

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Gamma-ray angular distribution and resonance strength measurements have been carried out on resonances in the reaction ^{56}Fe(P,γ)^{57}Co in the energy region Ep $\simeq$ 1400 - 1650 keV. The J^{π} values have been determined as 3/2 for the resonances at Ep = 1599, 1623, 1643 and 1649 keV. The resonances at Ep = 1623, 1643 and 1649 keV have been identified as the split analogue resonances of the 367 keV (J^{π} = 3/2) state in ^{57}Fe.

The resonance strengths have been determined for twelve resonances and the results are (Ep(keV); $\omega\gamma$) = (1403; 0.30), (1408; 0.42), (1416; 0.39), (1453; 0.43), (1460; 0.38), (1466; 0.40), (1525; 0.60), (1557; 0.42), (1599; 0.88), (1623; 1.33), (1643; 1.12) and (1649; 2.30).

Gamma-ray branching ratios of the split analogue and excitation energies for some low-lying states in ^{57}Co are also given. The M1 transition strengths to the corresponding antianalogue states have been measured and compared with theoretical predictions.

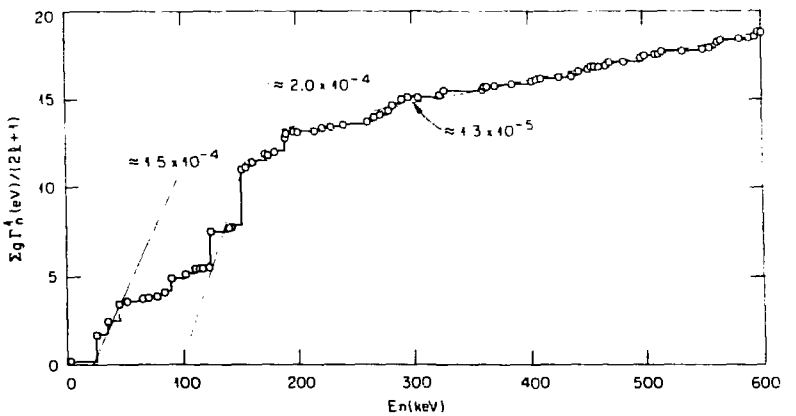
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[++]This work was supported by a grant from the Atomic Energy Control Board of Canada.

COMPARISON OF s-, p- AND d-WAVE NEUTRON STRENGTH FUNCTIONS FOR ^{206}Pb + n REACTION WITH OPTICAL MODEL CALCULATIONS*

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The 200-m flight path at the Oak Ridge Electron Linear Accelerator (ORELA) has been used to make high resolution neutron transmission and differential scattering measurements on ^{206}Pb. The s-, p- and d-wave neutron strength functions in the neutron energy interval of 25-600 keV show considerable microstructure, some of which have been interpreted in terms of doorway states arising from particle-core excitations.[1] Analyses of the data have been extended up to E_n = 900 keV. It appears as though the fluctuations in the strength functions tend to dampen with increasing energy of excitation (see figure).



The data have been analyzed using R-matrix codes which employed a boundary radius of 8.0 fm. Optical model calculations are being performed in a manner consistent with the data analyses. We are investigating whether a given set of optical model parameters can be found which will simultaneously reproduce the average values of the measured strength functions and potential phase shifts for s-, p- and d-waves.

Preliminary calculations indicate that this might not be possible. Parameters which give good agreement with the measured strength functions and phase shifts for s- and d-waves do not seem to do so for p-waves. This question is being pursued and the results will be discussed.

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NUCLEAR "TIME-DELAY" AND X-RAY-PROTON COINCIDENCES NEAR A NUCLEAR SCATTERING RESONANCE*

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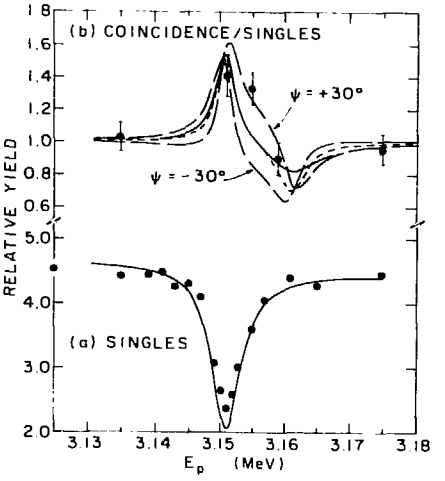
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We have observed the changing probability for production of K-shell x rays by protons elastically scattered from ^{58}Ni, as the incident proton energy is varied over the s nuclear resonance at 3.151 MeV[1]. In a time-dependent description, this change results from a nuclear "time delay" τ that causes the amplitude for excitation of an electron "on the way in" to be advanced in time relative to the amplitude "on the way out" by the factor $\exp(-i\omega\tau)$, where $\hbar\omega$ is the energy transferred to the electron. In a time-independent description, the time delay is manifested by the energy variation of the nuclear reaction amplitudes $f(\theta,E)$. The cross section for scattering a nuclear particle having incident c.m. energy E to angle θ, in coincidence with producing a K-shell x ray, is given by

$$\frac{d\sigma_{coinc}}{d\Omega} = 2\omega_K \sum_{l,m} \int_0^{\infty} d\varepsilon \left| A(\varepsilon,l,m) f(\theta,E-\hbar\omega) + B(\varepsilon,l,m) f(\theta,E) \right|^2 \quad .$$

where ω_K is the fluorescence yield, A and B are semiclassical amplitudes ("way in" and "way out", respectively) for exciting an electron into the continuum with final kinetic energy ε, orbital angular momentum l, and projection m. The cross section thus contains products of interfering nuclear amplitudes with differing projectile energies.

Protons were scattered from a 9 $\mu g/cm^2$ ^{58}Ni target on a carbon backing at 45° and were detected in a solid-state detector subtending 95±18°. X rays were detected by a Na(Tl) crystal placed at 90°. The proton singles excitation function is shown in part (a) of the figure. In part (b) is shown the ratio of the proton yield in coincidence with K x rays to the singles proton yield, normalized to unity off resonance. Because the width of this particular resonance (5.6 keV) is comparable to the electron energy transfer (> 8.3 keV), the interference effect is maximized. The short-dashed and long-dashed curves are derived from a "zero-order" calculation, in which only the monopole (l=0) term is considered, and the electron energy transfer is taken to be 10 keV. The coincidence to singles ratio then depends only on $R \equiv ImB/ReB$. The data support a value for R of about +0.6. The solid curve is the result of a more detailed calculation, involving semiclassical expressions for the monopole amplitudes; lack of agreement suggests that the imaginary parts of these amplitudes may not be given adequately by the standard theory.



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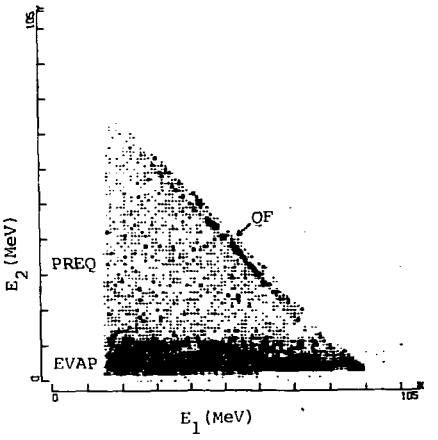
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COINCIDENCE STUDIES OF NUCLEON-NUCLEON INTERACTIONS IN THE NUCLEUS ^{58}Ni*

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The continuous (p,p') spectra resulting from 90 and 100 MeV protons on ^{58}Ni[1]) exhibit large yields of high energy protons at forward angles with a very broad peak at an energy consistent with scattering from a bound target nucleon. In order to study the role of the nucleon-nucleon interaction more fully in proton induced reactions we have performed a series of particle-particle coincidence measurements. Two triple-counter telescopes operated in coincidence were used to detect particles over a wide energy range. The figure shows a typical E_1 vs. E_2 plot for $\theta_1 = 35°$ and $\theta_2 = -48°$ in which only the high energy portion of E_1 is included. Three regions of events are labeled on the figure: the quasi-free scattering (QF) event, the pre-equilibrium (PREQ) event, and the "evaporation" (EVAP) event. Our results indicate that a major portion of the high-energy protons in the continuum is in coincidence with evaporation particles (both p and α). This result also holds true for angle pairs which were chosen to enhance the QF (p,2p) event. With one telescope fixed at either 15° or 35°, the angular correlation functions for QF and PREQ events peak near the beam direction, while that of the EVAP events is isotropic. Our results suggest that the initial nucleon-nucleon interaction between the incident proton with one of the target nucleons dominates the interaction and that this QF process acts as a doorway to more complicated states, i.e., one of the nucleons escapes the nucleus after the interaction, while the other nucleon suffers further interactions dissipating its remaining energy to other nucleons in the nucleus. The multiplicities of the evaporated protons and α's have also been measured by detecting two evaporation particles in coincidence and were found to be ∿2.5 and ∿0.5, respectively. With the inclusion of an estimate of the neutron evaporation based on calculations, the total evaporated particle multiplicity (including n, p and α) is ∿4-5. This is also consistent with the quasi-free doorway channel assumption, i.e., the incoming proton loses, on the average, half of its incident energy (∿50 MeV), leaving the target nucleus with ∿50 MeV of excitation energy. The target nucleus de-excites by evaporating particles.



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A THEORY OF (D,P) REACTIONS WITH DEUTERON BREAKUP†

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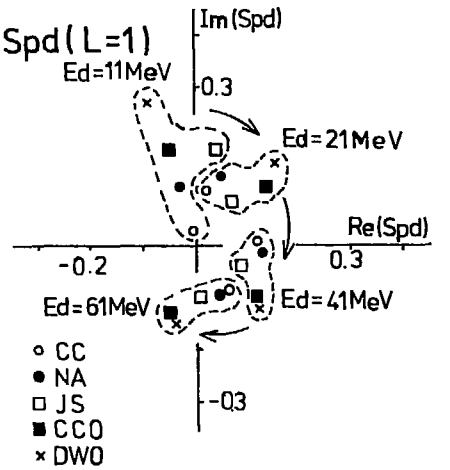
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The coupled channel variational method (CCVM) of Ref. [1]) was used to investigate the effect of the breakup of the deuteron in (d,p) and the associated (d,d) and (p,p) reactions in a three-body model of a proton, p, and a neutron, n, interacting with each other and with an innert target nucleus, A.

Coupled were the d- and p channels and the "channels" of the 10 discretized excited states of the deuteron which, together with the ground state, were prepared by the diagonalization of the hamiltonian of the n-p system in a space of a properly chosen set of 11 Gaussian functions. The energies of the deuteron states range up to 346 MeV. The radial wave function of relative motion in each channel was expanded in harmonic oscillator functions up to a certain radius outside the region of interaction and joined smoothly onto a Coulomb wave function satisfying a proper boundary condition. The expansion coefficients were varied in the Kohn-Hulthen-Kato type variational principle. The interaction potentials were assumed to be (a) the optical potentials at appropriate energies for A and p or n in the continuum, (b) a real Woods-Saxon potential for A and the bound n and (c) a Gaussian potential which fits the low energy p-n data for p and n.

Examples of the result are given in Fig. 1 which shows the calculated S-matrix element for $^{16}O(d,p)^{17}O(2s)$ for the total angular momentum L=1 at 11, 21, 41 and 61 MeV under various assumptions which are designated as follows. CC:full CCVM calculations with 12 coupled channels. NA: CC except the coupling of the p channel assumed weak. JS: NA with all the deuteron states assumed degenerate at the ground state, a simulation of the adiabatic model of Johnson and Soper[2]). CCO: only the d- and p channels were coupled to each other. DWO: CCO with the coupling assumed weak. All the weak couplings were treated as first order perturbation.

One readily sees that the effect of the deuteron breakup states is important, while the coupling of the p channel is much less so at high energies. The adiabatic model is good at 61 MeV, not so at 11 MeV and is always better than DWO. There are many other interesting features in these and other S-matrix elements.



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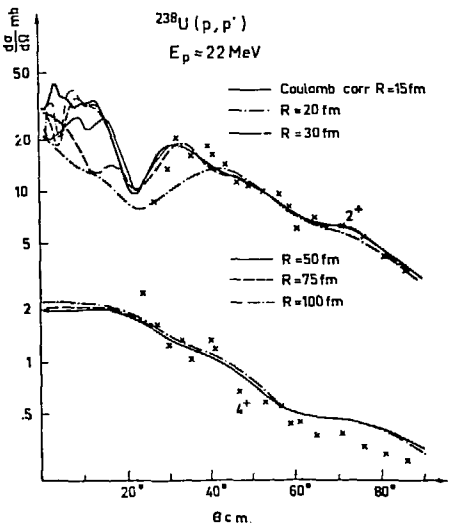
COULOMB EFFECTS IN PROTON INELASTIC SCATTERING ON HEAVY TARGET

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Coupled channel calculations of proton inelastic scattering are used to extract nuclear deformations. Usually, coulomb effects are not too important. However, for heavy targets and when the energy of the excited state is small, coulomb effects are large ; then, problems are the same as those encountered in heavy ion inelastic scattering : many partial waves and large integration range of coupled equations. A computation of DWBA Coulomb integrals from the matching point to infinity has been introduced[1] in the codes ECIS78/ECIS79, which allows the use of nuclear matching point in inelastic heavy ion scattering.

The inelastic scattering of 22 MeV protons on ^{238}U with the excitation of the $2^+,4^+,6^+$ has been studied without these Coulomb corrections[2] and a matching radius at 30 fm. Results of such calculations, including $0^+,2^+,4^+$ with no spin-orbit deformation and with matching radius 20, 30,50,75 and 100fm are shown on the figure.



The plain curve is obtained with Coulomb corrections at 15fm ; it agrees with the conventional 100fm results above 10°. This shows that a matching point of 30fm was enough in this case, due to the angular range of experimental data, but is too small to describe scattering to smaller angles.

The 4^+ forward cross-section decreases when the matching radius increases without Coulomb corrections.

With Coulomb corrections at 15fm, it is underestimated by 2% but correct with a matching radius at 20fm.

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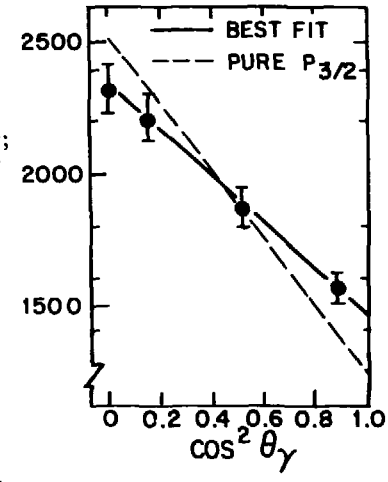
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USE OF INTERFERENCE EFFECTS IN ANGULAR CORRELATIONS TO MEASURE SMALL AMPLITUDES IN SINGLE-NUCLEON TRANSFER REACTIONS†

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We have used an angular correlation technique to study the interference between $p_{1/2}$ and $p_{3/2}$ pickup in the reaction $^{13}C(^3He,\alpha)^{12}C$ leading to the $E_x \approx 15.1$ MeV 1^+ level. This transition is dominated by $p_{3/2}$ transfer; the shell model calculations of Cohen and Kurath predict 260 for the ratio of the $p_{3/2}$ to $p_{1/2}$ spectroscopic factors[1]. The method used in the present work is not new[2], but has seldom been applied at bombarding energies where a direct reaction mechanism is expected to be dominant. Experimentally, we have measured the particle-γ angular correlation for the above reaction at bombarding energies of 24 and 25.5 MeV. Alpha particles were detected at zero degrees by a magnetic spectrometer; coincident gamma rays were detected by an array of four NaI(Tl) crystals. The experimental angular correlations, corrected for the finite angular acceptance of both the particle and gamma-ray detectors, were compared with the predictions of DWBA calculations using optical model potentials taken from the literature. In these calculations the ratio of the $p_{1/2}$ and $p_{3/2}$ amplitudes was treated as a free parameter. The fits were found to be insensitive to the parameters of the DWBA calculations as long as the calculated differential cross sections were required to be in agreement with experiment at forward angles. The results of independent measurements at the two bombarding energies agreed with each other within errors. The average experimental ratio between the $p_{1/2}$ and $p_{3/2}$ amplitudes is -0.086 ± 0.030. The best fit at a bombarding energy of 25.5 MeV is shown in the Figure, along with the prediction for pure $p_{3/2}$ transfer. The prediction of Cohen and Kurath for this ratio is -0.061, in good agreement with the experimental value. Note that the sign is unambiguously determined from the experiment.



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FIRST EXCITED 0^+-STATES IN THE GERMANIUM ISOTOPES VIA THE Se(d,^{6}Li) REACTION

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A complete and reliable description in terms of any single model is still lacking for nuclei in the Ge-Se region despite recent experimental information obtained from γ-ray spectroscopy and transfer reactions[1]. Particular attention has been paid to the lowest excited 0^+-states in the Ge isotopes whose energy varies strongly with neutron number N and which becomes the first excited level in ^{72}Ge. These 0^+-states have been tentatively explained as being either pure neutron or pure proton configuration states, but shape transitions between N=40 and N=42 have also been invoked to account for the (t,p) and (p,t) reaction data leading to these states[2].

We report on a study of the Se(d,^{6}Li)Ge reaction on all stable, even-A Se isotopes from ^{74}Se to ^{82}Se at a beam-energy of 45 MeV. Reaction products were momentum analysed and identified with the QMG/2 magnetic spectrograph and its focal plane detection system. Differential cross sections have been measured in the angular range from 6 to 32 degrees. They are well reproduced by zero-range DWBA calculations.

The present results are very similar to the (p,t) data leading to the same final nuclei, i.e. the first excited 0^+-state is strongly excited in ^{70}Ge (25% of the g.s. strength) and in ^{72}Ge (30%), whereas only upper limits <5% can be given for the other residual Ge nuclei. In the (t,p) reaction on the even-A germanium isotopes in contrast the first excited 0^+-state in ^{72}Ge is only weakly excited and it is strong in ^{76}Ge[2]. This feature led to the suggestion of a shape transition in germanium.

We tried to account for our findings with a model which describes successfully a large amount of data, including the (p,t) results for ^{72}Ge and neighbouring nuclei[1]. The first excited 0^+-state in the Ge isotopes is assumed to be a pure proton excitation of the form $\beta_A(p_{3/2})^4_0 - \alpha\ (p_{3/2})^2_0\ (f_{5/2})^2_0$. This configuration is then orthogonal to the ground state. The neutron configuration is the same for both states.

With a $\delta_A(p_{3/2})^4_0(f_{5/2})^2_0+\gamma_A(p_{3/2})^2_0(f_{5/2})^4_0$ proton configuration for the ground state of the Se target nuclei, and with an intrinsic cross section ratio $\sigma((p_{3/2})^2_0)\ /\ \sigma((f_{5/2})^2_0) = 10$, the strong population of the excited 0^+-state in ^{72}Ge and the absence of significant strength to the same state in heavier Ge isotopes are reproduced. To explain also the strong population of the excited 0^+-state in ^{70}Ge, a different configuration has to be assumed for the ^{74}Se target nucleus. It involves fewer $f_{5/2}$ protons and suggests the occurence of the same phase transition between N=40 and N=42 that was proposed for the germanium isotopes.

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STATISTICAL ANALYSIS OF THE ENERGY LEVEL WIDTHS*

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Characteristic nuclear level withs determined from various nuclear reaction for nuclei with $24<A<108$ have been compared with a microscopic theory which includes the nuclear pairing interaction. Sincle particle levels of Nilsson et al. and Seeger et al. have been used in the calculations. The gross features of the experimental data due to nuclear shells are reproduced with the microscopic theory. The agreement between experiment and calculated level widths obtained from this statistical analysis is good considering the uncertainties in the experimental data, the theoretical single-particle levels and the pairing energy. In addition, the general trend of $\ell n\Gamma$ versus $(A.E^*)^{\frac{1}{2}}$ agree with the semi-emperical result reported previously[1)]

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VECTOR AND TENSOR ANALYZING POWERS OF THE CONTINUUM SPECTRA

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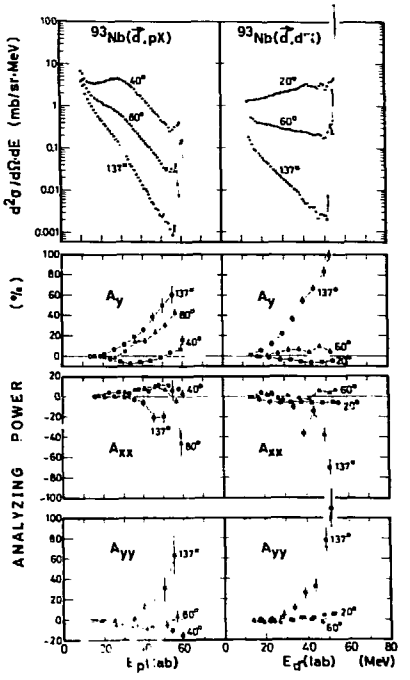
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Vector and tensor analyzing powers of the continuum energy spectra for ^{93}Nb, ^{209}Bi($\vec{d}$,d'X) and ($\vec{d}$,pX) reactions at $E_{\vec{d}}$=56MeV have been measured, for the first time, over the angular range from 20° to 137° and the energy range from ∿12 MeV to maximum energy which is kinematically allowed. The polarized deuteron beam was provided by the RCNP AVF cyclotron at Osaka University. The figure shows the energy spectra, the vector analyzing power A_y and the tensor analyzing powers A_{xx} and A_{yy} at various angles for the ^{93}Nb($\vec{d}$,d'X) and ($\vec{d}$,pX) reactions. The A_y, A_{xx} and A_{yy} for the ^{209}Bi target are in general similar for the ^{93}Nb target.

At forward angle where the pre-equilibrium process dominates, the A_y, A_{xx} and A_{yy} are small but not zero for almost all energy range. At 137° where the spectrum shape resembles to that of a evaporation spectrum, they are large in magnitude. At the lower energy end where the equilibrium process dominates, they are generally consistant with zero. These features on A_y are also observed in the reaction induced by 65 MeV polarized protons. Thus these A_y data indicate the importance of the spin dependent interaction in the understanding of the continuum spectra and also the importance of the direct reaction process at backward angle as well as forward angle.

While a theretical interpretation on the tensor analyzing power is still open, the present results seem to give a new information concerning the tensor force or the deuteron shape effect.



ANALYZING POWERS OF THE CONTINUUM SPECTRA

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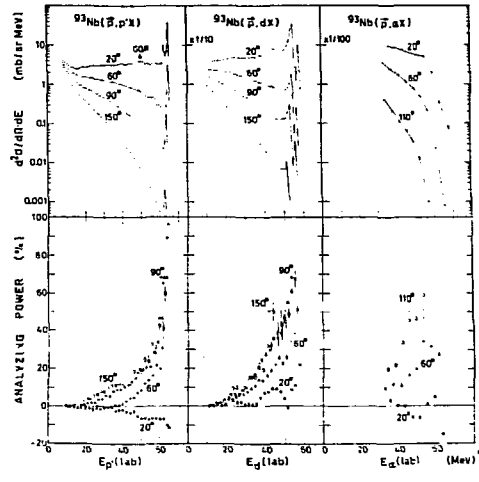
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We have measured the analyzing powers A_y of the continuum spectra for 65 MeV protons from ^{12}C, ^{28}Si, ^{45}Sc, ^{58}Ni, ^{93}Nb, ^{165}Ho, ^{166}Er and $^{209}Bi(\vec{p}, p'X)$ and $(\vec{p}, dX)$ reactions and from ^{93}Nb and $^{209}Bi(\vec{p}, X)$ reactions. The polarized proton beam was provided by the RCNP AVF cyclotron. Contiuum spectra were measured at laboratory angles from 20° to 150°. The figure shows the $d^2\sigma/d\Omega \cdot dE$ and A_y for $^{93}Nb(\vec{p}, p'X)$, $(\vec{p}, dX)$ and $(\vec{p}, \alpha X)$ reactions.

The prominebt features are;
(1) The A_y of the continuum spectra were found to be small at forward angles where the pre-equilibrium process is important. However there is no systematic tendency on A_y This fact indicates the importance of the spin-dependent interaction as well as the nuclear structure effect. (2) On the other hand the A_y were very large and positive at backward angles where the shape of the energy spectra resembles to that of an evaporation spectrum. (3) The maximum values of the A_y in the backward hemishere depnd on the target mass for the A < 45 mass region and they are as large as 15%, 20% and 35% for $^{93}Nb(\vec{p}, p'X)$, $(\vec{p}, dX)$ and (p, X) reactions at E_x = 20 MeV, respectively.

(4) These large values are mainly due to the entrance channel effect. This conclusion is based on the fact that the (p, αX) reaction has a large A_y values. The backward data suggest that the direct reaction process is very important and constitutes a large fraction of the continuum spectrum even at backward an (5) There is no appreci- al /en-odd mass effect on the A_y for medium mass nuclei. These features were unexpected from the conventional pre-equilibrium reaction models.



FORMULA FOR p-NUCLEUS POLARIZATION

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Proton-nucleus elastic and inelastic scattering (and polarization) are dominated by the simplest features of the nuclear geometry - a radius (c) and diffusivity (β). By exploiting this dominance, the elastic polarization may be calculated in terms of the experimental elastic cross section and the fundamental spin orbit to central amplitude ratio (w). This data-to-data relation, derived in Ref. 1, is

$$P(q) = 2q\ D(q)/(1 + q^2 D(q)^2) \quad , \qquad (1)$$

where

$$D(q) = \mathrm{Re}w - \frac{1}{2}\ \mathrm{Im}\ w\ \frac{e^{-2\pi\beta\delta q}\sigma(q-\delta q) - e^{2\pi\beta\delta q}\sigma(q+\delta q)}{\sigma(q)} \quad ,$$

q is the momentum transfer, and $\delta q = \pi/4c$. This result depends on approximating the fundamental NN amplitude by $T_{NN} = A(q) + C(q)\vec{\sigma}\cdot\hat{n} \simeq A(q)(1 + wq\ \vec{\sigma}\cdot\hat{n})$ which is valid for nuclear scattering applications when the central and spin orbit nuclear force ranges are short compared to the nuclear radius. Equation (1) has been applied to p-nucleus elastic scattering over a wide energy range with considerable success.

The data-to-data relation is more general however and could just as well be applied with inelastic cross sections to yield inelastic polarization. In Fig. 1 the measured inelastic analyzing powers of the 2^+ (1.408 MeV) and 3^- (4.782 MeV) excitations of ^{54}Fe for 800 MeV protons are compared with the prediction of Eq. (1) using the appropriate inelastic cross sections.[2] As has already been shown for inelastic cross sections which can likewise be simply related to elastic cross section,[1] it appears that inelastic polarizations also are controlled by the most general features of nuclear shape.

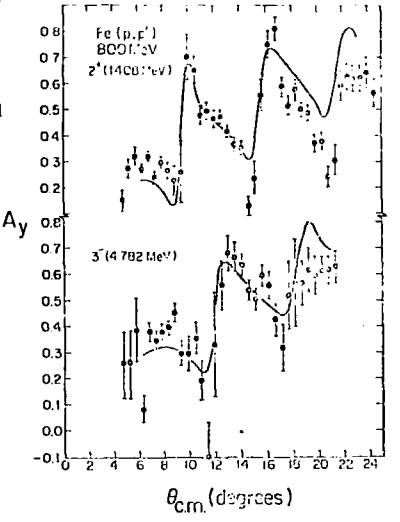


Figure 1

[+]Supported in part by the U. S. National Science Foundation.

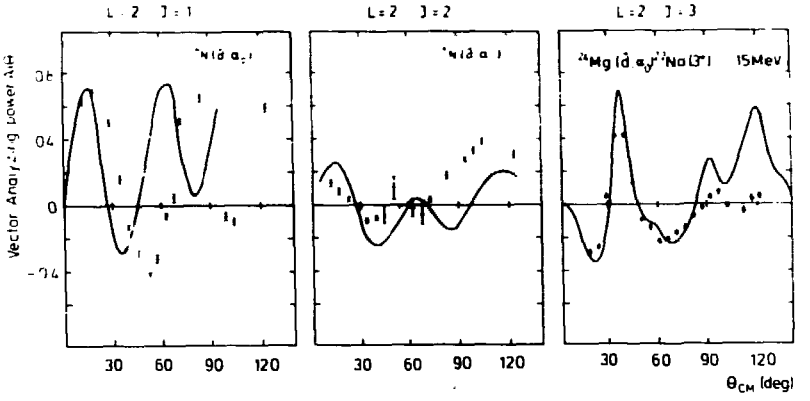
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INVESTIGATION OF $(\vec{d},\alpha)$-REACTIONS ON ^{14}N, ^{24}Mg, AND ^{27}Al WITH VECTOR- AND TENSORPOLARIZED DEUTERONS*

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The investigation of $(\vec{d},\alpha)$-reactions is an useful spectroscopic tool for the study of the levels in the residual nucleus. We have measured $(\vec{d},\alpha)$-reactions on the target nuclei ^{14}N, ^{24}Mg, and ^{27}Al with vector-polarized deuterons at E_d=10 MeV (^{14}N) and E_d=15 MeV (^{24}Mg, ^{27}Al), respectively. The tensor analyzing powers T_{20}, T_{21}, T_{22} have been determined for the $^{24}Mg(\vec{d},\alpha)^{22}Na$ reaction. Most analyzing powers show very pronounced structures, which are mainly determined by the transferred L and J of the neutron-proton pair. The observables are compared with DWBA and coupled channels calculations which allow a rather clear information about the transferred angular momenta. As an example for the J-effect in the vector analyzing power (VAP) at forward angles the figure shows three L=2 transfers with J = 1, 2, and 3. The VAP for J = L ± 1 exhibit large values of opposite sign whereas it is very small for J = L.



The tensor analyzing powers T_{20} are all positive for $\theta \to 0°$ for the natural parity states and negative for the unnatural parity states thus allowing a model independent parity asignment. All tensor analyzing powers are only badly described by the conventional DWBA thus indicating the influence of the D-state of deuteron and α-particle.

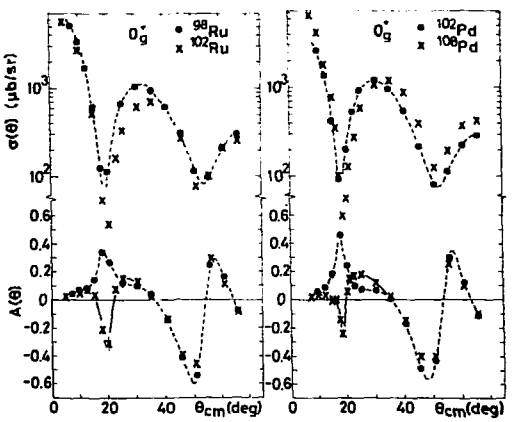
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NUCLEAR-STRUCTURE DEPENDENCE OF ANOMALOUS ANALYZING POWERS FOR (p,t) TRANSITIONS BETWEEN SUPERCONDUCTING NUCLEI

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Recently strong ground-state (p,t) transitions in nuclei of neutron number N=50-82 have been found to show anomalous analyzing powers which cannot be reproduced by direct one-step DWBA calculations at all[1]. In this work, measurements of the analyzing powers $A(\theta)$ for ground-state (p,t) transitions by using 22.0-MeV polarized protons have been extended to cover 17 nuclei of N=50-82 including four isotopes of Pd[A(final)=108,106,104,102] and three isotopes of Ru[102,100,98]. These isotopes have been investigated because the neutron $2s_{1/2}$ orbit is located near the Fermi surface and also because the largest quadrupole deformation among the nuclei of N=50-82 is observed in these isotopes. The most striking results are shown in the figure. A positive peak of the $A(\theta)$ around $\theta \approx 20°$ in ^{98}Ru(^{102}Pd) changes to a sharp negative dip in ^{102}Ru(^{108}Pd). On the other hand, all the corresponding cross sections $\sigma(\theta)$ have a deep minimum around $\theta \approx 20°$ and do not show such a drastic change. All of the $A(\theta)$ around $\theta \approx 20°$ are not reproduced in terms of the one-step DWBA while the angular shape of the corresponding $\sigma(\theta)$ is reproduced well. Then (p,d)(d,t) two-step processes are taken into account. The BCS wave functions are employed for the ground states and one-quasiparticle states are assumed to the intermediate states in the (p,d)(d,t) processes[1]. In consequence not only the $A(\theta)$ but also the absolute values of the $\sigma(\theta)$ are reproduced quite well. The anomalies in the $A(\theta)$ around $\theta \approx 20°$ are accounted for as an interference between the (p,d)(d,t) and the direct one-step processes. The variation of the $A(\theta)$ around $\theta \approx 20°$ is ascribed to (i) the variation of the dominant one-quasiparticle neutron orbits in the intermediate states of the (p,d)(d,t) processes and (ii) that of the imaginary part $W_S(d)$ of the deuteron distorting potential in the intermediate states. The $W_S(d)$ depends linearly on the deformation parameter β_2. The (p,d)(d,t) processes are as strong as the one-step process. This is a great surprise because (p,t) transitions between superconducting nuclei have been considered so far to proceed via a direct two-neutron pickup owing to the strong pairing interaction. The above-mentioned discovery is achieved by using the characteristic of analyzing powers which are much more sensitive to the nature of interference between transition amplitudes than the cross sections.



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ANALYSIS OF INELASTIC SCATTERING OF 25.25 MeV POLARIZED PROTONS FROM ^{28}Si WITH DIFFERENT DEFORMATION PARAMETERS FOR THE VARIOUS POTENTIALS OF THE DEFORMED COLLECTIVE OPTICAL MODEL POTENTIAL

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Analyzing powers and cross sections for elastic and inelastic scattering of 25.25 MeV polarized protons from ^{28}Si have been analyzed in the coupled-channels (CC) collective model using the full Thomas deformed spin-orbit term. In the CC calculations with the rotational model using the code ECIS 79[1]) the 0^+(g.s.), 2^+(E_x = 1.78 MeV) and 4^+(E_x = 4.61 MeV) states in ^{28}Si were coupled together. The optical model parameters used in the CC calculations were taken from ref.[2]) (setA) which gave a very good fit to the elastic cross section and analyzing power data. In this analysis, if the deformation parameters are kept to be the same for all potentials, β_2 = -0.40 and β_4 = 0.15, it was found that the magnitude of the analyzing power as well as that of the cross section for the 4^+ state are not well reproduced[2]). We therefore varied for each state the ratios β_I/β_{real}, β_{LS}/β_{real} and β_C/β_{real}, where β_I, β_{LS}, β_C and β_{real} are respectively the deformation parameters for the surface imaginary, spin-orbit, Coulomb and real central potentials of the deformed optical potential. Improved fits were then obtained mainly for the 4^+ state, and the results obtained are shown in Table 1.

TABLE 1
Ratios of deformation parameters (β_{real}=-0.40 for 2^+ and 0.15 for 4^+)

β_I/β_{real}	β_{LS}/β_{real}	β_C/β_{real}	$\chi^2_{\sigma_{gs}}$	$\chi^2_{p_{gs}}$	$\chi^2_{\sigma_{2^+}}$	$\chi^2_{p_{2^+}}$	$\chi^2_{\sigma_{4^+}}$	$\chi^2_{p_{4^+}}$	χ^2_{tot}
1.	1.	1.	1651	332	1520	674	1412	943	6535
1.26(2^+)	0.67(2^+)	0.71(2^+)	1743	290	1326	851	676	244	5132
0.79(4^+)	2.50(4^+)	0.67(4^+)							

We conclude that better agreement with the data is obtained by using different deformation parameters for the various potentials of the deformed optical potential.

To insure whether this is just a question of parametrization or that interrelations between the different deformation parameters really exist and are required, as was recently suggested[3]), this question has still to be investigated.

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SYMMETRICAL NUCLEAR STRUCTURAL MODELS FOR FISSIONABLE NUCLEI

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Symmetric binary fission being more common than teriary fission, we will be dealing mainly with the former. The fission phenomena has been analysed by the incompressible liquid drop and droplet models and by considering the differential of the energies of the whole nucleus and its primary two halves, correcting for asymmetry. By either methods the value of the Bohr-wheeler constant, Z/A,is identical. In magic numbers nuclei, however, the phenomenon is adequately explained by the Shell model.

The fission nuclear phenomena has been dealt with theoretically in terms of neutron cross-sections for fissile and non-fissile isotopes. For instance the neutron cross section of U^{235} is much larger than for the non-fissile isotope U^{238}. This has been confirmed experimentally, the ratio of neutron cross sections of U^{235} and U^{238} being 6.315 approximately.

Viewing from nuclear structural angle, the phenomenon of binary fission, requires good explanation for why the neutron cross-section of the fissile nucleus is larger at all. The phenomenon has to be understood in terms of nuclear structural difference. A pragmatic evaluation has to be made of nuclear structure itself. Even though, the picture may emerge at any one instant, we have to take into account a dynamic system of nucleons inside the nucleus.

We may take the Single Particle - Shell mixed modality. We cannot escape the conclusion that the nuclear forces are saturated in character, their range in the lighter normal nuclei being 1.2×10^{-13} cm. In a dynamic system, with the nucleons being in their respective Shells, within the zone of the spatial nuclear range, not more than four nucleons can accomodate themselves. Therefore, at any particular instant, these should form a conglomerate with $\frac{n(n-1)}{2}$ interactions. The fifth particle as an adjunct to this conglomerate in the exceptional Optical model does not count for drawing generalised conclusions.

One of the crucial tests of this combinational dynamical picture on the mixed modality would be its ability to yield a correct value of the binding energy per nucleon, -B/A, as nearly 8.5 MeV. Actually, when the six forces are computed, two exchange forces and four uni-directional change forces, the value of -B/A, hitherto evading a successful solution, yields the correct value.

This research profounds that the arrangement of nucleons in the fissile nuclei is symmetric whilst that in the non-fissile isotope is un-symmetric. The symmetric configuration facilitate the initial binary breaking of the fissile nucleus. Thus U^{235} nucleus would consist of a symmetric arrangement, viz 23 configurations of n,p; n,p on the sides of the ellipsoid and 35 n,n; n,n configurations in the middle with a trio of n-n-n in their respective shell positions, at any instant. This can be tested experimentally by scattering experiments, where the fissile nuclei would behave as at least two charge-centred bodies as against the non-fissile isotope being a single charge-centred body. Confirmations of this would be very interesting.

TOTAL KINETIC ENERGIES OF FISSION FRAGMENTS, TERNARY FISSION AND NEUTRON PRODUCTION FOLLOWING PROTON BOMBARDMENT OF ^{232}Th AND ^{235,236,238}U†)

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Masses and total kinetic energies of fission fragments induced by (p,pf) and (p,αf) reactions on ^{232}Th and ^{236,238}U have been measured at 13 and 26.5 MeV incident energy using semiconductor detector telescopes and a position sensitive ΔE,E ionization chamber. The total kinetic energies observed in (p,pf) on ^{232}Th and ^{236,238}U exhibit quite different slopes with excitation energy similar to observations in (α,αf) by the Groningen-Bonn collaboration[1]. The (p,αf) reaction is used to obtain values of the fission barriers for ^{229}Ac and ^{233,235}Pa with an unexpectedly small value for ^{229}Ac with about 6.9 MeV. At lower α-energies the ternary fission process seems to be important even at fission angles very close to the α-recoil axis.

Neutron emission at 0° and 90° with respect to the fission fragment direction has been measured for ^{235,237,238}U and several proton energies. Separation into pre- and postfission contributions shows that the minimum of the postfission neutron multiplicity near A ≈ 132 rapidly vanishes with increasing excitation energy. The average kinetic energies $\langle \epsilon_n^{cms} \rangle$ for postfission neutrons from p + ^{235,236,238}U essentially differ for the heavy fragment only (Fig.2). The same applies to the comparison of p + ^{238}U at different projectile energies, indicating that most of the increased excitation energy is transferred to the heavy fragment.

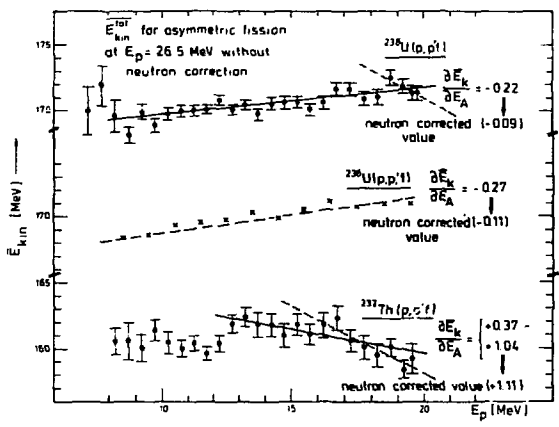


Fig. 1

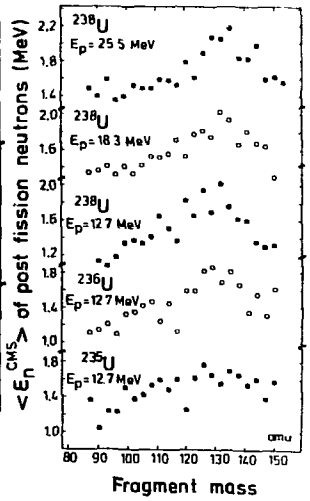


Fig. 2

†) Supported by the Bundesministerium für Forschung und Technologie

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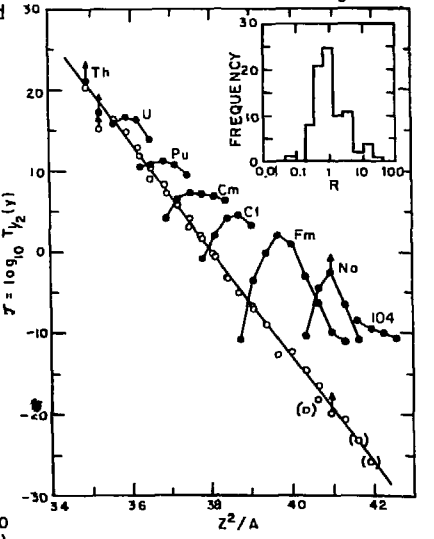
THE DROPLET MODEL AND A SYSTEMATIC STUDY OF SPONTANEOUS FISSION HALF-LIVES FOR THE EVEN-EVEN NUCLEI†

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Several attempts were made in order to correlate the spontaneous fission half-lives of nuclei, $T_{1/2}$, with simple nuclear parameters such as the mass number A, the neutron number A-Z, Z^2/A, and the fissility parameter[1,2]. Swiatecki[3]) has shown that the deviations from a smooth trend of $\tau=\log_{10} T_{1/2}$ vs Z^2/A could be explained by the deviations δM of the ground-state masses from a reference liquid drop model mass formula. We followed the Swiatecki's analysis as a guide to perform a similar systematics of spontaneous fission half-lives for the even-even nuclei of $Z \geq 90$. In the present analysis, however, we take δM as the difference between the calculated mass according to the Droplet Model of nuclei by Myers and Swiatecki and the experimental mass. The values of δM (in MeV) are those reported by Myers[4]).

The peculiarities of a plot of τ_e vs δM have suggested us a formula of the type $\tau=a-b\theta+c\theta\delta M$, $\theta=Z^2/A-d$, as a possible way to fit well the measured τ_e. A least-squares treatment with data rejection (taking ~80 values of τ_e from literature) resulted in $a=30.48\pm0.07$, $b=6.55\pm0.01$, $c=1.35\pm0.01$, and $d=33.39\pm0.01$. In the figure the "corrected" half-lives $\tau_e-c\theta\delta M$ (open circles) are seen to be fairly well distributed around the straight line $\tau_S=a-b\theta$. Points in parentheses refer to those nuclei for which experimental masses were taken from the 1977 Atomic Mass Table by Wapstra and Bos. Filled circles represent experimental half-lives. The goodness of this fitting procedure can be inferred from the distribution of the ratio R of calculated to experimental half-lives (inserted figure).



As conclusion, we point out that although the quantity δM defined in the present systematics includes semiempirical shell corrections to the ground-state nuclear masses (cf. Swiatecki[3])) its remaining fluctuations are still strongly correlated with the spontaneous fission half-lives when these latter are analysed in terms of Z^2/A.

†This work was supported by the Brazilian Conselho Nacional de Desenvolvimento Científico e Tecnológico-CNPq.

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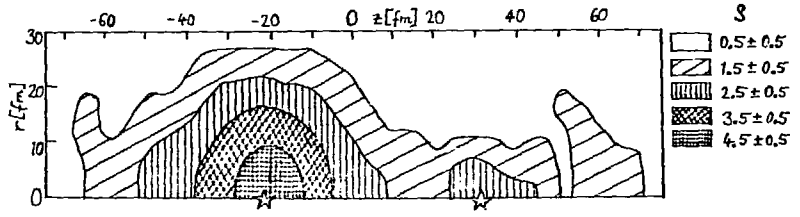
THEORETICAL STUDY OF FISSION DYNAMICS BY MUON-INDUCED FISSION

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If a target material is irradiated with a μ^- beam, some of the muons are captured into high-lying atomic states ($n \approx 14$) from where they cascade down to the 1s ground state of the atom by emitting characteristic x-rays or by radiationless transitions (Auger electrons, nuclear excitation). In the actinides, the maximum transition energies exceed both the neutron separation energy and fission barrier height so that prompt neutron emission or fission becomes possible. In a fission event, the muon will be ionized or remain at one of the fragments from where it decays by weak interaction resulting in delayed neutron emission. From a measurement of the delayed neutrons in coincidence with fission, one can deduce the probability P_H that the muon stays at the heavier fission fragment. Recent experiments by Schröder et al.[1] yield $P_H > 0.9$ for $_{93}$Np and $_{94}$Pu isotopes. The probability P_H, as well as the excitation energy of the muon, are expected to depend upon the fission dynamics.

In our theoretical model the fission mode is treated classically in terms of an elongation and a mass asymmetry coordinate, utilizing different friction coefficients. We solve the time-dependent Schrödinger equation for the μ^- wavefunction during fission of a $^{240}_{94}$Pu nucleus in a 2d spatial grid assuming symmetry around the Z-axis. The figure shows a contour plot (arbi-



trary units) of the muon position probability density for a separation s = 53 fm between the fission fragments; the center of each fragment is indicated by a star. We find an observable dependence[2] of the muonic final state upon the friction coefficient and the fragment mass asymmetry A_H/A_L which will be discussed in detail.

*Research sponsored by the Division of Basic Energy Sciences, U.S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation.

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EFFECT OF A PROTON SCATTERING RESONANCE ON THE TARGET K X-RAY PRODUCTION PROBABILITY*

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Blair et al.[1]) have demonstrated that the probability of Ni K x-ray production by protons elastically scattered from ^{58}Ni changes as the proton energy is varied across the $s_{\frac{1}{2}}$ nuclear resonance at 3.151 MeV (lab.). They show that this experiment determines the phase of the monopole Ni K-shell ionization amplitude on the way into the collision. They find a discrepancy with the results of the standard semiclassical approximation[2]) calculation for the monopole amplitude. In order to see whether this is a general phenomenon, we are determining the target K x-ray production probability by protons elastically scattered from various nuclei (^{88}Sr, ^{112}Cd, ^{54}Fe) in the neighborhood of pronounced proton resonances. So far we have shown that for the 5.056-MeV proton resonance in ^{88}Sr there is a variation of the Sr K x-ray production probability across the resonance, but the effect is not yet clearly outside of statistical uncertainties. Additional results will be reported at the Conference and a comparison with theory will be presented.

*Work supported in part by the National Science Foundation.
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††Recipient of Swiss National Science Foundation Fellowship (1979-80).
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STUDY OF BARYONIC (Δ++,2n) AND DIBARYONIC (T=1) COMPONENTS IN ^{3}He.

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Using the proton beam at T_p=925 MeV from the Saturne 2 synchrotron and the SPESI facility, both (p,t) and (p,d) transfer reactions have been studied with a liquid ^{3}He target. In both experiments missing mass spectra were recorded.

In the first one ^{3}He(p,d)X, tritons were detected at the following lab. angles : 6°, 10°, 14°, 22° and 40°. At each angle, the missing mass spectrum exhibits a hump around $M_X \sim 1232$ MeV superposed on a continuum corresponding to the inclusive reaction X=p+π^+. The forward triton emission corresponds to backward Δ++ emission, therefore the probability to see the contribution of ^{3}He baryonic component (Δ++,2n) is enhanced. The cross sections at the three smallest angles agree with previous measurements[1]). The increasing shape of the cross sections for $\theta^{lab}_{\Delta^{++}}$ less than 100° (θ^{lab}_t>22°), corresponds probably to other processes. Calculations, done by H.J.Weber[2]), are in progress.

In the reaction ^{3}He(p,d)X', deuterons were detected at the following lab. angles : 6°, 10° and 40°, with the aim to search for possible dibaryonic component $\mathcal{D}$(T=1) in ^{3}He (θ^d_{lab}=6°,10°) or to study the production of a such dibaryon in the final state (θ^d_{lab}=40°). In the last case, for a $M_{\mathcal{D}}$=2150 MeV, $\theta^{\mathcal{D}}_{lab}$=54°. The present missing mass experiment is particularly convenient to find narrow resonances and the data which were analysed so far in a very preliminary stage seem not to show (within the limits of a very small cross section) any resonance at $M_{X'}$=2020 or 2060 MeV as theoretically predicted[3]). At 6° and 10°, we have studied the $M_{\mathcal{D}}$ ranging from 1900 and 2120 MeV, and at 40° from $M_{\mathcal{D}}$=2100 until 2280 MeV. Final data will be presented and discussed.

*On leave of Rutgers University, U.S.A.

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THE MICROSCOPIC CALCULATION OF THE SPECIAL DISTORTION EFFECTS IN d+ ^{3}He ELASTIC SCATTERING

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The resonanting group mothod (RGM) is an effective mothod describing the clustering phenomena in light nuclei[1]. The purpose of the present paper is to study the influence of the special distortion effects on the differential cross sections of elastic scattering in d+ He system with channel spins $\frac{1}{2}$ and $\frac{3}{2}$. We did the calculations at 8.64 Mev , 10 Mev and 13.84 Mev c.m.energies. We took the following antisymmetic wave function with single channel approximation

$$\Psi_N(\vec{r}_1,\vec{r}_2,\cdots,\vec{r}_5)=\mathcal{A}[\phi_3(\vec{r}_1,\vec{r}_2,\vec{r}_3)\phi_d(\vec{r}_4,\vec{r}_5)\}(\sigma,\tau)F_3(\vec{r})+\sum_{i=1}^{N}\sum_{l=0}^{\infty}\widetilde{B}_{li}\widetilde{\Psi}_{li} \qquad (1)$$

where the second term represents the influence of the special distortion of deuterium in the system. In eq(1),

$$\phi_3(\vec{r}_1,\vec{r}_2,\vec{r}_3)=e^{-\frac{1}{2}\gamma\sum_{j=1}^{3}(\vec{r}_j-\vec{R}_3)^2} \qquad (2)\ ,\quad \phi_d(\vec{r}_4,\vec{r}_5)=\sum_{i=1}^{3}A_i e^{-\frac{1}{2}\alpha_i\sum_{j=4}^{5}(\vec{r}_j-\vec{R}_d)^2} \qquad (3)$$

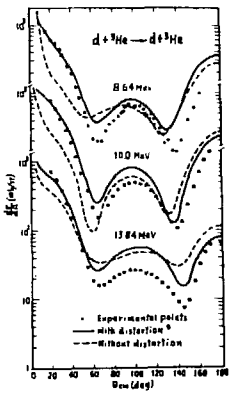
where $\vec{R}_3$ and $\vec{R}_d$ are the c.m. coodinates of ^{3}He and d respectively, γ=0.367 [2], A_1=1.0, A_2=3.631, A_3=5.746, α_1=0.07284fm^{-2}, α_2=0.3655fm^{-2}, α_3=1.4696fm^{-2} [3]. We require $\widetilde{\Psi}_{li}$ to satisfy the following relations:

$$\langle\Psi_{li}|\widetilde{\Psi}_{l'j}\rangle=\delta_{ll'}\delta_{ij} \qquad (4)\ ,\quad \langle\Psi_{li}|H|\widetilde{\Psi}_{l'j}\rangle=E_{li}\delta_{ll'}\delta_{ij} \qquad (5)$$

Using the projective equation, we can immediately deduce the equation, $\langle\phi_3\phi_d\xi|H-E'|\mathcal{A}\{\phi_3\phi_d\xi F_3(\vec{r})\}\rangle_{\vec{r}}$

$$=\sum_{i=1}^{N}\sum_{l=0}^{\infty}\frac{\langle\phi_3\phi_d\xi|H-E'|\widetilde{\Psi}_{li}\rangle_{\vec{r}}\langle\Psi_{li}|H-E'|\mathcal{A}\{\phi_3\phi_d\xi F_3(\vec{r})\}\rangle}{E_{li}-E'} \qquad (6)$$

where the Hamitonian H and the parameters concerned are taken from reference[2], except the nuclear force exchange mixing parameter, we took u=0.925. $\widetilde{\Psi}_{li}$ is a linear combination of χ_{li} which were obtained in reference[2]. According to the condition of the phase shift stability, we get immediately the nonlinear distortion parameters shown as follows: $\widetilde{\alpha}_i$=0.18, $\widetilde{\alpha}_2$=0.20, $\widetilde{\alpha}_3$=0.22, $\widetilde{\beta}_1=\widetilde{\beta}_2=\widetilde{\beta}_3$=0.30 for spin= $\pm$; $\widetilde{\alpha}_1$=0.90, $\widetilde{\alpha}_2$=1.20, $\widetilde{\alpha}_3$=1.50, $\widetilde{\beta}_1$=0.40, $\widetilde{\beta}_2$=0.31, $\widetilde{\beta}_3$=0.20 for spin= $\frac{1}{2}$. Finally, the elastic differential cross sections are obtained. From figure1, we can see that our calculation obtained with the special distortion effects agrees better with experimental results. Of couse, futher improvement could be achieved if other channels are taken into account.



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EXPERIMENTAL STUDY OF $^3He(p,\pi^+)^4He$ REACTION NEAR THRESHOLD

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The extensive study of (p,π^+) experiments undertaken with the beams from the Orsay Synchrocyclotron and the Saturne Synchrotron has been recently extended to $^3He(p,\pi^+)^4He$ reaction near threshold. The initial and final state wave functions are supposed well known up to very large momenta and one can hope to extract informations on the reaction mechanism.

The two energies of the new Orsay S.C. proton beam i.e. 166 MeV and 201 MeV have been used for the first steps of the investigation of the energy dependance near threshold which will be allowed in the next future, by a continuous variation between these two values. A special set up, described in the contribution $^3He(^3He,\pi^+)^6Li$ to this conference, has been built for the detection of pions. It has been tested on $^{10}B(p,\pi)^{11}B$ at T_p = 201 MeV and the results are in good agreement with those of Indiana [1].

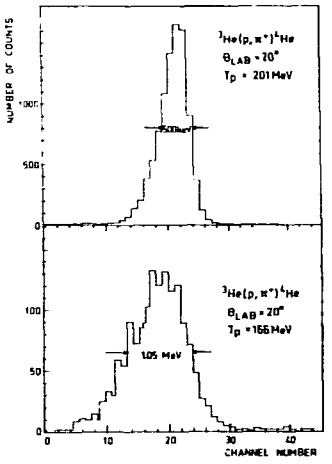


Fig. 1

For the $^3He(p,\pi^+)^4He$ experiment a 70 mg/cm^2 ^3He-liquid target has been used. The shapes of the crude peaks obtained in the focal plane are presented on Fig. 1.

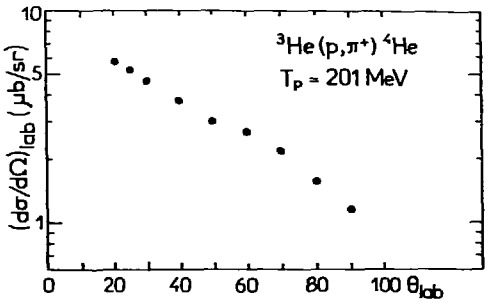


Fig. 2

At 201 MeV an angular distribution of the cross-section has been measured from 20°$_{lab}$ to 150°$_{lab}$. On Fig. 2 we only report very preliminary results for forward angles. Statistical error bars are included in the point size but the overall uncertainty on absolute values has still to be estimated.

At 166 MeV the peak of Fig. 1 is obtained by matching five measurements done at five different magnetic fields. The accurate absolute value is not yet extracted and one can only say that there is about one order of magnitude between high and low-energy measurements.

This experiment complements a previous one done at 415 and 716 MeV [2]. All the results are preliminary and will be precised in the next future.

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NUCLEAR STRUCTURE OF ^{99}Tc AND THE INTERACTING BOSON FERMION MODEL (IBFM)*

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The level scheme of ^{99}Tc was investigated with in-beam γ-spectroscopy using the ^{96}Zr(^{6}Li,3nγ)^{99}Tc* reaction. We have discussed the positive parity levels in the frame of the IBFM. As a first step we described the core nucleus ^{98}Mo by the IBA-1 model in the SU(5) limit. The data have been taken from ref. 3. F and G correspond to the parameters $\tilde{v}_2$ and $\tilde{v}_0$ in ref. 1. With this core and the hamiltonian for the odd nucleus of ref. 2 we described the positive parity levels of ^{99}Tc by a pure $g_{9/2}$ shell. In the figure we show besides the yrast band and the $(2^+ \times g_{9/2})$ multiplet the two lowest calculated states of each spin. The agreement is very satisfactory giving new evidence for the Pauli term in the IBFM hamiltonian.

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* Supported by BMFT

Fig. 1

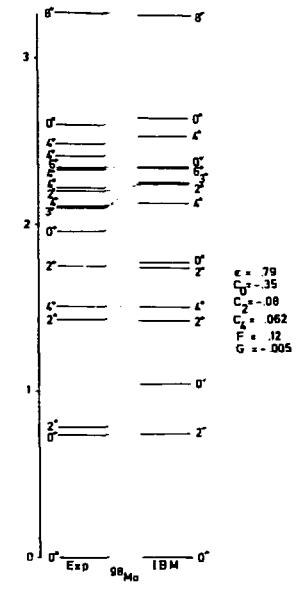
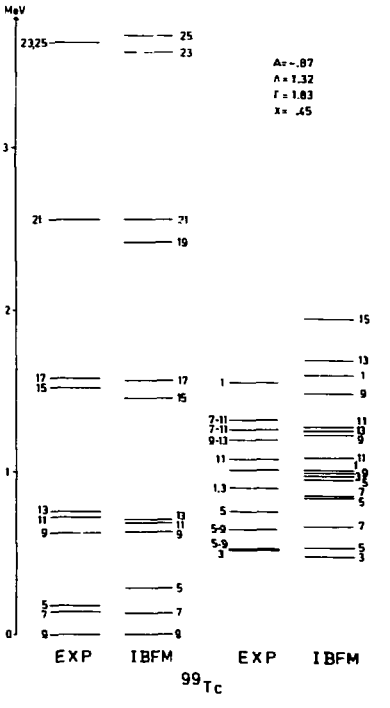


Fig. 2



EXPERIMENTAL INVESTIGATION OF PHOTONUCLEAR REACTIONS IN THE Δ-RESONANCE REGION+

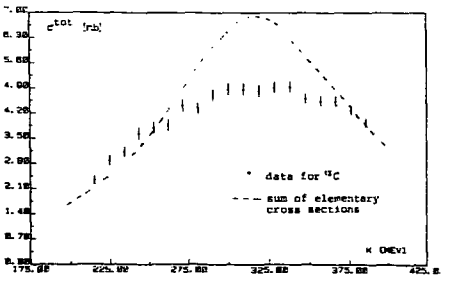
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Using the tagged photon beam of the Bonn 500 MeV synchrotron photonuclear reactions were investigated in the photon energy range 200-390 MeV for a series of nuclei (He, Be, C, O, Ti, Cu, Sn, Pb). The aim of these measurements was to get information on the total hadronic cross section as well as to study specific inclusive reaction channels.

Mass and energy of charged particles were determined simultaneously in the angular range 20^{o}-140^{o} using 5 time-of-flight spectrometers. In a second large solid angle scintillation counter setup charged and neutral hadrons could be detected in coincidence.

The integration of the measured energy- and angular distributions gives a lower limit for the total hadronic cross section. A correction for the unobserved fraction of the total hadronic cross section is made using the results of an intranuclear cascade computer code. Compared to the cross section for free nucleons an appreciable damping of the Δ-resonance excitation is observed for all nuclei under investigation. (see figure for ^{12}C)



The data obtained with this experimental setup can be further analysed for specific reaction channels. The main contributions to the total cross section in the photon energy range considered - quasifree pion production and quasideuteron reactions - are investigated and compared to Fermi-gas Monte Carlo calculations for nuclear photoabsorption.

+This work was supported by the Bundesministerium für Forschung und Technologie (BMFT).

ELASTIC AND INELASTIC PHOTON SCATTERING BY THE ^{12}C, ^{16}O, ^{28}Si, AND ^{52}Cr NUCLEI

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Using the beam of γ-bremsstrahlung from the Moscow State University Institute of Nuclear Physics betatron, we have measured the cross sections for the elastic scattering of photons from ^{12}C and ^{16}O nuclei and for the elastic and inelastic scattering leading to the excitation of the levels with J^{π} = $= 2^+$, 0^+, 2^+ at the energy 1.78, 4.98, and 15.3 Mev in ^{28}Si nucleus and of the levels with $J^{\pi} = 2^+$, 2^+ at the energy 1.43, 2.96 Mev in ^{52}Cr nucleus.

The scattered photons were detected by a scintillation spectrometer with NaI(Tl) cristal 15 cm in dia. and 15 cm high mounted at angle 90° relative to the primary γ-beam. The energy spectra of photons were measured at the end-point γ-bremsstrahlung energy E_{γ}^{max} = 32.0 Mev for ^{12}C and ^{16}O and at 16 values of E_{γ}^{max} (from 13.1 to 31.0 Mev) for ^{28}Si and ^{52}Cr. From these energy spectra, we have calculated the elastic and inelastic scattering cross sections. The position of the maxima of elastic scattering cross sections obtained is in reasonable agreement with their positions in total photoabsorption cross sections.

Within the framework of dispersion theory, we have analyzed the relationship between the maxima in the cross sections for total photoabsorption and elastic scattering. The analysis has revealed that the E1 photon absorption is dominant for maxima in the energy range from 22.0 to 24.0 Mev in ^{12}C, at 22.3 and from 24.0 to 25.0 Mev in ^{16}O, at 20.5 and 23.0 Mev in ^{28}Si and at 20.0 Mev in ^{52}Cr. The position of levels associated mainly with the E1 absorption of photons is quite consistent with shell-model calculations. For remaining levels of the intermediate structure there prevailes the photoabsorption of multipolarity other than E1.

The integrated cross sections for elastic scattering of photons in the energy region to 31.0 Mev are: 0.35 ± 0.03, 0.62 ± 0.07, 2.20 ± 0.40, and 6.00 ± 0.50 Mev·mb for ^{12}C, ^{16}O, ^{28}Si, and ^{52}Cr respectively. For ^{12}C and ^{16}O, the integrated cross sections for inelastic photon scattering do not exceed 5 % of the elastic scattering cross section. The integrated cross sections for inelastic scattering constitute 0.80 ± 0.30 0.70 ± 0.40, and 0.24 ± 0.02 Mev·mb when the 1.78, 4.98, and 15.3 Mev levels of ^{28}Si are excited and 3.00 ± 0.50 and 1.20 ± ± 0.50 Mev·mb for the 1.43 and 2.96 Mev of ^{52}Cr, respectively. A significant probably for the excitation of the first two levels of ^{52}Cr with $J^{\pi} = 2^+$ may suggest the existens of quadrupole component of nuclear vibration and a strong coupling between the dipole and quadrupole vibrations, which leads to high value for the tensor polarizability of the nucleus.

PHOTONUCLEAR CROSS SECTIONS OF ^{29}Si AND ^{30}Si†

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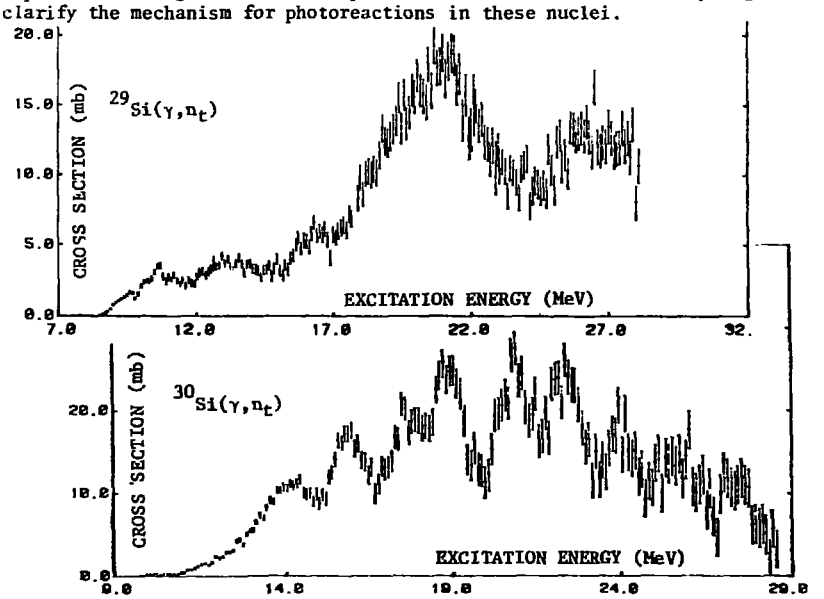
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The photonuclear cross sections of ^{29}Si and ^{30}Si were studied with reference to the effects produced by adding 1 and 2 neutrons to the closed subshell nucleus ^{28}Si. The influence of valence neutrons on the ^{16}O core has been observed previously by Johnson et al.[1].

Using isotropically enriched targets, photoneutron cross sections for ^{29}Si and ^{30}Si were derived from yield curves measured from threshold to 28 MeV at intervals of 100 KeV. The bremsstrahlung were obtained from a 35 MeV betatron in this laboratory, and the neutrons were detected using an efficient 4π $^{10}BF_3$ detector. The cross sections obtained are shown in the figure. The $^{29}Si(\gamma,n)$ cross section shows a basic similarity with the $^{28}Si(\gamma,n)$ cross section, with the presence of what might be strength due to the valence neutron below 17 MeV. The cross section $^{30}Si(\gamma,n)$ is more complex and not readily interpretable in terms of valence neutrons weakly coupled to a ^{28}Si core.

Measurements of the $^{29,30}S(\gamma,p)$ cross sections were also made by measuring yield curves of residual activity. The resolution of these cross sections is considerably less than that of the photoneutron cross sections, but it is expected that together with the photoneutron cross sections, they might clarify the mechanism for photoreactions in these nuclei.



† Supported in part by the Commonwealth Research Grants Committee.

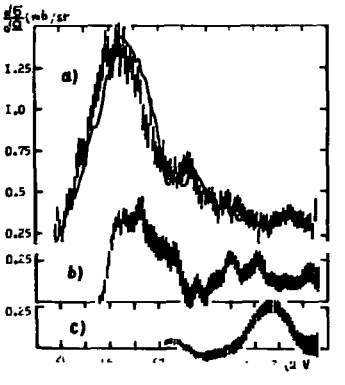
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A STUDY OF THE $^{12}C(\gamma,p)^{11}B$ REACTION LEADING TO THE FORMATION OF THE FINAL NUCLEUS IN INDIVIDUAL STATES

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The study of photonuclear reactions giving rise to occupation of certain low-lying levels of final nuclei makes possible a significant advance in our understanding of the nature of highlyexcited states in the giant dipole resonance region ($\approx$ 20 Mev). For the ^{12}C nucleus the greatest contribution to the photoabsorption cross section comes from the (γ,p) reaction. Our purpose was to obtain the energy dependence of the partial cross sections for the $^{12}C(\gamma,p)^{11}B$ reaction. Using a semiconductor-counter telescope, we have measured the photoproton energy spectra on the bremsstrahlung beam from a betatron. The end-point energy E_γ^{max} was: 21.7, 23.4, 25.0, 26.6, 28.2, 29.6, and 31.0 Mev. Each photoproton spectrum represents the sum of contributions from transitions to individual levels of the final nucleus. Measurements at the various E_γ^{max} values with a step less than the distance between levels (or between the centres of gravity of close lying levels) enables one to separate the individual reaction channels and to obtain the energy dependence of the partial cross sections [1]. The figure illustrates the obtained cross sections for the reaction $^{12}C(\gamma,p)$ resulting in the formation of the final nucleus ^{11}B in the ground state (a) and the states with the energies 2.12 Mev (b) - first excited state and 4.70 Mev (c) - a combination of a second and third excited states with energies 4.44 and 5.02 Mev. No population has been observed for the higher-lying groups of levels. The solid curve represents the data on the (p,γ_0) reaction [2]. In the region up to 30.5 Mev the integrated cross sections for partial reactions are 73.7 $\pm$ 1.0, 22.0 $\pm$ 0.6, 4.3 $\pm$ 0.3 % respectively of the total photoproton reaction cross section.



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FINITE SIZE EFFECTS ON THE CROSS SECTION OF BREMSSTRAHLUNG

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In most of the photonuclear reactions, it is customary to use a photon radiator to convert the primary incident electron beam into the beam of Bremsstrahlung radiation beam. While the result of the succeeding photonuclear reaction is meaningfully interpreted if the Bremsstrahlung intensity spectrum is accurately known, there has been no reliable experimental determination of the intensity spectrum. This makes it very important to have an accurate theoretical estimate of the Bremsstrahlung cross section availabile for various incident electron energies and for the entire region of the spectrum. There had been many such calculations, but none of them was suitable for multi-purpose use nor formulated in a compact analytic form.

Gargaro and Onley[1] have derived an expression for the matrix elements of the interaction between states of the relativistic electron in a simple closed analytic form in terms of the generalized hypergeometric functions. The central part of the matrix evaluation consists of the radial integral

$$\int_0^\infty dr\, r^{\alpha-1}\, e^{i2p'r}\, {}_1F_1(a';b';i2p'r)\,{}_1F_1(a;b;i2pr).$$

This neglects, however, first the finite nuclear size effect, second the momentum transfer to the radiator and, third the screening effect of the atomic electron cloud.

We report here that the first two corrections can be made by using the properties of the confluent hypergeometric functions, whereas the last correction is found to be included consistently. In order to account for the finite nuclear size effect, the integral is changed into a finite integral which introduces an incomplete gamma function. Further application of the multiplication theorem to the confluent hypergeometric functions makes the integral into series of the generalized hypergeometric functions without destroying the closed analytic form. The second correction for the momentum transfer, which is essential in the algebra of the manipulation, is taken care of by the addition theorem of the confluent hypergeometric functions, again introducing a series expansion without discarding the simple closed analytic form of the result. The numerical calculation of the cross section was performed using the IBM-3031 computer and a reasonable agreement with the existing calculations was obtained.

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ANGULAR DISTRIBUTION OF PHOTONEUTRONS FROM DEUTERIUM FROM 5 TO 28 MeV EXCITATION ENERGY

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The Kelvin Laboraotry has an electron linear accelerator capable of providing electron beams from 5 to 30 MeV in energy. This paper presents measurements of the angular distribution of photoneutrons from deuterium for excitation energies between 5 and 28 MeV.

The target used was a cylinder of perdeuteroethylene 2 cm in diameter and 2 cm in height. Bremsstrahlung photons were produced using a tantalum radiator whose thickness was 0.07 radiation lengths, and the photoneutron energies were measured by time of flight over seven flight paths whose lengths varied from 15 to 25 m, and whose angular range varied from 37½° to 156°.

Although the differential cross-sections are not absolute, considerable care has been taken in measuring the relative efficiencies of the neutron detectors, and checking for systematic errors arising from collimation misalignment.

The results are compared with the theoretical angular distribution calculated by Partovi.[1]

Small, but statistically significant, differences in the angular distribution coefficients have been found. The differences are consistent with the angular distribution of protons from the photodisintegration of deuterium measured by Weissman and Schultz[2] for excitation energies from 25 to 55 MeV.

*On leave from Chittagong University, Bangladesh.

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ANGULAR DISTRIBUTION OF GROUND STATE PHOTONEUTRONS FROM ^{40}Ca FROM (16-28) MeV EXCITATION ENERGY

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G. L. Cleland, M. N. Islam* and J. Robertson
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This paper presents the measurement of angular distribution of ground state photoneutrons from ^{40}Ca for excitation energies of (16-28) MeV using the 30 MeV electron linear accelerator at the Kelvin Laboratory. The angular distribution facility is described in another paper submitted to this conference on the angular distribution of photoneutrons from deuterium.[1)]

In the experiment a series of photon and point energies was used, the difference in energy between consecutive and point energies being 2 MeV. The target was a hollow cylinder of natural calcium 2 cm in height, 1 cm internal diameter, and 2 cm external diameter. Natural calcium contains 3.06% of isotopes other than ^{40}Ca, all of which have photoneutron thresholds below that of ^{40}Ca. It is possible to subtract the contribution to the total photoneutron spectra of photoneutrons from these isotopes, and obtain the spectra of ground state photoneutrons from ^{40}Ca at a particular end point energy, using the spectra measured at the adjacent, lower end point energy.

At each end point energy the angular distribution of photoneutrons from deuterium was measured under identical experimental conditions. This provided a constant reference for the ^{40}Ca measurements.

The angular distributions for ^{40}Ca and deuterium are expressed in the the form:

$$\omega(\theta) = a_0\left[\sum_{L=0}^{4} \frac{a_L}{a_0} P_L(\cos\theta)\right]$$

and the ratios a_L/a_0 are presented for L = 1 to 4.

*On leave from Chittagong University, Bangladesh.

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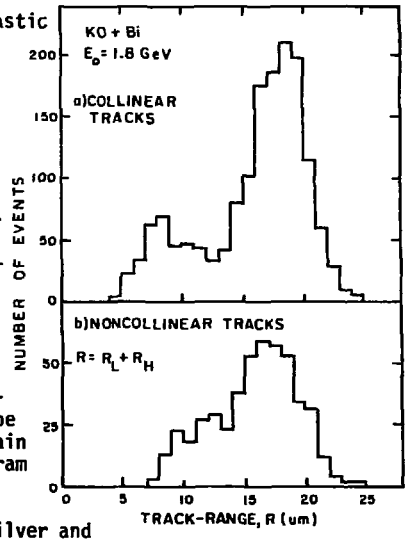
PHOTONUCLEAR REACTION IN ^{209}Bi BY 1-5.5 GeV BREMSSTRAHLUNG†

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High-energy photonuclear reactions in complex nuclei are well described at present by the "cascade-evaporation" model[1]), according to which a cascade of nucleon-nucleon or meson-nucleon collisions is initiated inside the nucleus by a high-energy incoming photon. The interpretation of such reactions by means of residual nuclei, however, encounters severe difficulties since there is a variety of post-cascade residuals, widely differing in both Z and A, which can undergo fission. The fundamental peculiarities between high-energy proton- and photon-induced reactions are to be found in the initial reaction step. For photons pion production processes dominate in contrast to the elastic scattering in the case of incident protons. Another difference is the small linear momentum transfer to the nucleus in the case of photon-induced reactions.

In the present work, the nuclear-track emulsion technique was used in order to observe fission-like events from residual nuclei at rest and in flight, which resulted by exposing ^{209}Bi-loaded nuclear emulsion plates at high-energy photon beams. The plates were exposed to high-intensity bremsstrahlung beams at the DESY electron-synchrotron. Details of the whole experiment have been reported previously[2]). Two types of events were selected in our analysis, i.e collinear and non-collinear tracks. Typical track-range distribution for both type of tracks are shown in the figure. The main peak (centred about 17μm) in each histogram corresponds to the bismuth-fission-like events, while the remaining track-ranges are due to either recoil or fission of silver and bromine nuclei. The track-range distribution showed in b) comprises the sum of the ranges of the light (R_L) and heavy (R_H) fragments. As conclusion, we point out that although the linear momentum transfer be small at high-energy photon-induced reaction, there is a remarkable contribution of non-collinear tracks to the total yield of the photofission process.



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***Permanent address: Istituto di Chimica Generale e Inorganica dell'Università, Roma, Itália.

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INFLUENCE OF HIGH-LYING N* RESONANCES ON DEUTERON PHOTODISINTEGRATION AT HIGH ENERGIES

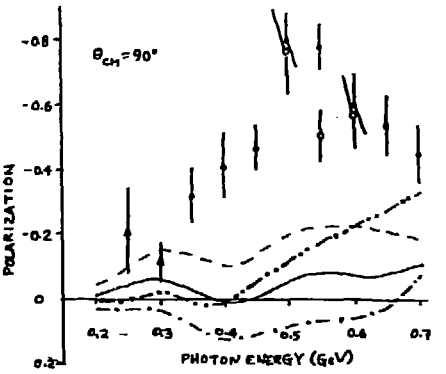
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Measurements[1]) of the polarization of the recoil proton in the reaction $\vec{\gamma}+d \to p + n$ exhibit a broad enhancement as a function of the photon energy for a fixed scattering angle between the photon and proton. For $\theta_{cm} = 90^{o}$, this peak is centered around a photon energy of $\omega = 550$ MeV, where the polarization has a value of nearly -0.8. This data has been interpreted as due to the intermediate excitation of one, or possibly two, dibaryon resonances[1]). It is of great interest to determine whether the observed enhancement is a genuine dibaryon resonance signal or an effect reflecting the opening of additional inelastic NN^* channels, e.g. those due to the P_{11} (1450), S_{11} (1510) and D_{13} (1530) resonances.

We have studied this reaction for photon energies of $0.2 \leq \omega \leq 0.7$ GeV using a non-relativistic model based on the plane wave Born approximation. Our basic model includes the usual impulse graph, the pionic exchange and pair current contributions, as well as intermediate Δ excitation followed by pion rescattering. The parameters in the model are adjusted to the differential cross section data around $\omega \simeq 0.3$ GeV where the intermediate Δ excitation process dominates. The polarization results for this model are shown as the solid line in the figure.

In addition to the Δ excitation, we have also included intermediate excitation of the P_{11}, S_{11} and D_{13} resonances using the multipole analysis from Berends and Donnachie[2]). However, the relative phase in the amplitude between these terms and the Δ excitation term can not be fixed from ref. 2. Consequently, we have considered three different values for this phase; 1, -1 and i with the resulting polarization shown in the figure as the dashed, dot-dashed and double-dot-dashed curves, respectively. The addition of intermediate excitation terms arising from these high-lying N^* resonances is not sufficient, within a non-relativistic model, to explain the large observed enhancement of the polarization.



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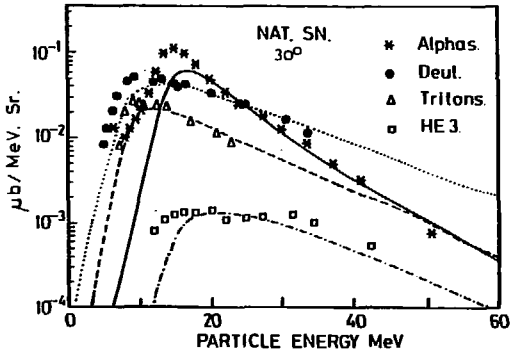
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ELECTRON AND GAMMA INDUCED PRE-EQUILIBRIUM COMPLEX PARTICLE EMISSION.

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Pre-equilibrium emission of complex particles (α,t,^{3}He,d, etc.) has been widely studied using nucleon induced reactions. The $A^{1/3}$ dependences of the cross sections indicate a surface type reaction mechanism. This fact and details of the particle energy spectra appear to be adequately described by cascade evaporation and exciton model calculations. To test these models for reactions involving the nuclear interior we have studied electromagnetically induced pre-equilibrium complex particle emission. Nuclei ranging from ^{12}C to ^{197}Au were bombarded with 120 MeV electrons and bremsstrahlung gamma rays using the Glasgow University linear accelerator. Charged particle spectra and angular distributions were measured using a magnetic spectrometer. The cross section for α particle emission has an observed $A^{\sim 1.7}$ dependence[1] which suggests an initial interaction through the quasideuteron process followed by a nucleon - α knockout reaction involving the whole nuclear volume. The spectral shapes are however reasonably well described by the exciton model. The d,t and ^{3}He cross sections fall off more slowly with particle energy as would be expected but have an A^{-1} dependence. Attempts are being made to explain these data in terms of the exciton model. Examples of preliminary results are shown in the figure.



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OPTICAL MODEL POTENTIAL AND NEUTRON STRENGTH FUNCTIONS

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One of the most important quantities obtained from the measurements of high resolution neutron total cross sections in nuclei are the neutron strength functions and their variation with mass number. This quantity which is directly related to the nature of neutron interaction with the nucleus by a complex optical model potential can be given by the relation $\langle \Gamma^{\ell}_{nJ} \rangle / \langle D_{\ell J} \rangle$, where $\langle \Gamma^{\ell}_{nJ} \rangle$ is the mean value of neutron reduced widths of resonances of same ℓ and J. $\langle D_{\ell J} \rangle$ is the corresponding mean value of the level spacing. In the past few years many precise values of S_0 and S_1 in the mass region of $40<A<70$ have been obtained by Garg et al.[1-5]) and others[6]) using high resolution neutron spectroscopy.

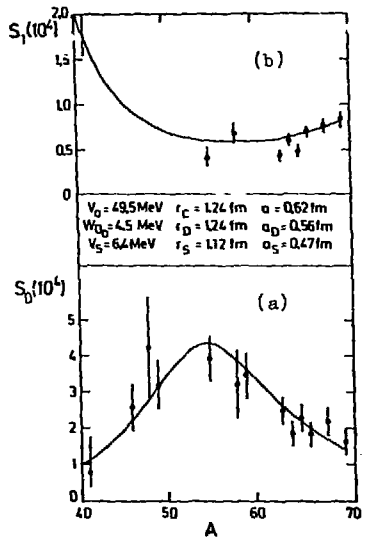


Fig. 1

An optical model code consisting of a Woods-Saxon real volume potential (V) and a derivative Woods-Saxon imaginary potential (W_D) and a conventional real spin-orbit potential (V_S) was used to calculate these strength functions. The results of these calculations for E_{lab} = 0.1 MeV and the experimental results obtained from measurements in the energy range 0 to 300 keV are shown in figure 1(a) and (b) for S_0 and S_1 respectively. There appears to be a very good agreement with most of the nuclei.

Moreover, the same parameters with the following energy dependence of the real and imaginary potentials :
$V = V_0 - 0.3\ E_n$, $W_D = W_{D0} + 0.4\ E_n$
where E_n is in MeV, gave an excellent fit to the measured total cross section data[6]) in zinc in the energy range of 0.1 to 10 MeV. It seems thus apparent that a single set of optical model parameters can describe the neutron interaction in the medium mass region of nuclei over a wide energy range. The effect of isospin term (N-Z/A) on strength function values was also investigated.

* Work supported in part by U.S.D.O.E.
† Permanent address, University of Albany, New-York, U.S.A.

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OBSERVATION OF A LONG LIVING 0^+-STATE IN ^{102}Pd

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Up to now little is known about the systematics of the 0_2^+-states in the even-even Pd isotopes. In the case of ^{102}Pd, Lange et al. [1] reported a 0^+-state at 1658 keV decaying to the 2_1^+-state. On the other hand, J. van Klinken et al. [2] reported the existence of a E0 transition in the $^{102}Ag^m$ (8 min.) decay, which they attributed to the $0_2^+ \rightarrow 0_1^+$-transition in ^{102}Pd. In the gamma spectrum no corresponding $E_2(0_2^+ \rightarrow 2_1^+)$ was observed.

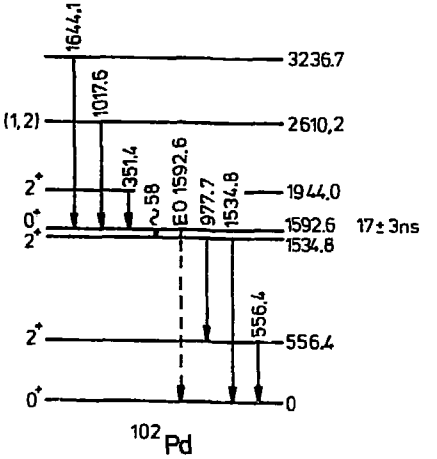
We performed a (e,γ)coincidence measurement on mass-separated $^{102}Ag^m$ sources with the help of a Mini-Orange spectrometer and a Ge(Li)-detector. The sources were produced using a $^{nat}Mo(^{14}N,xpyn)$ reaction. In such a reaction low spin $^{102}Ag^m$ is mainly produced via the decay of ^{102}Cd. To enhance the low spin isomer with respect to the directly formed $^{102}Ag^g$, the energy of the beam was optimised for the production of ^{102}Cd.

From the TAC-spectrum we could deduce the half-life of the completely converted 1592.6 keV transition to be 17 ± 3 nsec. Apart from the annihilation peak, three γ-lines were found to be coincident with the delayed electrons : 351.4 ± 0.2 keV, 1017.6 ± 0.2 keV and 1644.1 ± 0.4 keV. No prompt coincident γ-transition were found indicating that the 1592-keV is a level to groundstate transition.

Moreover, the three observed gamma-lines can be explained as separated transitions from levels at 1944, 2610 and 3237 keV that have been reported by Lange et al.[1] (see fig.). No corresponding $0_2^+ \rightarrow 2_1^+$-transition was observed in the γ-spectra.

From γ-γ coincidences performed on the decay of $^{102}Ag^m$ we found evidence for a branching of the 0_2^+ to the 2_2^+ at 1534.8 MeV. This branching is in the order of 10 % of the E0 decay to the groundstate.

No evidence was found for a 0^+ at 1658 keV[1]; nor in the single spectra, neither in the coincidences.



* Aspirant N.F.W.O.

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THE QUASI-FREE (e,e'p) REACTION ON ^{3}He

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The spectral function $S(E_m,P_r)$ has been extracted, in PWIA, from data obtained at Saclay in an (e,e'p) coincidence experiment on a liquid ^{3}He target. The region covered in the missing energy and recoil momentum plane is $-25<E_m<90$ MeV and $0<P_r<200$ MeV/c. The energy resolution of 1.2 MeV was sufficient to separate the two-body (E_m = 5.5 MeV) and the three body (E_m>7.7 MeV) break-up channels (Fig.1). The shape of the momentum distribution in the two-body break-up channel (without corrections for radiative processes) is in good agreement with the prediction of a three-body Faddeev calculation using a R.S.C. potential[1]) (Fig.2). The data are compatible with earlier measurements at Stanford[2]). The agreement between the measured and calculated three-body break-up momentum distributions is satisfactory (Fig.3). In the near future we shall extend the measurement of the spectral function up to P_r = 350 MeV/c.

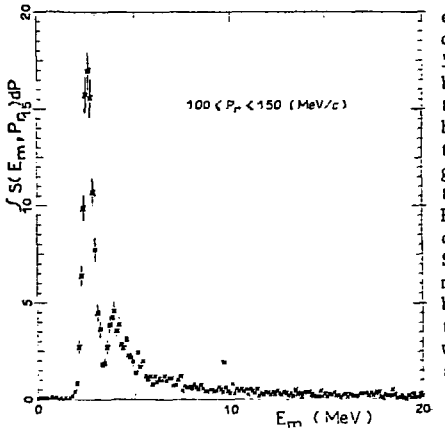


FIGURE 1

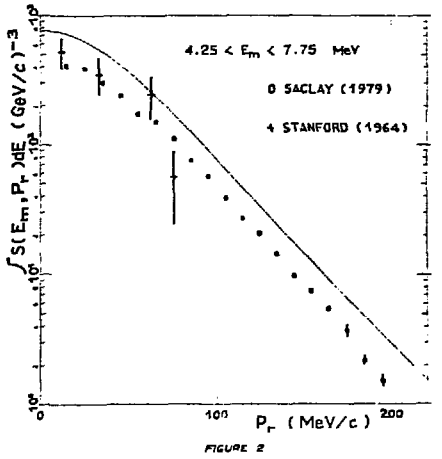


FIGURE 2

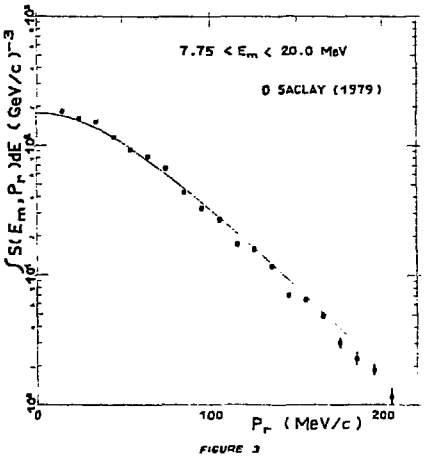


FIGURE 3

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DEEP INELASTIC SCATTERING OF ELECTRONS FROM ^{12}C

P. Barreau, M. Bernheim, M. Brussel, J. Duclos, M. Finn, J. Morgenstern, J. Mougey, D. Royer, B. Saghai, D. Tarnowski, S. Turck-Chieze

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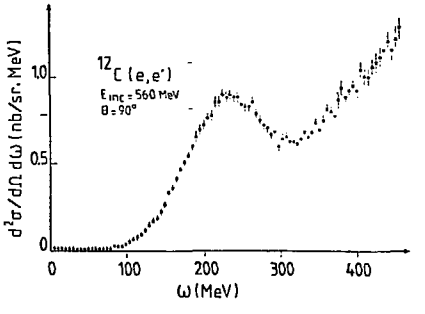
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A systematic study of the deep inelastic electron scattering response function of ^{12}C has been carried out at the Saclay Linear Accelerator. Measurements have been performed at scattering angles of 60°, 90°, 130° and 145° for incident electron energies between 120 and 560 MeV. Negative pion background has been suppressed by use of a silica aerogel Cerenkov counter with a refractive index of 1.06. The longitudinal and transverse components of the response function have been obtained by means of a Rosenbluth separation of the data in the interval 1 $fm^{-2} < q_\mu^2 < 16$ fm^{-2}. The maximal energy loss, ω, for the separations is 400 MeV at $q_\mu^2 \sim 4$ fm^{-2}.

Between the quasi-elastic and Δ-production peaks the cross section is in excess of current calculations. The Figure shows preliminary radiatively-corrected data at a scattering angle of 90° and an incident electron energy of 560 MeV. In addition to the quasi-elastic peak, at higher energy losses the quasi-elastic production of the Δ(3,3) resonance is also observed.



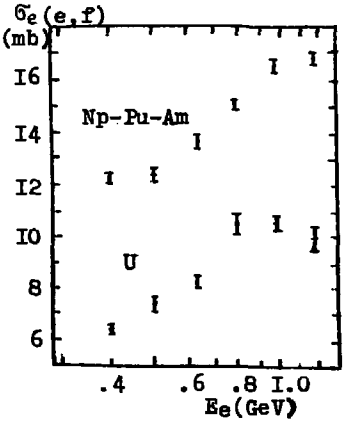
ELECTROFISSION AND TOTAL PHOTOABSORPTION CROSS SECTIONS OF TRANSURANIUM NUCLEI OVER 400-I200 MEV ENERGY REGION

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The photofission cross sections of transuranium nuclei $\sigma(\gamma,f)$ at energies above photomeson threshold are very close to total photoabsorption cross sections $\sigma_{\gamma A}$ (fissionabilities $\sigma(\gamma,f)/\sigma_{\gamma A} \approx I$)[1]. It is known also that in the relevant energy region the relationship between photon and electron induced reactions is valid 2): $\sigma_a/\sigma_e = \pi/(2\alpha \ln(E_0/m))$, where σ_a and σ_e is cross section (yield) per equivalent quantum and electron respectively; $\alpha = I/I37$, E_0,m - insident electron energy and rest mass. Therefore one can evaluate the $\sigma_{\gamma A}$ from the $\sigma_e(e,f)$. ($\sigma_{\gamma A} = d\sigma_a(\gamma,f)/d\ln E_0$ in photon spectrum $\sim I/E_0$ approximation).

We have measured the electrofission cross section (e,f) for ^{238}U, ^{237}Np, ^{239}Pu and ^{243}Am on the 2 GeV Linac of Kharkov Phys.Tech.Institute. Surface densities of the targets were determined at the limit of 3-5% accuracy. Fission fragments were registered by polycarbonate track detectors (Macrofol KG I0 mm thick) installed in vacuum chamber downstream I30 mm of the samples. Experimental results are shown on the figure. Becouse the data for ^{237}Np, ^{239}Pu and ^{243}Am were found to be the same within ± 5% the mean values for them are presented. The accuracy of data obtained is poor to get the energy dependance of $\sigma_{\gamma A}$ but allows a comparison to be made of integrated experimental ($\int \sigma_{\gamma A}\, dE$) and theoretical ($\int A\bar{\sigma}_{\gamma p}\, dE$) cross sections ($A = 240$, $\bar{\sigma}_{\gamma p}$ - elementary photon-nucleon cross section, smoothed to take nucleon motion inside the nucleus into account). The ratio $\int \sigma_{\gamma A}\, dE \,/\, \int A \cdot \bar{\sigma}_{\gamma p}\, dE$ was obtained to be I.54 ± 0.I2. for energy interval 400-I200 MeV. This result is in agreement with those of photofission experiment I) and shows that experimental photoabsorption cross section of heavy nuclei exceeds the theoretical values by I.5 times approximately in the nucleon resonance energy region.



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STUDY OF THE 1^+ STATE AT 3.48 MeV IN THE ^{88}Sr(e,e') REACTION

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P.K.A. de Witt Huberts (I.K.O., Amsterdam)

The 1^+ state at 3.48 MeV in ^{88}Sr has a dominant $|\pi p_{3/2}^{-1}\, p_{1/2}\rangle$ configuration [1]. The measured B(M1↑)-value [2] of 1.1 μ_N^2, which is much smaller than the single-particle estimate, could be explained [1] by including ground-state correlations and an admixture of the Giant Dipole Resonance $|\nu g_{9/2}^{-1}\, g_{7/2}\rangle$. The estimated amount of ground-state correlations agrees with the results of projected BCS calculations [3] including π2qp and ν1p-1h excitations.

We investigated the formfactor for this M1 transition by low-energy (e,e') with the high-resolution equipment at the Darmstadt Linear Accelerator in the range 0.36 fm^{-1} ≤ q ≤ 0.62 fm^{-1}. The experimental data are shown in fig.1.

Calculations were performed with the programs Forks and Duels using the dominant components of the wavefunction of ref. 1: $|1^+\rangle = \alpha|\pi p_{3/2}^{-1}\, p_{1/2}\rangle + \beta|\nu g_{9/2}^{-1}\, g_{7/2}\rangle$. Ground-state correlations were accounted for by taking α = .512 and β = .05. The results are shown in fig. 1 both with Harmonic Oscillator (b = 2.16 fm) and Woods-Saxon (r_0 = 1.28 fm) single-particle wavefunctions. Although the measured B(M1↑)-value is reproduced, both the shape and the magnitude of the calculated formfactor are wrong for q > 0, especially when the more realistic Woods-Saxon wavefunctions are used. The shape can be improved (see fig. 2) by taking into account a $|\pi f_{5/2}^{-1}\, p_{3/2}\rangle$ component (this does not affect the B(M1↑)-value), which is present in the PBCS wavefunction of the 1^+ state, but the amplitude needed is .28 (with HO wavefunctions) and is much larger than any PBCS estimate.

The introduction of an effective g_s-factor does not lead to an improvement either, unless the admixture of the G.D.R. is strongly reduced. With $g_s^{eff} = 0.75$ and no G.D.R. component we find B(M1↑) = 0.7 μ_N^2 and we still need about .14 $|\pi f_{5/2}^{-1}\, p_{3/2}\rangle$ to obtain a good shape (see fig. 2.)

It seems that the measured B(M1↑)-value and formfactor cannot correctly be described within this configuration space, even not by introducing an effective g_s-factor. More refined core-polarisation calculations as well as measurements of the formfactor beyond the first minimum are highly desired.

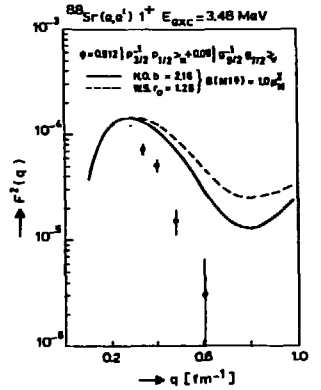


fig.1

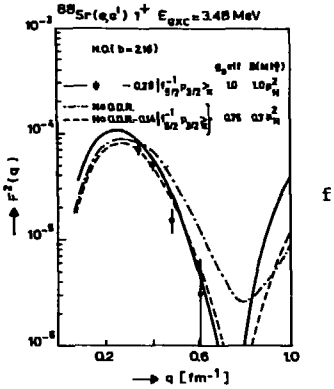


fig.2

We thank prof.dr. A. Richter, dr. E. Spamer and dr. R. Frey for the opportunity to perform this experiment and for their help during the measurements and analysis.

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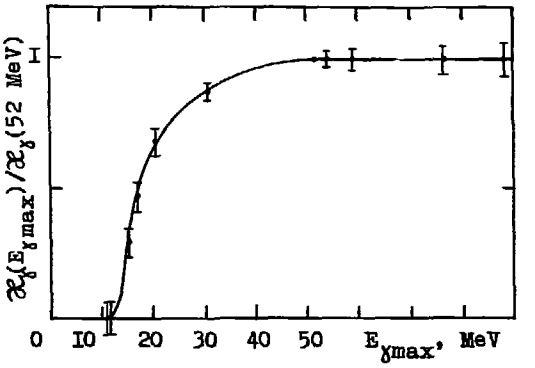
ISOMERIC YIELD RATIOS FOR THE REACTIONS $^{197}Au(\gamma,n)^{196m,g}Au$ AND $^{197}Au(e,e'n)^{196m,g}Au$ IN THE ENERGY RANGE 10-90 MeV

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Production of the high spin isomers $^{196m_1}Au(J^{\pi}=12^-$, $T_{1/2}=9.7$ h) together with ground state nuclei $^{196g}Au(J^{\pi}=2^-$, $T_{1/2}=6.2$ day) was found in various reactions[1]. Later on the second isomeric state $^{196m_2}Au(J^{\pi}=5^+$, $T_{1/2}=8.2$ sec) was discovered[2]. We have measured isomeric yield ratios $\varkappa=Y^{m_1}/(Y^{m_2}+Y^{g})$ in the (γ,n)- and $(e,e'n)$- reactions.

The ^{197}Au samples were irradiated with electron beam of INR linear accelerator. The upstream tantalum radiator was used in the case of the (γ,n)-reaction measurements. The residual activity method was used. Gamma-ray spectra were measured with the Ge(Li)-detector. For the (γ,n)-reaction at $E_{\gamma max}=52$ MeV we have obtained $\varkappa=(6.1\pm0.4)\cdot10^{-4}$. The energy dependence of the ratio $\varkappa_\gamma(E_{\gamma max})/\varkappa_\gamma(52$ MeV) is shown in the figure. These results allow one to assume that the $^{197}Au(\gamma,n)^{196m_1}Au$-reaction threshold is ~4 MeV higher than for the ground state reaction, and the major part of the $\sigma^{m_1}(\gamma,n)$ is at E_γ~16-24 MeV. For the $(e,e'n)$-reaction the obtained energy dependence of the ratio $\varkappa_e(E_e)/\varkappa_e(52$ MeV) has approximately the same character as in the figure. Possible admixtures of the electric quadrupole (E2) giant resonance in the values $\varkappa_\gamma$ and $\varkappa_e$ were estimated using a rather simple model which takes into account the relative numbers of E2 and E1 photons in spectra of real and virtual photons, the strong dependence of the $^{196m_1}Au$ production probability on the angular momentum transfer[1], and supposed ratio for E2 and E1 strengths. This estimation gave $(\varkappa_e/\varkappa_\gamma)=1.16$ at ~50 MeV. The obtained experimental result was $(\varkappa_e/\varkappa_\gamma)=1.15\pm0.03$ at 59 MeV. In principle parameters of this model may be found in experiments with different ^{197}Au-sample thicknesses (in this work it was 15 μm). Nevertheless we may say that the obtained difference between $\varkappa_e$ and $\varkappa_\gamma$ is connected with E2 admixture. Thus, reactions of such a type may be used as one more way for studying E2 resonance. Moreover, since the cascade γ-transitions seem to play the main role in populating high spin isomeric states in these reactions, the experimental data of the type described above may be used to verify statistical model parameters.



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TESTING AND CALIBRATING A SEMIPHENOMENOLOGICAL TRANSITION MATRIX FOR LOW ENERGY NUCLEON-NUCLEUS ELASTIC SCATTERING

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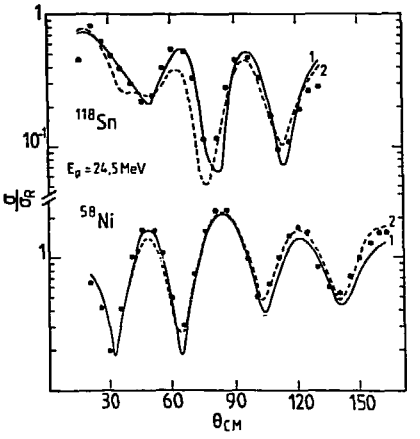
In the model of optical potential we previously developed[1]), the point of view was to reproduce the elastic scattering observables from the gross properties of nuclei (namely ρ_p and ρ_n), rather than from more detailed nuclear structure, and to include in the folding model only the necessary features of the two-nucleon t-matrix ; this description is intermediate between the standard phenomenological OMP and sophisticated theoretical derivations[2]). We start from a folding model approach and include an exchange term, which involves a local potential approximation yielding an effective mass that accounts for the Perey effect.

The real part of the t-matrix was constructed from the M3Y force of the MSU group with the density dependence taken into account by a factor $(1-c\rho^{2/3})$. The imaginary part is written : $t(0)(1-\lambda^2 q^2/6 + \ldots)$ with $t(0)$ taken from the optical theorem (i.e. $t(0) = k\bar{\sigma}/4\pi$) where the total cross section $\bar{\sigma}$ is corrected from the Pauli principle (which gives strong density dependence), and λ is phenomenologically adjusted. First guess values of c and λ were taken from comparison of our potential to standard ones, and yielded a reasonable description of the elastic observables.

After some exploration of the sensitivity of the angular distributions to the different parameters of the transition matrix, we allowed variation of a few parameters, namely P_r and μ, strength and rms range of the real force, $R_{ST} = Vol_{SE}/Vol_{TE}$ as isospin dependence, c density dependence parameter, P_i and λ, strength and rms of imaginary force. A slight energy dependence is allowed for each parameter. These parameters are then calibrated by a least square fit to data for a range of targets and incident energies from 17 to 50 MeV. Proton densities were taken from electron scattering and neutron densities from high energy hadron scattering.

The agreement with data thus obtained is as good as from the standard average potentials. We nevertheless could not find unambiguous parameter set, namely a better fit could be obtained in a restricted range of calibration masses with slightly different parameters (see table). As an example, some angular distributions, corresponding to different interactions are presented on the figure.

P_R	R_{ST}	μ	c	P_I	λ	
1	0.64	2	0.65	1.[illegible]	1.6	curve 1
1.09	0.64	2.2	0.65	1.1	1.25	curve 2



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PROTON AND ALPHA INDUCED KNOCKOUT REACTIONS ON ^{16}O AND ^{40}Ca[†]

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A. Nadasen, and J. Wesick

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Experimental data have been obtained for the (p,2p) reaction on ^{16}O and ^{40}Ca at 101 MeV, for the (p,2p) reaction on ^{40}Ca at 76 MeV, and for the (α,αp) reaction on ^{16}O and ^{40}Ca at 140 MeV. Incident beams were obtained from the University of Maryland Isochronous Cyclotron and the emitted particles were detected in ΔE-E telescopes consisting of Si surface barrier transmission detectors followed by either Si or intrinsic Ge stopping detectors. Particle identification and random event subtraction were carried out by computer software.

The objectives of this study were threefold. Firstly, in view of the large quasi-free (p,2p) contribution to the processes whereby protons lose energy to nuclei[1,2]) it is important to test current distorted wave impulse approximation (DWIA) descriptions of this reaction. At 150 MeV the factorization approximation, in which the off-shell nucleon-nucleon amplitude is approximated by the free scattering amplitude, is successful.[3]) However, at lower energies very large distortion effects may modify this result.[4]) In order to clarify the situation we have obtained quasi-free angular distributions at 101 MeV and 76 MeV for ^{40}Ca which will be compared to the existing data [3,5]) at 150 MeV and at 45 MeV. Similarly, data for ^{16}O at 101 MeV will be compared with existing 200 MeV data.[6])

Secondly, a comparison of the (α,αp) data with the above (p,2p) data is sensitive to the detailed radial form of the ejected proton bound state wave function. This results simply from the very different radial localization of the two reactions.[7]) Analyses will be presented for the four transitions seen strongly in this work, specifically the removal of $1p_{3/2}$ and $1p_{1/2}$ protons from ^{16}O and the removal of $2s_{1/2}$ and $1d_{3/2}$ protons from ^{40}Ca.

Thirdly, additional data were obtained for the (p,2p) reaction in non-quasi-free geometries which enhance the importance of off-shell effects and also for the reactions (p,pd), (p,pt), (α,αd), (α,αt), (α,$\alpha\tau$) and (α,2α) on ^{16}O and ^{40}Ca targets.

[†]This work was supported in part by the National Science Foundation.
[††]Permanent address: National Accelerator Centre, CSIR, Pretoria, S. Africa.

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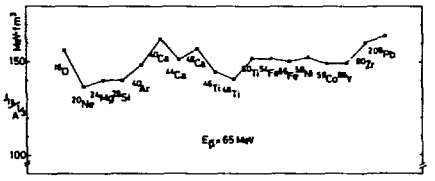
THE SHELL EFFECT OBSERVED IN THE SPIN ORBIT PART OF THE OPTICAL POTENTIAL

H. Sakaguchi, M. Nakamura, K. Hatanaka, A. Goto,
T. Noro, F. Ohtani, H. Sakamoto, and S. Kobayashi

Department of Physics, Kyoto University, Kyoto, Japan

Since Haxel et al. and Mayer pointed out the fundamental importance of the spin-orbit splitting, the search for its origin has been one of the most important problems in nuclear physics. Experimentally, from our systematic study[1] of the optical potential at the proton energy of 65 MeV we could derive the systematics of the spin orbit potential in a direct way.

In the phenomenological spin-orbit potential we have three independent parameters V_{ls}, r_{ls} and a_{ls}. In order to reduce the ambiguity, we discuss the volume integral values of the form factor of the $(l\cdot s)$ potential $J_{ls} \equiv 4\pi\int r^2 U_{so}(r)dr$ and fix the diffuseness parameter a_{ls} of the $(l\cdot s)$ potential. In the figure, $J_{ls}/A^{1/3}$ values are plotted for each target nuclei. A remarkable shell effect is noticed. For the double closed shell nuclei such as ^{16}O, ^{40}Ca, ^{48}Ca ^{90}Zr and ^{208}Pb the value of $J_{ls}/A^{1/3}$ becomes large. Namely the depth of the $(l\cdot s)$ potential becomes deeper. In the middle of a shell the depth is the shallowest and it becomes deeper, when the shell becomes more closed. For the single closed shell nuclei such as ^{50}Ti, ^{54}Fe, ^{89}Y the depth of the $(l\cdot s)$ potential is in the middle between the two utmost.



The observed shell effect is about 10% of the total $J_{ls}/A^{1/3}$ in magnitude. But the change of the nuclear radius parameter in one open shell is less than 1 or 2%. In the fitting to experimental data the change of the radius parameter is compensated by the strength of the potential. The net effect to the J_{ls} is minor. For the 10% change of diffuseness a_{ls}-value in one open shell (which seems to be a too large change) the change of the $J_{ls}/A^{1/3}$ value can be estimated to be about 2-3%. So in conclusion, although the shell effect observed in $J_{ls}/A^{1/3}$-value is small (10%) but it cannot be explained by the nuclear shape or size effect. The microscopic calculation including the second order tensor force in the nucleon-nucleon interaction may explain this effect.

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65 MEV POLARIZED PROTON ELASTIC SCATTERING AND THE EFFECTIVE TWO-BODY INTERACTION RANGE

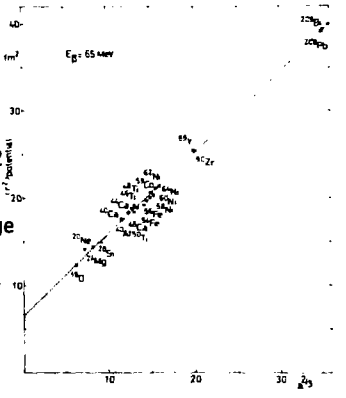
H. Sakaguchi, M. Nakamura, K. Hatanaka, A. Goto,
T. Noro, F. Ohtani, H. Sakamoto, and S. Kobayashi

Department of Physics, Kyoto University, Kyoto, Japan

Recently there has been a considerable progress in understanding the nucleon-nucleus optical potential from the standpoint of the nuclear matter theory. The critical check to these global theories seem to be the target mass number dependence and the incident energy dependence of the obtained optical potential. Using the 65 MeV polarized protons of RCNP Osaka cyclotron, we have been measuring systematically the elastic scattering from various target nuclei over the whole periodic table and doing the optical potential fit to the obtained data. A part of this work[1] were published already.

From the real central part of the obtained optical potential the mean square radius of the potential $\langle r^2\rangle_{pot}$ was calculated and was plotted as a function of $A^{2/3}$ in the figure. The solid line is a linear fit by the least square method, and is expressed

$$\langle r^2\rangle_{pot}=(0.928\pm0.023)A^{2/3}+6.57\pm0.29 \text{ fm}^2 \quad .$$



Similar relation for the mean square radius of the charge distribution $\langle r^2\rangle_{charge}$ is obtained by least-square linear fitting to the electron scattering data,

$$\langle r^2\rangle_{charge}=(0.768\pm0.011)A^{2/3}+(2.60\pm0.23) \text{ fm}^2$$

Using the folding model, $\langle r^2\rangle_{pot}$ and $\langle r^2\rangle_{charge}$ are expressed as

$$\langle r^2\rangle_{pot} = \frac{3}{5}r_m^2A^{2/3} + \frac{7}{5}\pi^2a_m^2 + \langle r^2\rangle_d \quad ,$$

and $$\langle r^2\rangle_{charge} = \frac{3}{5}R_p^2 + \frac{7}{5}\pi^2a_p^2 + \langle r^2\rangle_{proton} \quad ,$$

where $\langle r^2\rangle_d$ and $\langle r^2\rangle_{proton}$ are mean square radii of the effective interaction range and the charge distribution of the proton itself, respectively.

A recent argument[2] based on the experimental data and the Los Alamos experimental results show that the difference between the root mean square radius of the nuclear matter distribution and that of the point proton distribution is less than 0.1 fm, which is smaller than our $\langle r^2\rangle_d$-value error. So the average density distribution of the point nucleon is thought to be equal to that of the point proton. By comparing the above two relations, the effective two-body interaction range is obtained to be

$$\langle r^2\rangle_d = 4.49\pm0.37+(0.159\pm0.026)A^{2/3} \text{ fm}^2 \quad .$$

This kind of mass number dependence may be explained by taking into account the Pauli-principle effect on the effective interaction.

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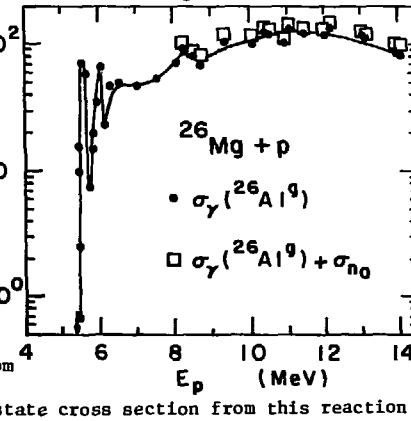
$^{26}Al^{g,m}$ PRODUCTION CROSS SECTIONS FROM THE $^{26}Mg(p,n)^{26}Al$ AND $^{23}Na(\alpha,n)^{26}Al$ REACTIONS†

E.B. Norman, K.T. Lesko, P. Schwalbach* and T.E. Chupp

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$^{26}Mg/^{24}Mg$ isotopic abundance excesses that are correlated with the Al/Mg elemental abundance ratios have been observed in inclusions from the Allende meteorite. This suggests that ^{26}Al was present at the time of formation of the inclusions and later decayed in situ to produce the observed ^{26}Mg excess.[1] Depending on the conditions at which the nucleosynthesis of ^{26}Al occurs, several different nuclear reactions may play significant roles. We have therefore measured the ^{26}Al production cross sections from the $^{26}Mg(p,n)$ reaction and have begun a study of the $^{23}Na(\alpha,n)$ reaction.

The ^{26}Al [5+] ground state, $^{26}Al^g$, has a half-life against electron-capture and β^+ decay of 7.2×10^5 yr. However, the first excited state, $^{26}Al^m$, is a 0^+ level which β^+ decays to ^{26}Mg with a half-life of 6.3 seconds and does not decay to the ^{26}Al ground state. Thus any ^{26}Al formed in this isomeric level will not survive long enough to become incorporated into a meteoritic inclusion as ^{26}Al. To distinguish between yields to the ground state and isomer we have studied γ-ray transitions in ^{26}Al following the neutron evaporation from the (p,n) and (α,n) reactions. We have measured the γ-ray cross sections from threshold to $E_p = 14$ MeV ($E_\alpha = 26$ MeV) using a 50 cm^3 coaxial Ge(Li) detector. By summing the γ-ray production cross sections for all of the observed ground-state (isomer) transitions, we obtain lower limits to the total ground-state (isomer) cross sections from these reactions. This technique is obviously insensitive to direct neutron evaporation to the ground state or isomer. However, in the case of the (p,n) reaction, these cross sections have been measured over a limited energy range.[2] The closed circles in the figure represent only our ground-state γ-ray cross sections, while the open squares include the effect of direct neutron evaporation to the ground state. For the energies where the data overlap, our results are in reasonable agreement with the $^{26}Al^g$ cross section measurements of Furukawa et al.[3] Analysis of the γ-ray data from the $^{23}Na(\alpha,n)$ reaction is currently in progress. To obtain the total ground-state cross section from this reaction we will measure the total neutron yield from the (α,n) reaction using a neutron detector, and we will measure the total isomer cross section using a radioactivity technique. Data from these two experiments will be presented.



†This work is supported in part by the U.S. Department of Energy.
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WINE-BOTTLE BOTTOM SHAPE OF THE NUCLEON-NUCLEUS POTENTIAL AT INTERMEDIATE ENERGY

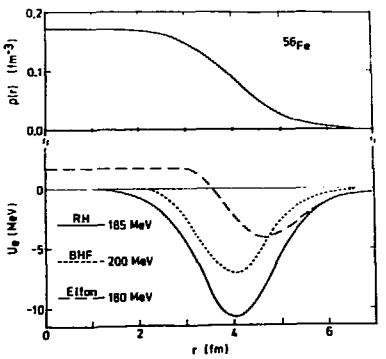
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We have studied the nucleon-nucleus optical potential in the framework of a relativistic quantum field model, in which the nucleon field is coupled to two massive fields, associated with the exchange of a scalar meson (σ) and of a vector meson (ω), respectively. In spherical nuclei this optical potential, which should be introduced in a Dirac equation, is the sum of a Lorentz-scalar operator U_s and of a Lorentz-vector component U_0. In the relativistic Hartree approximation, these quantities are independent of energy. It is possible to construct a Schroedinger-equivalent average nucleon-nucleus potential U_e, which is energy-dependent and should be introduced in a Schroedinger equation. The quantity U_e can thus be compared to empirical potentials.

We have extended the work of Brockmann[1]) and performed a self-consistent Hartree calculation of U_e for ^{16}O and ^{40}Ca. The sole input of this calculation is the contribution of σ- and of ω-exchange to the nucleon-nucleon OBEP of Erkelenz, Holinde and Machleidt. At low and intermediate energy, the agreement between calculated and empirical optical potentials is quite good[2]).

One of the striking features of the calculated optical potential is that it has an attractive pocket at the nuclear surface at the energy (E = 200 MeV) at which the optical potential becomes repulsive in the nuclear interior[2]). We now show that this "wine-bottle bottom shape" also emerges in the framework of a local density approximation. In the upper part of the figure, we have plotted the density distribution of ^{56}Fe. The full curve in the lower part represents the Schroedinger-equivalent potential U_e at 185 MeV, as calculated in the framework of the relativistic Hartree approximation and of the local density approximation. This theoretical optical potential is strikingly similar to the empirical potential determined by Elton [3]) (long dashes), and also to the potential calculated in the framework of the non-relativistic Brueckner-Hartree-Fock approximation (short dashes) with Reid's hard core nucleon-nucleon interaction[4]).



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THE LEVEL SCHEMES OF ^{85}Sr AND ^{87}Sr

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The ^{85,87}Rb(p,nγ)^{85,87}Sr reactions and the decay of ^{85}Y, produced by proton capture in ^{84}Sr, were studied in an attempt to resolve some of the discrepancies between recently published level schemes for ^{85}Sr and ^{87}Sr.

Thin targets of natural Rb and enriched ^{85}Rb and ^{87}Rb, in the form of both chlorides and nitrates, were bombarded with protons from a Van de Graaff accelerator at a series of energies between 2.2 and 3.8 MeV. In the case of the ^{85}Y decay studies, $^{84}SrCl_2$ targets were activated by 3.8 MeV protons. In each case the resulting gamma rays were detected by means of both a high-resolution large Ge(Li) detector with an efficiency of about 17 % and a small (1 cm^3) intrinsic Ge detector.

More than sixty gamma rays in ^{85}Sr and about eighty transitions in ^{87}Sr, many of which had not been reported before, were observed. They were fitted into level schemes up to 1700 keV in ^{85}Sr and 3100 keV in ^{87}Sr on the basis of their threshold behaviours, together with stringent requirements on consistency in energy summation. In addition, similar shapes for the respective excitation functions in the (p,nγ) studies were demanded, from which branching ratios were derived.

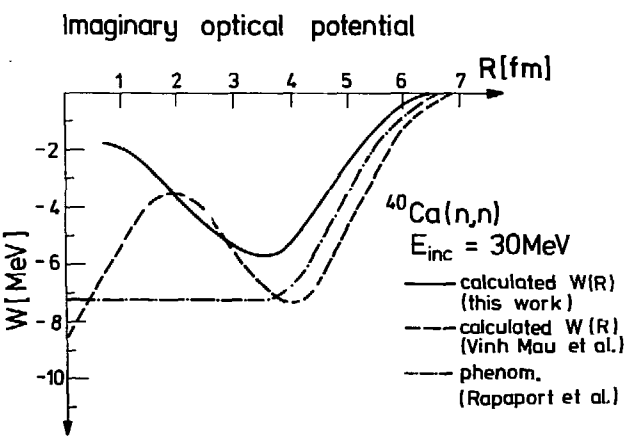
The final level schemes differ in a number of respects from both the evaluated and previously published ones and contain several newly proposed excited states and transitions. Attempts to fit the observed excitation functions by means of optical model and Hauser-Feshbach calculations and to derive information on the spins and parities of levels, will be described.

THE IMAGINARY PART OF THE NUCLEON-NUCLEUS OPTICAL POTENTIAL

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A fully microscopic, antisymmetrized calculation of the imaginary part W of the nuclear optical potential has been performed to second order in an effective projectile target-nucleon interaction (PTI) for a finite nucleus. An optical Green's function is used for the propagation of the intermediate projectile and all energetically open inelastic and charge exchange RPA-intermediate states[1]) are included. Charge exchange processes are rather important accounting for more than 1/3 of W in elastic neutron scattering. The calculated W tends to be surface peaked largely due to surface peaked transition densities of the collective intermediate states; a strongly surface peaked potential does not occur when simple particle-hole intermediate states are used. In the figure we compare the "equivalent local" potential of the calculated non-local one for ^{40}Ca(n,n) with a phenomenological potential (PPOT) of ref. 2 and also with a calculation of Vinh Mau et al.[3]). In comparison with PPOT we find that the calculated potential is surface peaked but that it underestimates PPOT by about 2 MeV in depth and that it is also shifted by 0.5 fm to the inner region of the nucleus. Preliminary calculations show, however, that the latter discrepancy is removed when a density dependent PTI is used. Therefore we conclude that a density dependent PTI together with nuclear collectivity will probably lead to a microscopic imaginary potential which has surface absorption in agreement with phenomenological potentials.



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PRESCRIPTION FOR STRIPPING TO NARROW UNBOUND LEVELS

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A method of DWBA analysis of stripping to unbound levels has evolved in only slightly differing versions from work by Vincent and Fortune[1] and by Huby and others[2]. It differs from DWBA calculation for stripping to a bound level through the wave function used to describe the state formed by nucleon transfer to the target. The prescription for the reaction $A(d,n)B^*_\lambda$ where B^*_λ is unstable against proton decay, may be stated as follows. Suppose the observed (d,n) yield peaks at an energy $E_{n\lambda}$ corresponding to a resonance energy $E_{p\lambda}$ of the residual (p+A) system. One calculates a single-particle wave function for (p+A) scattering, using the Coulomb potential plus a Woods-Saxon potential whose depth is varied to yield exact resonance at the observed energy $E_{p\lambda}$. This wave function is normalised to the asymptotic form $(2m/\pi k)^{\frac{1}{2}} G/kr$, where G is the usual irregular Coulomb wave function. Substitution of this wave function in the DWBA integrals in place of a bound wave function yields the peak double-differential cross-section, denoted $(d^2\sigma/dE_n d\Omega)^{DWBA}$, appropriate for a hypothetical single-particle resonance. According to the theory, the observed differential cross-section $(d\sigma/d\Omega)_{obs}$ (i.e. $d^2\sigma/dE_n d\Omega)_{obs}$ integrated over the resonance and summed over open channels) is $\frac{1}{2}\pi\,\Gamma_{a\lambda}\,(d^2\sigma/dE_n d\Omega)^{DWBA}$, where $\Gamma_{a\lambda}$ is the partial width of the unbound level in the channel of proton plus A in its ground state. So $\Gamma_{a\lambda}$ is $(d\sigma/d\Omega)_{obs}$ divided by $\frac{1}{2}\pi(d^2\sigma/dE_n d\Omega)^{DWBA}$. Next one calculates the single-particle width Γ_λ^{sp}, and the spectroscopic factor S_λ is taken to be

$$S_\lambda = \Gamma_{a\lambda}/\Gamma_\lambda^{sp} = (d\sigma/d\Omega)_{obs}\left[\tfrac{1}{2}\pi\Gamma_\lambda^{sp}(d^2\sigma/dE_n d\Omega)^{DWBA}\right]^{-1}. \quad (1)$$

This procedure runs into difficulty when Γ_λ^{sp} becomes very small. Both Γ_λ^{sp} and $(d^2\sigma/dE_n d\Omega)^{DWBA}$ become difficult to evaluate separately, and unduly dependent on details of the Coulomb-plus-centrifugal barrier, whereas S_λ (determined by their product) should be weakly dependent upon such details. A procedure which circumvents this is inherent in the theory developed by Huby. It rests on using a resonant single-particle wave function which is differently normalized. Writing the single-particle potential as U/β, one again varies β until the regular wave function is asymptotically proportional to G at the observed resonance energy. Then U is rescaled to make β unity at this energy, and $d\beta/dE$ is calculated here. The resonant wave function ϕ_λ at this energy is normalized so that

$$-(d\beta/dE)\langle\phi_\lambda|U|\phi_\lambda\rangle = 1. \quad (2)$$

The result obtained using this wave function in DWBA gives the differential cross-section (i.e. $d^2\sigma/dE_n d\Omega$ integrated over the peak) for a hypothetical single-particle resonance. Calling this $(d\sigma/d\Omega)^{DWBA}$, we calculate the spectroscopic factor by

$$S_\lambda = (d\sigma/d\Omega)_{obs}/(d\sigma/d\Omega)^{DWBA}. \quad (3)$$

The numerical work involved in calculating eqs. (2) and (3) becomes easier, more accurate, and less dependent on barrier details as Γ^{sp} narrows. A procedure is developed for incorporating this wave function into an existing DWBA program (DWUCK4, written by P.D.Kunz and extended by J.R. Comfort) which has been supplied through the kind offices of J.M.Nelson.

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NUCLEAR DYNAMICS CLUES FROM LOW ENERGY NEUTRON SCATTERING[†]

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Neutron scattering at energies $E_n \gtrsim 7$ MeV has been shown to be quite sensitive to collective excitations of target nuclei[1]). Accurate measurements of elastic and inelastic scattering to the 2_1^+ level provide determinations of quadrupole moments of the mass distributions of deformed nuclei. But if the geometrical character of the E2 excitation is unknown, that information cannot be extracted from the neutron scattering cross sections[1]). Even such different modes as surface vibrations of a spherical nucleus or rigid rotations of a permanently deformed nucleus provide nearly identical angular distributions for elastic scattering and scattering to a 2_1^+ level[1]).

However recent work with the Pt isotopes at low incident energies, ~2-4.5 MeV, shows much greater sensitivity of the scattering to the character of collective excitations. Excitations of ^{194}Pt at these energies are strong for axially symmetric and asymmetric modes. Two models are being tested to describe the neutron scattering, a triaxial rotor and an anharmonic vibrational model, which implies a surface "soft" to γ-vibrations. Both have matrix elements or coupling strengths adjusted to fit low-lying excited levels and their E2 decay rates. At 2.5 MeV the elastic data alone differentiate between the two models, showing a clear preference for the γ-vibrational model. But the inelastic scattering is not helpful, since the 2_2^+ level scattering is dominated by compound system contributions. At 4.55 MeV incident the 2_2^+ direct excitation data clearly separate the two models, but now the elastic scattering calculations for the two models are only slightly different. Together these results show the strong sensitivity of the elastic scattering at low incident energies, which rapidly diminishes as the bombarding energy increases. At higher energies accurate inelastic scattering cross sections provide the requisite data for separating models.

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CHARGED PARTICLE CONTINUA FROM NEUTRONS ON CARBON AT 60 MEV*

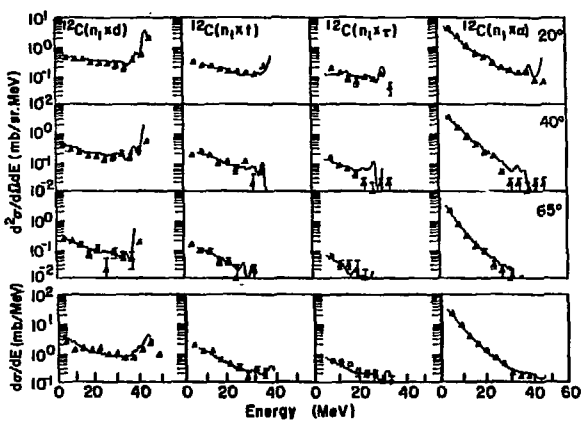
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Continuum differential cross sections for deuterons, tritons, ^{3}He and alphas have been measured at nine angles ranging between 15° and 150°, for 60 MeV neutrons on carbon using the neutron-induced, charged-particle facility at the Crocker Nuclear Laboratory.[1]) Both double-differential and angle-integrated laboratory cross sections are compared with charge symmetric proton-induced reaction data[2]) [viz. (n,xd) with (p,xd), (n,xt) with (p,xτ), (n,xτ) with (p,xt) and (n,xα) with (p,xα)] in the figure. Our data are represented as experimental points and the proton data as a line. The close agreement observed confirms the expected similarity between cross sections for reactions induced by protons and neutrons in self-conjugate nuclei.



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The Isospin Mixing in Ni Double-hole State Analogues

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The excitation of double hole state analogues (DHIAS) in light nuclei has extensively been measured by Berkeley Group using (p, t) reactions[1]. With the increase of mass number, the excitation energy of the DHIAS becomes high and the cross section decreases roughly proportional to $1/T^{2}$, which have hampered the detailed investigation of the DHIAS in heavier nuclei.

The magnetic spectrograph "RAIDEN" was used to observe the DHIAS in Ni isotopes via (p, t) reactions at 55 and 65 MeV. The energy resolution obtained was 15 keV to 20 keV depending mainly on the target thickness. The variation of the triton line width for the ^{58}Ni level with the excitation energy is shown in fig. 1. The width grows rapidly above the proton and neutron separation energies. The DHIAS in ^{58}Ni showed a distinctly structured profile as shown in fig. 2. The spectrum was decomposed into four lines by using a line shape of the low lying state as a standard for the instrumental line profile. The angular distribution of each line showed a characteristic pattern for $J^{\pi}=0^{+}$. The Coulomb matrix elements between the DHIAS and three $T_<$ states were calculated to be 5.3, 2.8 and 3.7 keV, respectively. Fig. 3 shows the DHIAS in ^{62}Ni nucleus. After a careful correction for the energy loss effect on the line shape, the width of the DHIAS in ^{62}Ni was derived to be less than 10 keV, which is remarkablly narrow considering the high excitation energy of the state. Since the proton decay to the excited analogue states in ^{61}Co is expected to be considerablly reduced by the barrier penetration effect (E_p=1.0 MeV, $\Delta\ell$=1), the obtained width would represent the spreading width of the DHIAS. It is interesting to note that the spreading width or the isospin mixing matrix elements for the DHIAS in ^{58,62}Ni and ^{60}Ni (not shown here) are comparable or less than those observed in the single hole state analogues in Ni isotopes[3].

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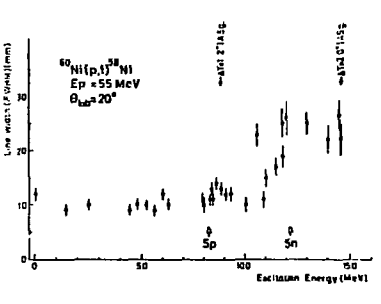


Fig. 1

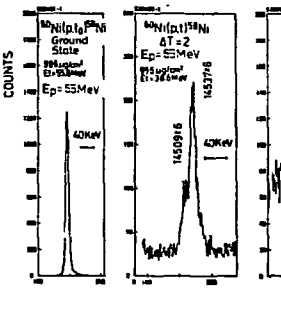


Fig. 2

Fig. 3

STATISTICAL MULTISTEP DIRECT EMISSION IN SOME p,n REACTIONS

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Following the theory by Feshbach, Kerman and Koonin[1,2] which describes correctly the nuclear reaction mechanism called pre-compound emission, we have calculated the multistep direct contribution to the reactions Sn(p,n) Zr(p,n) and Pb(p,n) measured by Galonsky at 45 Mev incident proton energy.

The cross-section for emission of particles according to the SMDE is given by

$$\left(\frac{d^2\sigma}{dU\,d\Omega}\right)_{\substack{multi\\ steps}} = \sum_{\nu}\sum_{m=\nu-1}^{\nu+1} \int\frac{d\vec{k}_1}{(2\pi)^3}\int\frac{d\vec{k}_2}{(2\pi)^3}\cdots\int\frac{d\vec{k}_\nu}{(2\pi)^3}\,\frac{d^2W_{m\nu}(\vec{k}_\nu,\vec{k}_m)}{dU_\nu\,d\Omega_\nu}\,\frac{d^2W_{m-1,m}(\vec{k}_m,\vec{k}_{m-1})}{dU_m\,d\Omega_m}\cdots\frac{d^2\sigma_{fi}(k_1,k_L)}{dU_1\,d\Omega_1}$$

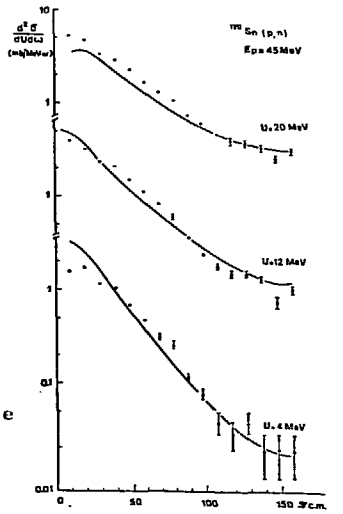
where ν labels the stage of the chain and in the exit mode.

The details of the calculation of the necessary matrix elements have been obtained on the basis of a microscopic description of the two-body interaction in the nucleus. This basic interaction is described by means of a Yukawa potential.

The calculation of the first step of the transition to the continuum, the usual direct effect is performed by the method of averaging on final levels, in the same way of what is done for the next steps.

For incoming and outgoing distorted waves, the optical model potential of Becchetti and Greenless was used.

A good agreement of calculations with experimental results was obtained. The results in absolute value, are shown in the figure which displays the angular distribution of neutrons emitted at three different energies.



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1977 - CLUED - Milano

NEUTRON-NUCLEUS TOTAL CROSS SECTIONS FROM 200 TO 590 MeV[+]

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Neutron-nucleus total cross sections have been measured for the following 14 nuclei: Be, C, O, Al, V, Mn, Co, Cu, Ag, Ce, Ta, Pb, Bi, and U. It was our aim to give a survey across the whole periodic table and to cover in a single experiment the intermediate energy range from 200 to 600 MeV which includes the pion production thereshold. The experiment has been performed at the SIN-neutron beam using the transmission method in "good geometry". For the neutron detection a liquid hydrogen target was used in connection with a magnetic spectrometer for the momentum analysis of the recoiling protons from the n+p → p+n reaction. Because of the extremely small solid angle of about 1 μsteradian defined by the detector, no extrapolation was necessary. The lengths of the absorbers corresponded to a transmission of about 60 %. The influence of double scattering by the absorbers is estimated to be negligible. This has been verified experimentally with copper absorbers of different transmissions. No significant effect could be observed.

From the measured attenuations the cross sections have been evaluated at 20 energies. In the case of oxygen, a water absorber was used and the proton contribution was subtracted using our previous σ_{tot} data[1]. The results have typical statistical errors between 1 % and 2,5 %. The systematic errors, mainly due to beam fluctuations are less than 0,3 %.

The cross sections show minima around 290 MeV for the lighter elements, which shift slightly to about 310 MeV for the heavier elements. Our data agree well with the results of Schimmerling et al.[2], except for Be, Cu, and U, where small but significant discrepancies occur. Our data agree also well with proton total cross sections of Schwaller et al.[3]. For the self conjugate nuclei ^{12}C and ^{16}O it may be useful to compare quantitatively neutron and proton total cross sections. Using the data of Ref.[3] together with ours we get an averaged difference

$$\langle(\sigma_p-\sigma_n) / \sigma_p\rangle \text{ of } 0.006 \pm 0.019 \text{ and } -0.005 \pm 0.015,$$

respectively. In order to extract the global feature of the A-dependence we fitted our data according to the expression $\sigma_{tot}(A,E) = \sigma_o(E)\cdot A^{\beta(E)}$. This results in a β which is linearly decreasing with neutron energy from $\beta = .81$ at 200 MeV to $\beta = .77$ at 590 MeV.

[+]This work was supported by the German Bundesminister für Forschung und Technologie.

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SPIN-TENSOR INTERACTION IN POLARIZATION TRANSFER REACTIONS†

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Beta-emitting nuclei have been polarized in $(\vec{p},n)$, $(\vec{d},n)$, $(\vec{d},p)$, and $(\vec{p},\alpha)$ polarization transfer reactions in thick crystalline targets. All recoil nuclei are stopped in the thick target which is placed in a strong magnetic field to preserve polarization. The asymmetric beta decay of the implanted recoil nuclei is detected to measure the polarization transferred. We have observed polarization transfer in 17 reactions: $^{7}Li(\vec{d},\vec{p})^{8}Li$, $^{11}B(\vec{d},\vec{p})^{12}B$, $^{16}O(\vec{d},n)^{17}F$, $^{19}F(\vec{p},n)^{19}Ne$, $^{19}F(\vec{d},\vec{p})^{20}F$, $^{23}Na(\vec{p},n)^{23}Mg$, $^{25}Mg(\vec{p},n)^{25}Al$, $^{28}Si(\vec{p},\alpha)^{25}Al$, $^{27}Al(\vec{p},n)^{27}Si$, $^{27}Al(\vec{d},p)^{28}Al$, $^{28}Si(\vec{d},n)^{29}P$ $^{29}Si(\vec{p},n)^{29}P$, $^{31}P(\vec{p},n)^{31}S$, $^{32}S(\vec{d},n)^{33}Cl$, $^{35}Cl(\vec{p},n)^{35}Ar$, $^{39}K(\vec{p},n)^{39}Ca$, and $^{40}Ca(\vec{d},n)^{41}Sc$.

A simple spectator model (Fig. 1) describes the deuteron stripping polarization transfer reactions. The addition of a single spin-polarized nucleon to the valence orbit of the unpolarized target nucleus determines that the polarization transfer to the product nucleus will be positive if the valence orbit is a stretched configuration and negative if it is jack-knifed.

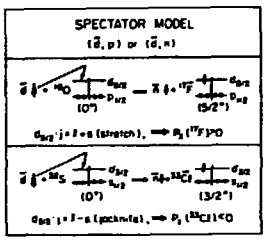


Fig. 1

A simple quasi-elastic model (Fig. 2) describes the charge-exchange polarization transfer reactions. The proton and neutron exchange charge but rarely spin, so the recoil neutron spin is preferentially parallel to the projectile proton spin. If the product nucleus is an odd proton mirror of the target nucleus, the polarization transfer will be positive if the valence orbit is stretched and negative if jack-knifed. If the product nucleus is an odd neutron mirror of the target nucleus, the unpaired neutron will have spin preferentially antiparallel to the projectile proton and the polarization transfer will be negative if the valence orbit is stretched and positive if jack-knifed.

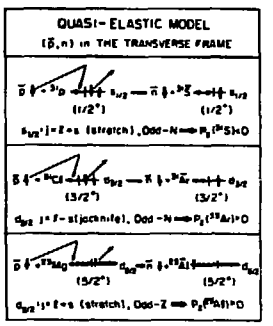


Fig. 2

A DWBA calculation of the $^{31}P(\vec{p},n)^{31}S$ reaction can describe the sign and general shape of the polarization transfer (Fig. 3). The nucleon-nucleon interaction includes a charge-exchange potential $V_{\sigma\tau} = 9$ MeV, a spin-flip potential $V_{\sigma} = 6$ MeV, and a spin-tensor potential $V_{T} = 8 \pm 4$ MeV. This result is consistent with recent observations of the polarization and angular distribution of neutrons from the $^{11}B(p,n)$ and $^{14}C(p,n)$ reactions.

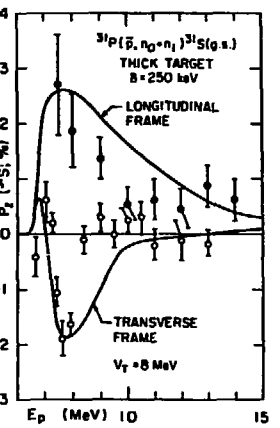


Fig. 3

†Supported by the National Science Foundation.
††Present Address: Shell Development Co., Physics, Math & Comp Sci Dept., P.O.Box 481, Houston,TX 77001.

SYSTEMATICS OF NONFISSION REACTIONS INDUCED BY PROTONS WITH ENERGIES GREATER THAN 100 MeV.†

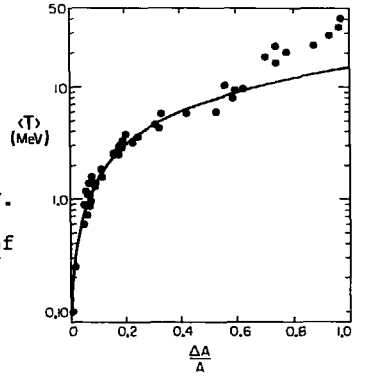
Lester Winsberg

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Experimental results for nonfission reactions induced by protons with energies greater than 100 MeV are analyzed by simple models[1]). Spallation reactions are assumed to occur in two steps: an initial fast process in which momentum is transferred to the struck nucleus in the forward direction, followed by an isotropic random-walk process. The reaction parameters are divided into three groups. The first two correspond to these two reaction steps and the third is based on an energy inventory of the overall reaction. Systematic deviations from this model are attributed to the presence of fragmentation.

First step. The combined spallation and collision-tube models give the mass Δm of the effective target, the excitation energy E^* (which includes the kinetic energy of the excited nucleus and the separation energy of the emitted nucleons), $E^*/\Delta A$ where $\Delta A = A$ (target nucleus) $- A_{REC}$ (observed nucleus), and $\Delta A/\Delta m$. SYSTEMATICS: (1) Δm, E^*, the binding energy per nucleon, and the average mass of the emitted particles increase with ΔA. (2) $E^*/\Delta A$ decreases with ΔA. (3) $\Delta A/\Delta m \approx 15$ for the reactions in gold that were analyzed. (4) The collision-tube model is not valid in light nuclei when ΔA is large.

Second step. The average recoil energy imparted in this step to the observed nucleus is $\langle T \rangle$. The average energy of the recoil partners is ε_S in a random-walk process and ε_F in two-fragment breakup. SYSTEMATICS: (1) Spallation is indicated if $\Delta A/A < 0.67$ and $\langle T \rangle = \varepsilon_S \, \Delta A/A$ MeV with $\varepsilon_S \approx 17$ MeV, see figure. The average energy of ^2H, ^3H, ^3He, and $^4He \approx 16$ MeV. This result is evidence for a random-walk process, caused by the emission of these particles. (2) A combination of fragmentation and spallation is indicated if $\Delta A/A > 0.67$, $A_{REC} > 5$, and $\langle T \rangle = 20$-50 MeV. (3) The largest values of $\langle T \rangle$ are found in fission (50-100 MeV).



Probability of various reaction modes. The upper limit to the probability of a given reaction mode P_{max} can be calculated from an energy inventory of the reaction. SYSTEMATICS: (1) P_{max} is largest for nucleon emission if ΔA is small and is zero for large values of ΔA. (2) P_{max} is larger for α emission than for nucleon emission but $\to 0$ for very large values of ΔA. (3) $P_{max} = 1.0$ for most reactions involving two-fragment breakup.

†This work was supported by the National Science Foundation and the Division of Nuclear Physics of the U.S. Department of Energy.

1) L. Winsberg, submitted to the Physical Review C.

CORRELATION EFFECTS IN HIGH ENERGY (p,d) REACTION

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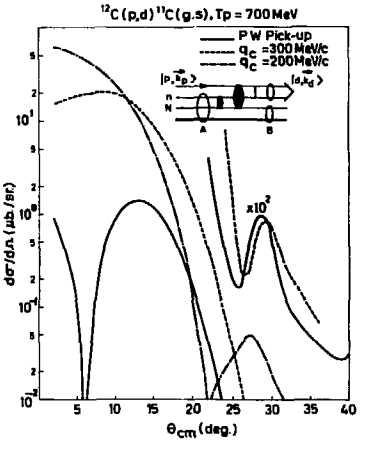
The (p,d) reaction at high energy are described by considering the interaction of the incident proton with the correlated pair in the nucleus. For the diagram shown in the figure, the cross-section for (p,d) reaction may be written as

$$\frac{d\sigma}{d\Omega} = F_{kin} \overline{\sum} \left| \langle \underset{\sim}{k}_d, \varphi_d(01)\psi_{\alpha_2}(2) | V_{01} | \{\chi_s(02)\{\underset{\sim}{k}_p, \chi_b(12)\psi_{\alpha_1}(1)\psi_{\alpha_2}(2)\}\} \rangle \right|^2$$

where F_{kin} is the kinematic factor and ψ_α are the single particle bound state wave functions. f are the correlation functions. They are written as $f = 1 - g$. Where

$$g(r) = \frac{1}{4\pi} \int dq\, d\Omega\, W(q)\, e^{i \underset{\sim}{q} \cdot \underset{\sim}{r}}$$

In this preliminary investigation we have assumed $f_s = f_b$ and $W(q) = \delta(q - q_c)$. Using Reid soft core deuteron wave function and Elton-Swift wave functions for bound nucleons results corresponding to q_c = 200 and 300 MeV/c are shown in the figure. For comparison the plane wave predictions of the normal pick-up model are also shown. It shows that the cross-section is very sensitive to the correlations. The correlations change both the magnitude as well as the shape of the angular distribution. In line with the experiments[1] (not shown in the figure) the results with correlations have lesser structure.



1. S.D. Baker et al., Phys.Lett. B52 (1974) 57

TWO NUCLEON MODEL FOR (p,d) REACTION AT HIGH ENERGY

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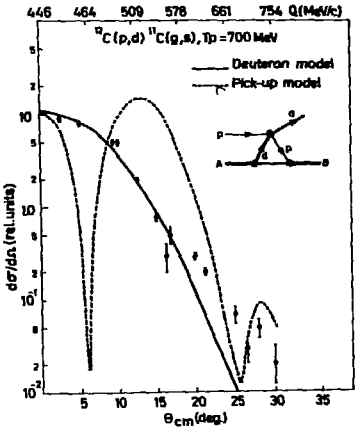
Calculations are done for (p,d) reaction at 700 MeV for $^{12}C \rightarrow {}^{11}C$ (g.s.) transition in the quasi-deuteron model. In this model the cross-section may be written as

$$\frac{d\sigma}{d\Omega} \propto \left(\frac{d\sigma}{dE\,d\Omega}\right)_{pd} |F(k_p, \theta)|^2$$

where $(d\sigma/dE\,d\Omega)$ is the free p + d → p + d cross-section at energy E. F is the structure factor, given by

$$F(k_p, \theta_d) = \sum_{i_n i_p} \int d\vec{P}_p'\, d\vec{P}_p\, d\vec{P}_n\, \psi^*_{i_p}(\vec{P}_p') \left\{ \varphi_d\left(\tfrac{1}{2}(\vec{P}_n - \vec{P}_p)\right) \psi_{i_p}(\vec{P}_p)\, \psi_{i_n}(\vec{P}_n) \right\} \delta(\vec{k}_p + \vec{P}_n + \vec{P}_p - \vec{k}_d - \vec{P}_p')$$

where i_p and i_n are the sums over protons and active neutrons respectively. Using the Reid soft core deuteron wave function, Elton-Swift wave functions for nucleons and the experimental pd cross-section of Vincent et al[1] results are shown in fig. 1. Since in this calculation the attenuation of the outgoing deuterons and incoming protons is not included, we have compared only the shapes of the computed and measured distributions[2]. For comparison the predictions of the usual pick-up model in plane wave are also shown. It is evident that, in contrast to the pick-up model, quasideuteron model reproduces the shape of the distribution to a great extent. Calculations with the inclusion of distortion of protons and deuterons are in progress.

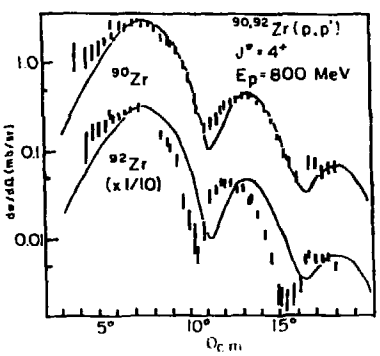


1. J. Vincent et al., Phys. Rev.Lett. 24 (1970) 236
2. S.D. Baker et al., Phys. Lett. B52 (1974) 57

$^{90,92}Zr(\vec{p},p')$ REACTIONS AT 800 MeV*

F. T. Baker[a], C. Glashausser[b], A. Scott[a], G. Adams[c], M. Grimm[a], G. Hoffman[d], G. Igo[c], W. G. Love[c], J. Moss[d], V. Penumetcha[a], W. Swenson[e], and B. E. Wood[f]

Angular distributions of differential cross sections and analyzing powers have been measured for elastic and inelastic scattering of 800 MeV protons from ^{90}Zr and ^{92}Zr. The data, acquired in 0.3° steps for the angular range 2°-18°, were obtained using the High Resolution Spectrometer at LAMPF. Excited states for which data have been obtained are the 2^+ (2.18), 5^-, 3^-, 4^+, 2^+ (3.31), 6^+, 8^+ for ^{90}Zr and 2^+ (0.93), 4^+, 2^+ (1.83), 3^-, 5^-, for ^{92}Zr. The data for elastic scattering and inelastic scattering to the more collective 3^- and 5^- states are virtually identical in shape for the two targets; collective-model DWBA analyses provide excellent fits to these data and, particularly from the fits to the analyzing power data, strongly indicate the need for deforming the spin-orbit potential. Significant differences, however, have been observed for the less collective first 2^+ states and for the 4^+ states of ^{90}Zr and ^{92}Zr. The data for the differential cross sections of the 4^+ states shown in the Figure are representative of these differences. Although similar differences may be seen in the analyzing power data, these are somewhat less convincing because of larger experimental uncertainties. Also shown in the Figure are collective-model DWBA predictions using equal deformations for all potentials. Since these two calculations are virtually identical, they emphasize the differences between the two nuclei. It is generally assumed that the dominant configurations for these J=2,4 states are $(\pi g_{9/2})^2_J$ for ^{90}Zr and $(\nu d_{5/2})^2_J$ for ^{92}Zr. We therefore expect that microscopic-model impulse-approximation analyses of these data will yield interesting results concerning the sensitivity of intermediate-energy proton scattering to the microscopic nature of the states excited.



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TWO-STEP PROCESSES IN THE $^{112}Sn(p,t)^{110}Sn$ REACTION AND THE VALUE OF D_0

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The cross section for a (p,t) reaction in zero-range DWBA is proportional to the zero-range normalisation constant D_0^2. The value often used (D_0^2 = 25-40 in units of 10^4 MeV^{2}fm^3) is not a theoretical estimate[1] ($D_0^2 \approx 8$), but is obtained from cases, where the nuclear wave functions are assumed to be known. So contributions of e.g. two-step processes are incorporated in the value of D_0^2.

The influence of such process was investigated in the $^{112}Sn(p,t)^{110}Sn$ reaction at E_p = 27.5 MeV. One- and two-step calculations were performed with CHUCK using spectroscopic amplitudes calculated from number-projected BCS wave functions. These calculations reproduce the single-neutron transfer[2]. Great care was taken to treat consistently the various phase factors. The calculations were done in zero-range. Finite-range and nonorthogonality effects are estimated to be small[3].

The one-step description of the ground-state transition requires D_0^2 [illegible], but fails to reproduce the shape of the angular distribution (see fig. 1). The two-step process (p,d)(d,t) accounts for about half of the cross section (the contributions of the various orbitals adding coherently). Combination of the two-step contribution with a one-step transition with D_0^2 = 23 yields a rather good description of the data. These calculations used a model space of one major shell. The use of three major shells reduces D_0^2 to about 10.

For the 2^+ state the influence of sequential transfer is negligible due to destructive interference between the various components, but here the inelastic excitation of the core preceding or following two-neutron transfer is important. The one- and two-step contributions yield the same shape and interfere contructively. The measured angular distribution is well reproduced (see fig. 2). The inclusion of the two-step processes reduces the value of D_0^2 needed to explain the data from 32 to 7.

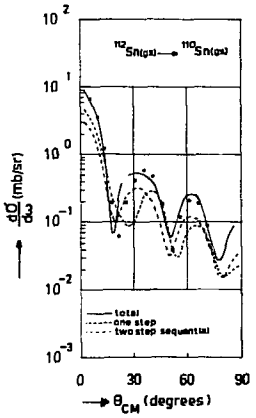


fig. 1

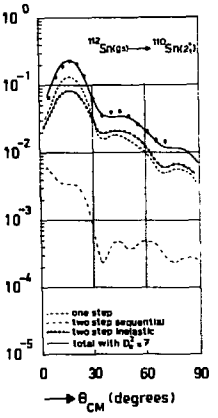


fig. 2

1) T.K. Lim, Phys.Rev. C7 (1973) 1288
2) P.J. Blankert, Thesis, Vrije Universiteit, Amsterdam (1979)
3) N. Hashimoto and M. Kawai, Prog.Theor.Phys. 59 (1978) 1245
N. Hashimoto and M. Kawai, Prog.Theor.Phys. 59 (1978) 1562

THE SPIN-ORBIT FORCE AND BEATS IN p-NUCLEUS SCATTERING

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The universally similar nature of a wide variety of elastic and inelastic proton-nucleus scattering phenomena at intermediate energies arises from the dominance of the nuclear geometry which for a Fermi distribution is characterized by two parameters, the half density radius, c, and the diffusivity, β.[1] A useful heuristic approximation to the scattering amplitude which displays this dominance is $A_o\, Re^{-iq\,b_o}$, where $b_o = c + i\pi\beta$, which displays the oscillations and exponential fall-off characteristic of scattering in this regime. The fact that the nuclear geometry dominates allows one to include spin dependent forces simply. If the fundamental nucleon-nucleon amplitude is written $T_{NN}(q) = A(q) + \vec{d}\cdot\hat{n}\, C(q) \simeq A(q)\,(1+qw\vec{\sigma}\cdot\hat{n})$, where w is constant, one can derive spin channel optical potentials of the form

$$V^{\pm}_{opt}(r) = V_c(r) \mp iw \frac{d}{dr} V_c(r).$$

Noting that the spin orbit "length" parameter, w, is much smaller than the dominant characteristic length, b_o, we may invoke Taylor's theorem to write $V^{\pm}_{opt}(r) \cong V_c(r \mp iw)$.

For a Fermi distribution this is equivalent to the change $b_o \to b^{\pm}_o = c \pm \mathrm{Im}\, w + i\pi(\beta \mp \mathrm{Re}w/\pi)$.

The spin orientation only changes the effective size of the target nucleus. Whatever analysis one uses to convert V_c into (spin-independent) cross sections may now be used to convert $V^{\pm}_{opt}$ into spin channel cross sections and thus determine polarizations.

A transparent illustration where changing the effective nuclear radius for spin channels has dramatic consequences is when c/Imw is the order of a few and Rew/πβ is small. Then within the usually observed angular range the spin channel cross sections will have sufficiently different periods to produce a beat-like phenomenon in the unpolarized cross section, that is the filling-in and subsequent reappearance of diffraction minima. The 135 MeV ^{90}Zr(p,p) data[2] shown in Fig. 1 is a striking example of this effect.

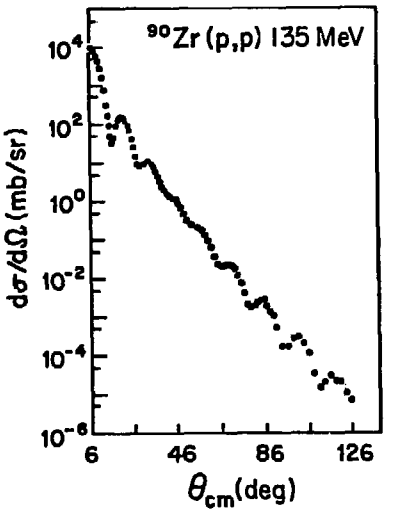


Figure 1

†Supported in part by a grant from the U. S. National Science Foundation.

1. R. D. Amado, F. Lenz, J. A. McNeil and D. A. Sparrow, submitted to Phys. Rev. C.
2. Reproduced from Indiana University Cyclotron Facility Newsletter No. 22, Feb. 1978.

STUDY OF THE $^{41}K(p,n)^{41}Ca$ REACTION

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Spectroscopic information similar to that obtainable from (d,p) reactions can be extracted from a study of the isobaric analog resonances (IAR) populated through (p,p) and (p,n) reactions. When the analog states are below the Coulomb barrier of the proton plus target system, the corresponding anomalies in the (p,p) channel are very weak. These states, however, show up rather prominently in the (p,n) channel[1] and can be shape analysed to obtain the spectroscopic information on the parent levels. Thus the study of the (p,n) reactions at sub-Coulomb energies is a very convenient tool to study low-lying IAR and to extract the proton optical model parameters at low energies.

The total (p,n) cross-sections for the reaction $^{41}K(p,n)^{41}Ca$ have been measured utilizing a 4π -geometry neutron counter and K_2SO_4 targets ($\sim$ 1.6 keV thick for 2 MeV protons). The excitation function was measured in 5 keV steps for E_p = 1.460-4.100 MeV. Strong IAR were observed at E_p = 1.465, 1.880, 2.358, 2.790, 3.545 and 3.900 MeV. The results of the optical model, Hauser-Feshbach (HF) and HF Moldauer calculations are shown in fig.1. The shape analysis of the IAR was carried out using the Robson-Johnson[2] expressions. A typical case is shown in fig.2.

The spectroscopic factors for the IAR at E_p = 1.564, 1.880, 2.358 and 3.545 MeV extracted from the present analysis are 0.19, 0.61, 0.1 and .08 respectively. (d,p) results are not available in literature for comparison.

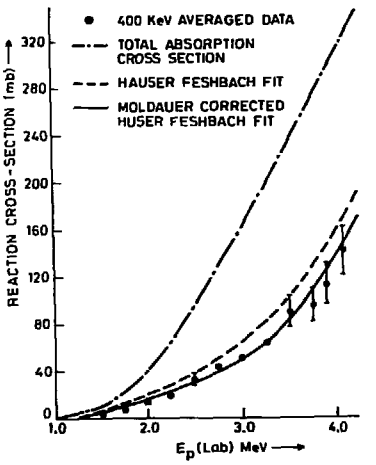


Fig.1

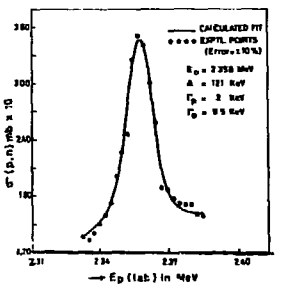


Fig.2

* DAE Research Fellow.

1. Y.P. Viyogi et al, Phys. Rev.C18 (1978) 1178, S. Kailas et al, Nucl. Phys. A315 (1979) 157, Phys. Rev.C12 (1975) 1789.

2. C.H. Johnson et al, Nucl. Phys. A107 (1968) 27.

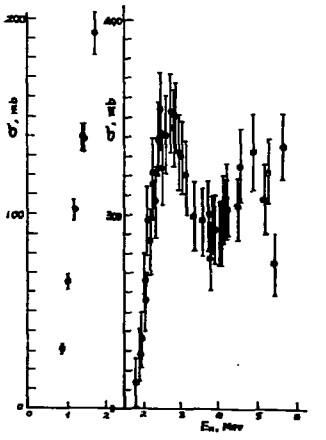
THE BROAD STRUCTURE IN THE EXCITATION CURVE OF $^{115}In(n,n')^{115m}In$ REACTION

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Huang Jian-zhou

Institute of Atomic Energy
Academia Sinica, Beijing China

Cross section for the $^{115}In(n,n')^{115m}In$ reaction has been measured by the activation method in the neutron energy range of 0.88-5.65 MeV and 14.1-14.8 MeV with uncertainty about ±5%.

The excitation curve (Fig1) for $^{115}In(n,n')^{115m}In$ reaction exhibits a hump at about 2.7 MeV and a valley at about 4 MeV, then the cross section increases with energy and shows slight fluctuation in the 5-5.4 MeV region. Similar structure, but not as conspicuous, also exists in the results of other authors [1,2] without explicitly mentioning.



The explanation could be the following: the result of the varying contributions from discrete levels and the high continuous states of ^{115}In, the result from direct interaction or from the (n-p) pairing effect.

1. D. L. Smith et. al ANL-NDM-14(1975)
2. D. C. Santry et. al NSE 58 (1975) 377

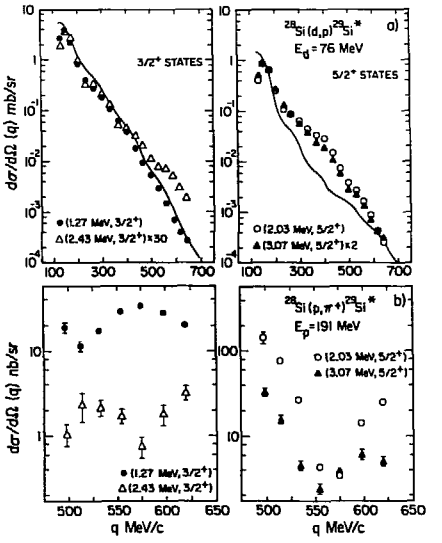
COMPARISON OF (d,p) AND (p,π^+) ON ^{28}Si AT SIMILAR MOMENTUM TRANSFERS†

W. W. Jacobs, A. G. Drentje,* P. H. Pile,** P. P. Singh, T. P. Sjoreen, and S. E. Vigdor

Indiana University Cyclotron Facility, Bloomington, Indiana 47405

With a view to compare and contrast the (d,p) stripping reaction with the (p,π^+) reaction, cross section angular distributions have been measured at momentum transfers (q) up to 600 MeV/c for the two reactions. In both cases two $3/2^+$ states (E_x=1.27 and 2.43 MeV) and two $5/2^+$ states (E_x=2.03 and 3.07 MeV) in ^{29}Si were clearly resolved. Of particular interest is a comparison of (d,p) and (p,π^+) results for relative population of states of the same J^π, but different single-particle strengths, in ^{29}Si. Such a comparison should be sensitive primarily to differences in residual-state wave function components sampled by the two reactions; other differences, e.g., in angular momentum coupling/matching, and in distortions of incident and outgoing waves, should effectively cancel for population ratios.

For the (d,p) results in the figure, the 3.07 MeV cross section has been multiplied by 2 (the spectroscopic strength ratio observed for (d,p) at E_d=18 MeV[1]), and the E_x=2.43 MeV data by a factor 30 (this state has a non-stripping character at lower energies[1]). The similarity over a wide range of q of the distributions observed for states of the same J^π, but very different microscopic structure, suggests that here the (d,p) reaction is sampling primarily the single-particle components of the bound-state wave functions. For the weak 2.43 MeV state, the onset of another reaction process may cause the enhancement at large q. The solid lines are DWBA calculations for the 1.27 and 2.03 MeV states with spectroscopic factors (0.74 and 0.12, respectively) from low-energy (d,p)[1].



For both pairs of states (especially $3/2^+$) we observe substantially greater differences between the (p,π^+) distributions than between those for (d,p), and also significantly different angle-averaged population ratios. Calculations within a pionic stripping model confirm expectations that the (p,π^+) differences cannot be attributed to Q-value effects. This comparison thus suggests that (p,π^+) is more sensitive than (d,p) to other than single-neutron components in the bound-state wave function. More specific conclusions concerning mechanism differences await comparison of such data (especially state-to-state differences) with calculations based on various models.

†This work supported in part by the National Science Foundation and NATO.
*On leave from Kernfysisch Versneller Instituut, Groningen, The Netherlands.
**Present address: Carnegie-Mellon University, Pittsburgh, PA 15213
1) M. C. Mermaz et al., Phys. Rev. C 4 (1971) 1778.

THE $^{40}Ca(p,t)^{38}Ca$ REACTION AT 45 MEV*

Kamal K. Seth and A. Saha

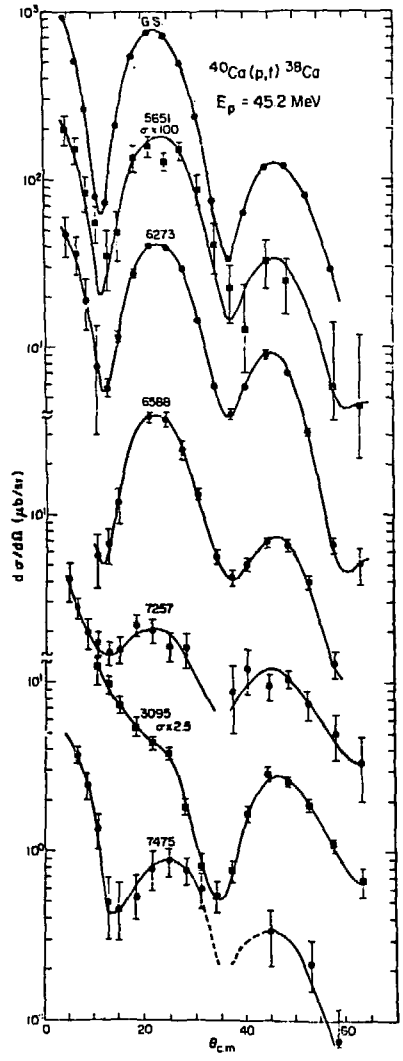
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We have studied the reaction $^{40}Ca(p,t)^{38}Ca$ at the Michigan State University cyclotron-spectrograph facility at E_p=45.24 MeV. An energy resolution, FWHM 12-15 keV was obtained and data was taken in the angular range 4° to 60°. Fourty-four states were resolved up to an excitation energy of 8 MeV whereas only sixteen were known before[1] J^π have been assigned for thirty-four of the observed states. This includes seven 0^+, ten 2^+, twelve 3^-, three 4^+ and two 5^- states. Correspondence with the mirror states in ^{38}Ar is found to be generally good.

Earlier s-d shell calculations[2] completely fail to reproduce the observed density of positive parity states. For example, these calculations predict only one excited 0^+ state below 7.5 MeV whereas in our experiment at least seven 0^+ states are observed, as illustrated by the angular distributions in Fig. 1. We have done $f_{7/2}\ d_{3/2}^{-1}$ shell model calculations with configurations up to (4p-6h) included, and these do lead to a fairly good reproduction of the energy spectrum. However, detailed agreement with our differential cross section data continues to remain quite poor.



*Work supported in part by the U.S. Department of Energy

†Now at Indiana University, Bloomington, Indiana 47401

1) P. M. Endt and C. Van der Leun, Nucl. Phys. A310 (1978)

2) B. H. Wildenthal et al., Phys. Rev. C4 (1971) 1266.

SYSTEMATICS OF GROUND STATE (p,t) TRANSITIONS IN CALCIUM ISOTOPES*

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In order to study the systematics of the ground state (p,t) transitions in terms of nuclear models, it is necessary to measure accurate relative cross sections. Using the 40 MeV proton beam from the MSU cyclotron we have measured differential cross sections at θ_L = 18°, 20° and 23° near the ∿22° maximum of the L = 0 angular distributions using targets with several different mixtures of the isotopes as listed in Table 1. For ^{40,44,48}Ca the results are in good agreement with those of Bassani and Hintz[1] who used 5-10 mgm/cm^2 targets which could be easily weighed, but differ by 25% from those of Crawley et al.[2] who used a 1.1 mgm/cm^2 target.

For the ^{43}Ca(p,t)^{41}Ca(g.s.) a clear L = 2 component (17% ± 2%) was identified in the predominantly L = 0 angular distribution[3]. When this contribution is subtracted and the cross sections are corrected for Q-value differences by means of DWBA calculations, it is found that σ(θ(cm) = 22°) are ^{42}Ca:^{43}Ca:^{44}Ca:^{48}Ca as 1.00:0.71(2):1.36(4):0.71(3). The predictions of a simple $1f^n_{7/2}$ model for these ground states are 1:3/4:3/2:1. The agreement is therefore quite good except for ^{48}Ca, for which the discrepancy may be attributed to the participation of the $2p_{3/2}$ orbit.

Table I. σ(θ(cm)=22°) in μb/sr for g.s. (p,t) transitions in calcium isotopes.

Target Calcium Isotopes	40	42	43	44	48
a) "$"[33.5%(40),34.2%(44),32.4%(48)]	338			737	337
b) "^{43}Ca"[12.8%(40),5.4%(42),81.1%(43)]	350	568	441	743	
c) "^{42}Ca"[5.0%(40),94.4%(42),0.56%(44)]	345	565			
d) Average (±10% absolute,±3% relative)	344	567	441	740	337
e) Bassani (±20% absolute,±10% relative)		560		770	355
f) Our Relative σ(θ), L = 0 part only	.59(2)	<u>1.0</u>	.65(3)	1.30(4)	.59(2)
g) Relative σ(θ), Q corrected		<u>1.0</u>	.71(3)	1.36(4)	.71(3)
h) $f^n_{7/2}$ model prediction		<u>1.0</u>	.75	1.50	1.0

*Supported in part by the U.S. Department of Energy.
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ABOUT THE ANOMALY OF THE IMAGINARY POTENTIAL AROUND A = 105*

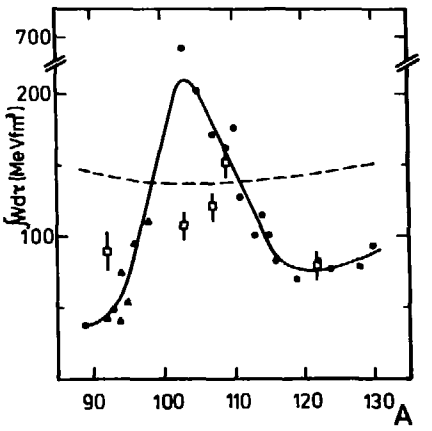
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Many (p,n) cross sections were measured by Johnson et al.[1] and Flynn et al.[2] in the mass region $89 \leq A \leq 130$ for energies from 2 MeV to 6 MeV. To fit these data with the absorption cross section calculated from the optical model only the depth, W_D, and the diffuseness, a_D, of the imaginary potential had to be adjusted. The diffuseness amounts to $a_D = 0.4 \pm 0.04$ fm for all mass numbers but the depth shows a strong A-dependence, rising from $W_D = 5$ MeV at A = 89 to $W_D = 30$ MeV at A = 103 and decreasing again to $W_D = 12$ MeV at A = 120.

Because of this unexpected result, we investigated another quantity, the analyzing power of the elastic proton scattering, which strongly depends on the imaginary potential. This quantity was measured at an energy around 6 MeV for ^{122}Sn, ^{109}Ag, ^{107}Ag, and ^{103}Rh. In all cases, the proton energy was below the first isobaric analog resonance. The analyzing power was measured in the angular range from 40 to 160 degree having two maxima and a minima with values of about $4 \cdot 10^{-3}$. Details of the experiment will be published elsewhere[3].

In this subcoulomb energy region, the analyzing power determines only the product $W_D \cdot a_D$ and thereby the volume integral of the imaginary potential. Therefore, in the figure, we plotted this value versus the mass number using the parameters determined by Johnson et al. (dots) and Flynn et al. (triangles). The full curve interpolates between these (p,n) data. Our results (squares) show large discrepancies for ^{107}Ag and ^{103}Rh. However, in these cases we can also reproduce the measured (p,n) cross section at $E_p = 6$ MeV, taking $a_D = 0.4$ fm. The differences occur at lower energies.



In the figure we also plotted the volume integral calculated with the global parameters of Becchetti and Greenlees (dashed curve). Our values scatter around this prediction, only at the magic numbers they lie definitively lower. The anomaly around A = 105 with values of 200 MeVfm³ cannot be confirmed from our measurements at $E_p = 6$ MeV.

*This work was supported by the Deutsche Forschungsgemeinschaft

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STUDY OF (d,π^-) REACTIONS ON LIGHT NUCLEI

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Pion production by 300 MeV and 600 MeV deuterons has been studied. The experiment was performed at the Saturne II synchrotron by means of the SPES I facility. Inclusive π^-spectra have been measured at 600 MeV on ^{6}Li, ^{10}B and ^{9}Be targets at 15° lab. The Lorentz invariant cross-sections deduced at this energy are plotted (fig.1) versus the scaling variable $x=k_{//}/k_{//\,max}$ where $k_{//}$ is the longitudinal momentum of the pion in the overall center of mass system. The error bars are due to statistics and beam monitoring uncertainty. An overall error of ±14% must be added for ^{9}Be and ^{6}Li data and of ±18% on ^{10}B data. The most striking feature of the data is the tendency of the data to be on top of each other for the three targets. High energy data of Papp et al.[1] obtained for lower values of x do not fall on the same curve. The scaling behavior does not seem to persist at energies lower than 1 GeV and for values of x near 1. It must also be kept in mind that the experiment was performed at a fixed lab. angle and $k_\perp$ is not quite constant. This effect must be important near x=1.

Negative pion production leading to discrete excitation levels of the residual nucleus has also been investigated on ^{6}Li target at 300 and 600 MeV. A spectrum obtained on-line at 300 MeV is presented on fig.2. A very preliminary cross-section of about 0.5 nb/sr can be deduced for the excitation of the g.s. of ^{8}B. A complete analysis is in progress and will be presented.

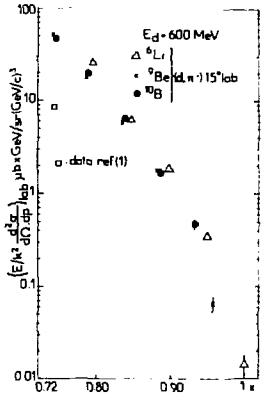


Fig. 1

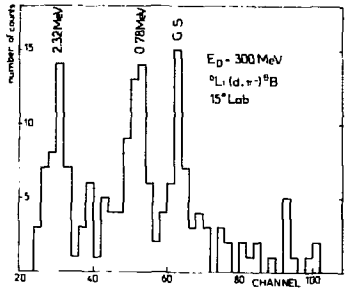


Fig. 2

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NEW PHENOMENA IN DEUTERON BREAK-UP NEAR THE COULOMB BARRIER[§]

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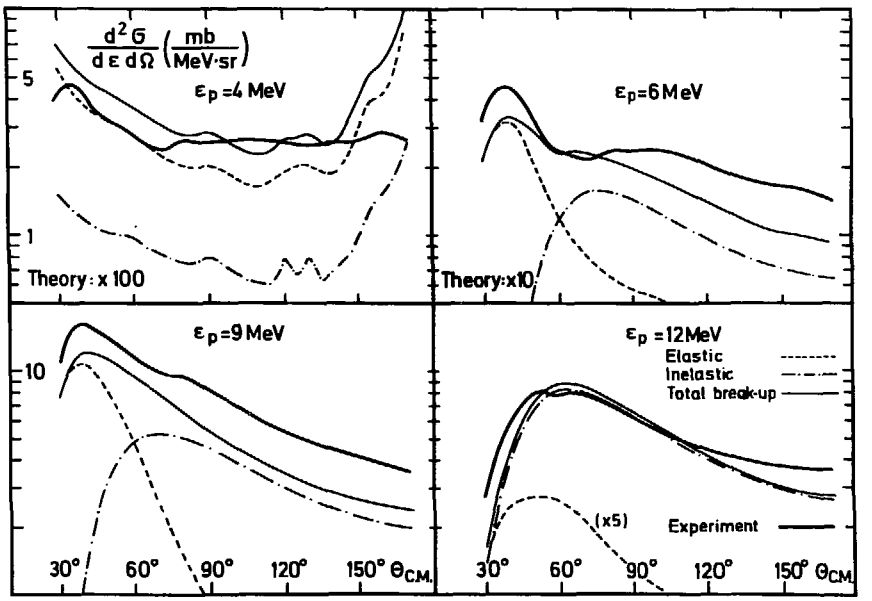
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Inclusive proton spectra from the break-up of 15 MeV deuterons on ^{27}Al, ^{62}Ni, ^{93}Nb, ^{119}Sn, ^{181}Ta and ^{232}Th were studied at lab angles from 23° to 170°. Compared with previous work[1]) at 25.5 MeV new phenomena appear for the heavier targets (A > 93) where the incoming energy is near the Coulomb barrier. As a representative case we show in the figure four angular distributions of the $^{232}Th(d,pX)$ reaction at different proton energies.

At 12 MeV near the break-up threshold the inelastic mode[1]) strongly dominates; it takes into account non-elastic reactions of the unobserved neutron with the target nucleus. At 9 MeV, at about the maximum break-up energy the DWBA theory[1]) predicts an angular separation of the elastic and inelastic mode in good agreement with the experimental sum cross section. Experimentally, this phenomenon is even more pronounced at lower energies. However, the theory underestimates the observed cross sections by a factor of 10 at 6 MeV, and up to 100 at 4 MeV (see figure). This discrepancy is currently investigated in terms of a polarisation of the deuteron in the Coulomb field of the target nucleus.

[§]This work was supported by the Bundesminister für Forschung und Technologie.

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FOUR-NUCLEON TRANSFER REACTIONS ON sd-SHELL NUCLEI

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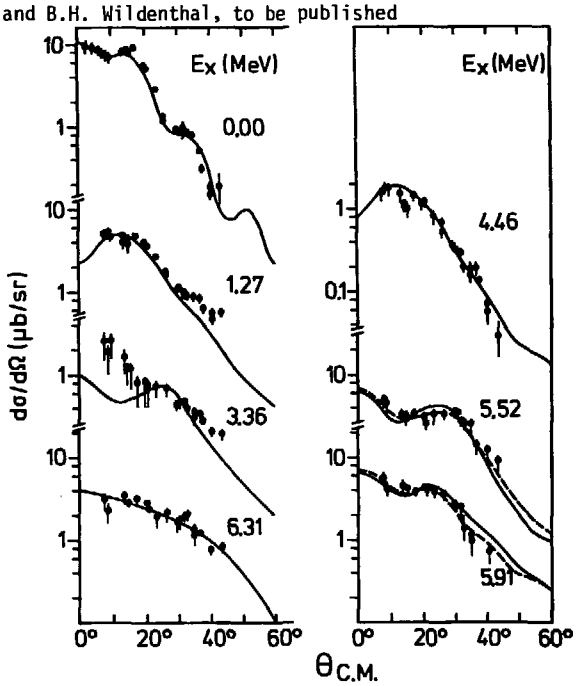
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The (d,^{6}Li) alpha transfer reaction has been measured on nuclei of the sd-shell at E_d=80 MeV. Spectroscopic information was obtained by a finite range DWBA analysis.

A systematic ground state to ground state transition study resulted in a good agreement of experimental and theoretically predicted[1] alpha spectroscopic factors (S_α) for nuclei with A<30. For heavier masses, however, S_α factors are observed to be significantly larger than the predicted ones.

In general the experimental S_α values for excited states (relative to the ground state transition of the same nucleus) agree rather well to shell model predictions. In some cases, however, the assumed direct one-step reaction process seems not to meet the actual physical conditions. For instance: in ^{22}Ne the experimental angular distribution of the first 4^+ state at 3.36 MeV (see Fig.) is not reproduced by DWBA calculations; the extracted "S_α factor" is larger by a factor of ten than the theoretical one which itself is predicted[1] to be small. The experimental angular distribution of the second 4^+ state at 5.52 MeV is well fitted by the DWBA calculation; the extracted S_α factor is only about 20 % larger than the predicted[1] relative value. Coupled channel calculations are in progress and seem to be important for a better description of the reaction mechanism.

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SEARCH FOR THE INTERMEDIATE STRUCTURE OF NUCLEAR REACTION INDUCED BY LOW ENERGY DEUTERON

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There was lack of conspicuous evidences of intermediate structure in nuclear reactions induced by deuteron. We tried to look for the intermediate structure in the nuclear reaction induced by low energy deuteron on light nuclei. Some(d,p) reactions have been studied in energy region E_d<2.5 MeV.

Some possible intermediate resonances in $^{12}C(d,p)$ and ^{28}Si (d,p) reaction have been studied. In $^{12}C(d,p)$ reaction an isolated resonance at E_d=1.73 MeV with width about 120 kev was observed, particularly in (d,p_g) channel, In $^{28}Si(d,p)$ reaction a new intermediate resonance at E_d=1.90 MeV with width about 150 kev and two other resonances at E_d=2.13 MeV and 2.33 MeV were also observed. For these mentioned resonances there are unambigious correlations between excitation functions at different angles and different channels as well. The angular distributions vary smoothly across the resonances and there are some fine structures in these resonances. Spin and parity of the resonance state in $^{12}C(d,p)$ reaction at E_d=1.73 MeV has been determined from average angular distribution to be 2^- and that corresponding to $^{28}Si(d,p)$ resonance state at E_d=1.90 MeV is 2^+.

In contrast, the $^{19}F(d,p)$ reaction shows the typical direct pattern with l=0 in angular distribution and its excitation functions vary smoothly with deuteron energy.

THE ROOT MEAN SQUARE RADII OF NEUTRON ORBITS IN ^{61}NI AND ^{89}SR

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The root mean square /RMS/ radii of the orbits of loosely bound neutron in certain nuclei can be measured with high accuracy using /d,p/ reactions in the energy region below and near the Coulomb barrier. In the work presented here angular distributions of proton groups from two reactions were measured: 1/ ^{60}Ni/d,p/^{61}Ni studied at E_d=3.3 MeV and 2/ ^{88}Sr/d,p/^{89}Sr studied at E_d=3.4, 3.8 and 4.0 MeV. The experimental data were compared with the DWBA predictions and spectroscopic factors were obtained. The optical model potentials for protons and deuterons taken from [1,2,3] were adopted. Corrections for the finite-range and non-localities were included. In the Saxon-Woods potentials of the neutron bound states, the values a_n=0.65 fm and λ=25 were used and the depths U were adjusted to reproduce the experimental binding energies. The radius parameters were adopted by carrying out a sum-rule analysis of available stripping and pick-up data [3,4,5]. From these potentials the RMS radii of the single-particle wavefunctions were deduced. They are listed in the Table together with the single-particle binding energies E_{nlj} which were calculated as the centroid energies of particle and hole states [5].

Nuclei	nlj	r_{on}/fm/	E_{nlj}/MeV/	r_{nlj}/fm/	Δr_{nlj}/fm/
^{61}Ni	2p3/2	1.30	-10.21	4.59	0.03
	2p1/2	1.20	- 9.00	4.47	0.02
	1f5/2	1.30	- 8.04	4.41	0.03
	1g9/2	1.21	- 5.08	4.64	0.03
^{89}Sr	2d5/2	1.20	- 6.17	5.11	0.06
	3s1/2	1.20	- 5.35	5.42	0.06
	2d3/2	1.20	- 4.20	5.28	0.07

The error Δr_{nlj} accounts only for the uncertaintes in evaluation of the r_{on} values and hence is related to the errors of the spectroscopic factors. In case of ^{61}Ni, Δr_{nlj} does not include any contribution from possible inadequacies of the DWBA method.

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BREAK-UP OF 56-MeV DEUTERONS IN THE FIELDS OF NUCLEI

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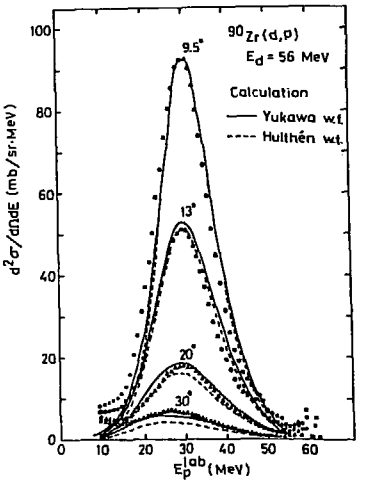
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In order to study the deuteron break-up process, we have measured the proton continuum spectra induced by 56-MeV deuterons for 14 elements ranging from ^{12}C to ^{209}Bi. The experiments were carried out at Research Center for Nuclear Physics, Osaka University. Protons were detected using two sets of ΔE(400μm Si)+E(15mm high purity Ge) counter telescopes. The energy spectra were measured in the angular range from 9.5° to 58°.

Typical proton energy spectra at several lab angles are shown in the figure for ^{90}Zr. Each spectrum shows a prominent bump due to the break-up of the incident deuteron. Similar bump spectra are observed for all target nuclei. The peak energy of the bump is about a half of the deuteron energy for light elements and increases slightly for heavier elements.

The proton bump spectra were compared with break-up calculations[1,2] reflecting the proton momentum distribution in the deuteron. A Yukawa-type wave function and a Hulthén-type wave function were used to obtain the proton momentum distribution. In the calculations, the absolute cross sections were normalized to the peak cross section at 9.5°. As shown in the figure, the break-up calculations reproduce well the spectral shapes and the angular dependence of the bump spectra. Similar results have been obtained for other target nuclei. These results show that the proton bump spectra reflect the momentum distribution of the proton in the deuteron. The behavior of the deuteron wave function at large distances is important to determine the spectral shapes at forward angles.



The total break-up cross sections were estimated by integrating the calculated values of $d^2\sigma/d\Omega dE$ over the energy and angle, the absolute values of which were fitted to the peak cross section at 9.5° for each target. The obtained result is given by

$$\sigma^{bu}(d,p) \simeq 23.7\ (A^{1/3}+0.8)^2 \quad \text{mb}.$$

The target mass dependence indicate that all partial waves smaller than the grazing angular momentum contribute to the deuteron break-up cross section at this energy. The mass dependence presents a striking contrast to the $A^{1/3}$ dependence observed in the ^3He break-up reactions[2]. The total break-up cross section amounts to 24-35% of the deuteron total reaction cross section. The fairly large break-up cross section suggests the importance of the break-up channel to other deuteron induced reactions.

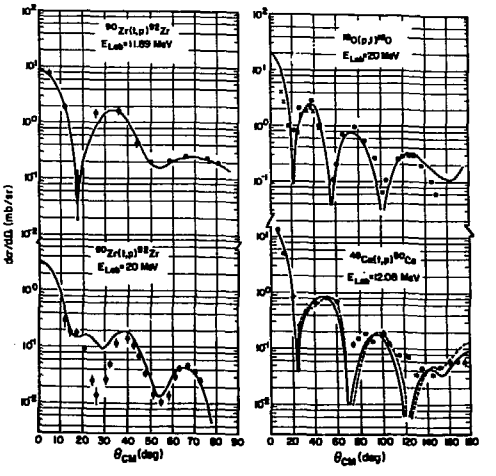
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A TEST OF DWBA FOR (p,t) AND (t,p) REACTIONS†

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Theoretical calculations of (p,t) and (t,p) cross sections have generally proved unsatisfactory. Although the shapes of angular distributions are predicted rather well, exact finite range calculations consistently under predict their absolute magnitudes. Recent studies have shown that these cross sections can be quite sensitive to the detailed structure of the triton, the form of the transfer interaction and the requisite nuclear structure overlaps. The question of whether contributions from higher-order processes, such as sequential transfer of neutrons, are needed to bring the theoretical cross sections into agreement with experiment cannot be answered unambiguously until first-order DWBA calculations are performed which include the important features mentioned above. In our present work[1)] we have analyzed the ground state reactions shown in the figure employing a realistic triton wavefunction, a realistic transfer potential and extended basis shell model overlap function. We emphasize that the theoretical computations are predictions having no normalization factor or adjustable parameters. Our results show a systematic agreement between the theoretical cross sections and the experimental data, both in shape and magnitude. Thus the present first-order DWBA calculations give a good account of the data and provide no support for the need of higher order mechanisms in these reactions.



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1) D. H. Feng, M. A. Nagarajan, M. R. Strayer, M. Vallieres, and W. T. Pinkston, Phys. Rev. Lett., to be published

NUCLEAR STRUCTURE OF THE ^{78,80,82,84}Se ISOTOPES USING THE (t,p) REACTION AT 17 MeV INCIDENT ENERGY

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and

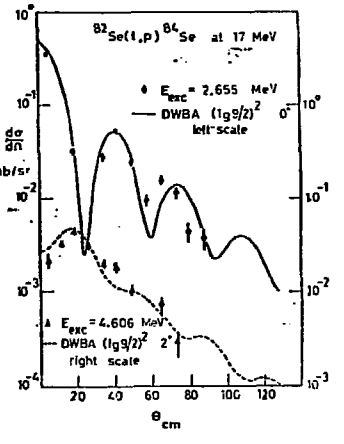
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It is well known that the (t,p) reaction is an excellent spectroscopic tool with which to study states in the residual nucleus, since the two neutrons are transferred as a spin zero pair. Thus if the target nucleus has a 0^+ ground state, there is a unique J^π transfer if the reaction proceeds via a direct single step process. These conditions are realized for the even mass ^{76,78,80,82}Se target nuclei.

The absolute differential cross-sections for the (t,p) reaction leading to states in the even selenium isotopes from mass 78 to 84, was measured using the multigap magnetic spectrograph on the tandem accelerator at the University of Pennsylvania. The outgoing protons were recorded using nuclear emulsion plates and the data extracted by manual scanning of the plates on a microscope. This yielded differential cross-sections from 4^o to 89^o c.m. for many excited states in each of the residual nuclei.

The data were analysed by comparison with predictions using the DWBA code DWUCK4 and yielded information on the spin and parity of a number of previously unassigned levels. Examples are shown in the figure where the previous assignment of (0^+) to a level is confirmed and a previously unassigned level is assigned (2^+). Spin assignments to the levels of ^{82}Se have been made where previously there was no information available.



A New Spectroscopic Tool (α, ^{6}He) Reaction

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Although the (p,t) and (t,p) reactions provide a sensitive test[1] of shell model configurations of the transferred two nucleons in the nuclei, these reactions are limited to the relative angular momentum between the two nucleons $\tilde{l} = 0$. The (^{18}O,^{16}O) and (^{16}O,^{18}O) reactions also have been shown[2] to have minor $\tilde{l} \neq 0$ contributions since the cross sections of $(2s_{1/2}^2)$ are enhanced and dominates the transitions. However, (α,^{6}He) reaction has a unique feature that it may have $\tilde{l} \neq 0$ as a dominant component depending upon the configurations, and thus this reaction may be powerful tool to study two nucleon correlations in the nuclei.

Using a multipole expansion for $\tilde{l}$ as developed by Chant[3] and Takemasa[2], the angular momentum selection rules for the (α,^{6}He) reaction have $\tilde{l} + S$ = even due to the antisymmetrization of the two neutrons , where S is the total spin of the transferred pair. Since the two neutrons in ^{6}He predominantely occupy the $1p_{3/2}$ shell, $\tilde{l}$ = odd (for S= 1) is allowed as well as $\tilde{l}$ = even (for S = 0). As an example we take the ^{92}Zr(α,^{6}He)^{90}Zr(2^+) reaction, and assume single configurations $(2d_{5/2}^2)$, $(2d_{5/2}1g_{9/2})$ and $(1g_{9/2}^2)$ for the transition.

Table 1 shows the results of the Moshinsky transformation of the pairs. The amplitudes of $\tilde{l}$ = 1 components are quite different in each configuration. DWBA calculations have been performed using the exact finite-range DWBA code TWONUC/TWOFNR[4], which calculates single particle wave functions in a Woods-Saxon potential for the two nucleons in both ^{92}Zr and ^{6}He systems, and expands the wave functions with multipolarity $\tilde{l}$. This method allows $\tilde{l} \geq 2$ for ^{6}He in addition to $\tilde{l}$ = 0 and 1. The result of the DWBA calculations for the single configurations are shown in Fig. 1. Two important facts can be seen in the figure: As is expected from the Table the cross sections of the $\tilde{l}$ = 1 and 2 components strongly depend on the configurations and are comparable to those of $\tilde{l}$ = 0. The other fact is that the shape of the calculated angular distributions are quite different depending on the configurations. Note this shape difference is due to the mixing of the $\tilde{l} \neq 0$ components which come in only when finite range effects are exactly taken into account.

Table 1

$\tilde{l}$	$(d_{5/2}^2)$	$(d_{5/2}g_{9/2})$	$(g_{9/2}^2)$
0	0.08	0.16	0.10
1	0.24	0.02	0.36
2	0.21	0.32	0.41

Therefore, the (α,^{6}He) reaction may allow one to study not only the configuration mixing but also the two nucleon correlation in the nuclei. The experiment is in progress.

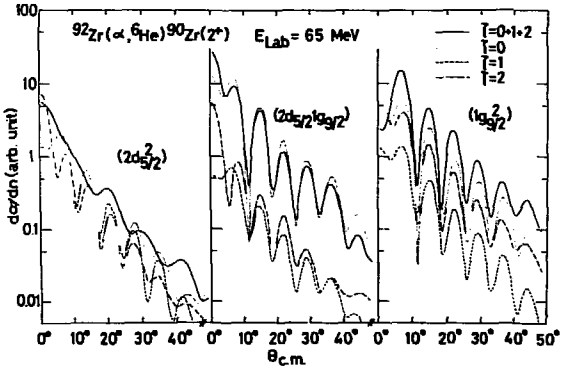


Fig. 1

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2) T.Takemasa, Nucl. Phys. A220 (1974) 31.
3) N.S.Chant, Nucl. Phys. A211 (1973) 269.
4) M.Igarashi, Private communication.

SEPARABLE POTENTIAL FOR $\alpha-\alpha$ SCATTERING IN THE ENERGY RANGE 0-120 MeV.

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The $\alpha-\alpha$ scattering data in the energy range 0-120 MeV for partial waves 2,4 and 6 have been fitted to the second rank separable potential. For the form factors we have used the choice of Mongan[1]. With the parameters listed in table good fits to the phase shifts in the whole energy range is obtained.

1. T.R. Mongan, Phys. Rev. 175 (1968) 1260.

Table.

$$V(p,p') = -\frac{\hbar^2}{2\pi^2 M_\alpha}\left[\lambda_a^2 f(b_a,p) f(b_a,p') - \lambda_R^2 f(b_R,p) f(b_R,p')\right]$$

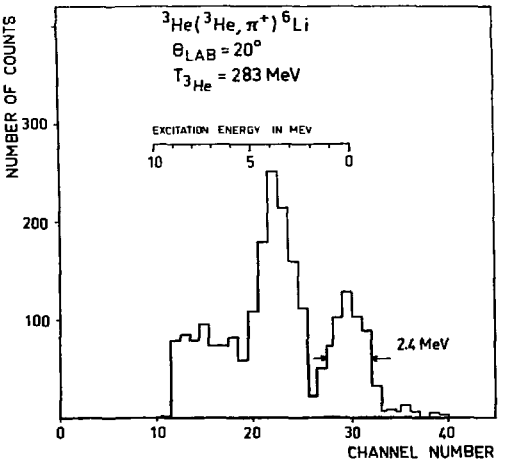
	ℓ	λ_a ($F_m^{-1/2}$)	b_a (F_m^{-1})	λ_R ($F_m^{-1/2}$)	b_R (F_m^{-1})
Case I $f(b,p) = \frac{p^\ell}{(p^2+b^2)^{\frac{\ell+1}{2}}}$	2	60.2217	1.6149	100.00	1.6869
	4	2.5676	1.90	—	—
	6	2.3215	1.60	—	—
Case II $f(b,p) = \frac{p^\ell}{(p^2+b^2)^{\frac{\ell+2}{2}}}$	ℓ	λ_a ($F_m^{-3/2}$)	b_a (F_m^{-1})	λ_R ($F_m^{-3/2}$)	b_R (F_m^{-1})
	2	71.2390	2.0302	336.8199	2.3959
	4	22.77	2.5	—	—
	6	16.9285	1.9	—	—
Case III $f(b,p) = \frac{p^\ell}{(p^2+b^2)^{\ell+1}}$	ℓ	λ_a ($F_m^{-\ell-\frac{3}{2}}$)	b_a (F_m^{-1})	λ_R ($F_m^{-\ell\cdot\frac{3}{2}}$)	b_R (F_m^{-1})
	2	139.2979	2.0035	1926.0247	3.7818
	4	3.5377	3.76	—	—
	6	18.6547	3.39	—	—

FIRST MEASUREMENTS ON THE $^3He(^3He, \pi^+)^6Li$ REACTION NEAR THRESHOLD

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Pion production near threshold induced by composite projectiles requires a high energy from the internal move of nucleon and/or coherent effect. Up to now there was little obviousness for exclusive reaction of this kind. The ability to use at Orsay a 283 MeV ^3He beam on a liquid ^3He target (70mg/cm^2) has allowed a trial to identify positive pions. A special set up has been built for pions detection with a low $B\rho$ spectrometer and two quadrupole lenses to increase the solid angle to 6.2 msr. The pions identification is realised by a coïncidence between four scintillators on which the (dE/dx) measurements are also done. Moreover two time of flight measurements are used to reduce the background. The localisation behind the spectrometer is done by two wire-chambers and a on-line calculation giving the intersection of the pions trajectories with the focal plane.



The results obtained at $20°_{lab}$ are presented on the figure. A ^6Li characteristic pion spectrum has been obtained in the focal plane. The ratio peak/background is good. The main contribution to the total resolution is the difference between the energy losses in the target by ^3He or π^+. The first level seems to be pure as no peak appears at 2.18 MeV. Other identical measurements have been taken at $40°_{lab}$ and $60°_{lab}$ and will provide the shape of the angular distribution.

These results come from an extremely recent experiment and it is not yet possible to give the accurate cross-section values(it roughly seems to be of the order of several tens nb/sr). Precise analysis of the measured data have to be completed. These reactions studies will be carried on by experiments on heavier targets.

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COMBINED BREAKUP AND TRANSFER IN ^{3}He INDUCED REACTIONS

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Elastic projectile breakup has been found to be the dominant process contributing to the continuum spectra of protons and deuterons in ^{3}He induced reactions[1]). We have observed similar continuum structures in the inclusive triton spectra from reactions at $E_{^{3}He}$=52 MeV for the targets ^{12}C, ^{26}Mg, ^{27}Al, ^{28}Si, ^{58}Ni, ^{108}Pd, ^{197}Au and ^{208}Pb. Their shapes are suggestive for a process in which elastic breakup of the ^{3}He is followed by neutron pickup by the deuteron.

In order to further investigate the mechanisms of these reactions, a coincidence experiment has been performed with two ΔE-E solid state counter telescopes at $E_{^{3}He}$=52 MeV on a ^{nat}Si target. One telescope was kept fixed at θ_1=+10°, with the other the angular ranges θ_2=+10° to −70° and θ_2=+30° to +70° were covered. Double differential energy integrated cross sections and projected energy spectra were obtained for coincident p-d,p-t and d-d events. With the deuterons detected at θ_1=10°, the angular distribution of the coincident protons has an oscillatory pattern and the centroid of the projected proton energy spectrum oscillates between 14 and 20 MeV. With the protons detected at θ_1=+10° the coincident deuterons show a Rutherford type correlation. Apparently several mechanisms contribute to the (^{3}He,p+d) breakup reaction, one of them involving the proton as a spectator.

The (^{3}He,p+t) data show that the average proton energy is only a few MeV below that corresponding to a pure spectator. The deuteron spectrum from the (^{3}He,d+d) reaction shows a slow and a fast component. Both reactions seem consistent with the picture of ^{3}He breakup followed by neutron pickup either by the deuteron (p+t) or the proton (d+d).

Furthermore a gamma-ray multiplicity of $\langle M \rangle = 1.1 \pm 0.3$ was found for the inclusive triton spectrum induced by 60 MeV ^{3}He on a ^{58}Ni target.

1. N. Matsuoka et al., Nucl. Phys. A311 (1978) 173.

The $^{92}Zr(\alpha,^{6}He)^{90}Zr$ Reacton at 64.6 MeV

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The $(\alpha,^{6}He)$ reactions may possibly provide a test[1] of not only the shell model configurations but also the two nucleon correlations in nuclei. We chose ^{92}Zr target since the structure of ^{92}Zr and ^{90}Zr are rather well understood and the data of the $^{92}Zr(p,t)$ reaction[1] are available for comparison.

We have measured the angular distributions of the $^{92}Zr(\alpha,^{6}He)$ reaction at 64.6 MeV. An alpha beam was obtained from the INS SF cyclotron. The differential cross sections were taken from $\theta_{c.m.}$ = 4.5° to 40°. The ^{6}He ejectiles were detected with a position sensitive detector placed on the focal plane of QDD magnetic spectrograph. This detector consists of a drift type position sensitive proportional counter and two ΔE proportional counters which provide a unique mass identification.

Typical angular distributions are shown in Fig. 1. The shapes of the angular distributions for the 0^+ states are very similar to those for 2^+ states but the others are quite different. Fig. 2 shows the relative cross sections of the two reactions $^{92}Zr(\alpha,^{6}He)$ and $^{92}Zr(p,t)$. These were taken on the first peak in the angular distributions. The differential cross sections for the ground state transitions are normalized to unity in both reactions. In the transitions to the even parity states around 4 MeV the cross section ratio of the $(\alpha,^{6}He)$ reaction to the (p,t) reaction increases as the value of the spin increases. The negative parity states are more strongly excited in the $(\alpha,^{6}He)$ reaction than in the (p,t) reaction. Only the 3^- states are excited with appreciable cross sections in both reactions. Some of the (p,t) reaction are not shown in the figure since the correspondind cross sections are not available in ref. 1.

Analyses by exact finite-range DWBA calculations with microscopic form factors are in progress.

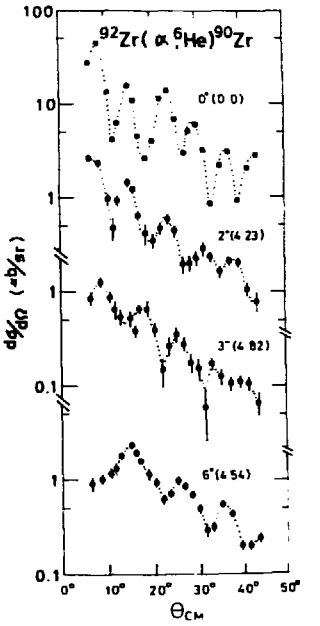


Fig. 1

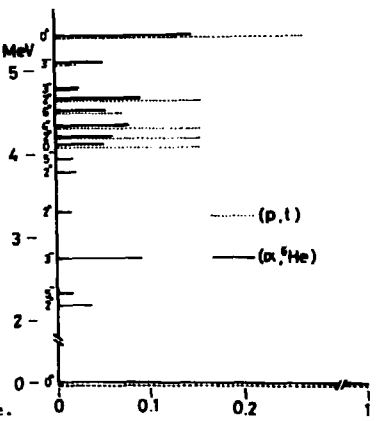


Fig. 2

1) The contribution "The New Spectroscopic Tool $(\alpha,^{6}He)$ reaction" to this conference.
2) J.B.Ball et al., Phys.Rev. C4(1971)196.

IMPORTANCE OF THE TARGET EXCITATION DURING THE ^{3}He BREAK UP BY NUCLEUS

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T. Shibata, M. Sasao, H. Suzuki, and K. Maeda

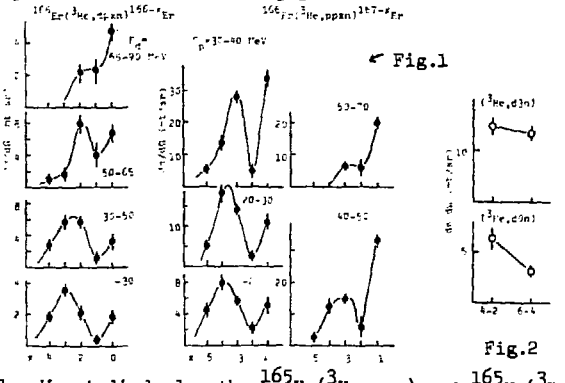
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Projectile break up process in the ^{3}He+^{166}Er reaction was studied at E_{in}=100 MeV. The evidence of the ^{3}He break up process with target excitation was obtained using the particle-γ coincidence technique. Emitted particles (proton and deutron) were measured in coincidence with yrast γ-rays of the Er isotopes. The coincidence with the γ-rays of Er made it possible to identify the residual nucleus, namely the neutron multiplicity of the reactions ^{166}Er(^{3}He,dpxn)$^{166-x}$Er and ^{166}Er(^{3}He,ppxn)$^{167-x}$Er.

By measuring the neutron multiplicity, we could distinguish the following two reaction processes. (i) Direct break up process of ^{3}He into p+d with target excitation. This process transfers fairly small amount of energy to the target nucleus. Therefore this process is characterized by the small (x=0) neutron multiplicity. (ii) The (^{3}He,p) and (^{3}He,d) stripping reactions followed by sequential decays of one proton and probably several (x=2-5) neutrons. The energy transfer to the target nuclei can be large enough to emit many neutrons in this process.

In Fig. 1, cross sections for protons and deutrons detected at 17° are plotted against the neutron multiplicity x. For almost all of the energy bins of the protons and the deutrons, the pattern of the cross sections shows a broad bump at x=2-4 and the sharp rise at x=0 for deutron and x=1 for proton. The sharp rise corresponds to the (^{3}He,dp) type reaction with no neutron decay. These two parts, the broad bump and the rise at x=0 or 1, can be attributed to the two different reaction mechanisms discussed above. The rise at x=0 or 1 is due to the (^{3}He,dp) break up process with target excitation, and the broad bump at x=2-4 to the sequential decay after stripping.[1]

In Fig. 2, the coincidence cross sections for the two typical reaction processes of ^{166}Er(^{3}He,dp)^{166}Er and ^{166}Er(^{3}He,dp2n)^{164}Er are shown for the individual γ-decay. The ratio $\sigma(4\text{-}2)/\sigma(6\text{-}4)$ is larger in the (^{3}He,dp) reaction than in the (^{3}He,dp2n) reaction. This suggests that the angular momentum of the target nucleus, if excited, following the direct break up process (^{3}He,dp) is much smaller than that of the (^{3}He,dp2n) reaction. This may be because the break up proton and deutron take away most of the angular momentum introduced by the projectile, transferring rather small angular momentum to the target nucleus.



← Fig.1

Fig.2

1. We studied also the ^{165}Ho(^{3}He,pxn) and ^{165}Ho(^{3}He,dxn) reactions with the same technique, and observed only the broad bump in the neutron multiplicity distribution.

MICROSCOPIC CALCULATIONS OF AN ABSORPTIVE NUCLEUS-NUCLEUS INTERACTION

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The effective nucleus-nucleus interaction given by Feshbach's formula[1]

$$V_{eff}(E) = PVP + PVQ \cdot (E + i0 - QHQ)^{-1} \cdot QVP \qquad (1)$$

has been calculated microscopically for the α-α system starting from a schematic two-nucleon force. Assuming 1p-1h excitations in one of the fragments to be the dominant absorption mechanism from the entrance channel P, we took as the Q-space all channels with one 1p-1h excited α-particle of symmetry S=T=0. The antisymmetrized channel states were constructed via momentum projection techniques[2] and then orthogonalized to ensure PQ=0.

Using the non-local and energy dependent interaction (1), scattering phase shifts and transmission coefficients (with no adjustable parameters) were computed for angular momenta L=0,2,4,6. Fig.1 shows the transmission coefficient for L=2. The distinct structures are due to the fact that a dominant part in the ^{4}He 1p-1h-excitations is the so-called α*-resonance (at 20.1 MeV excitation energy) and that the relative α-α* interaction also gives rise to resonances.

The diagonal matrix elements of the absorptive and dispersive part of V_{eff} (called I^{PP} and R^{PP} respectively) are shown in fig.2 for E = 22.5 MeV (above α-α threshold, c.m. system) and L=2. The "nonlocality" at 4fm relative distance is about 1fm. Although the strength of these effective potentials is clearly energy dependent, the shape varies only smoothly with energy and is nearly independent of angular momentum. It can be concluded that - at least for the reactions considered - absorption only occurs at relatively large distances between the fragments.

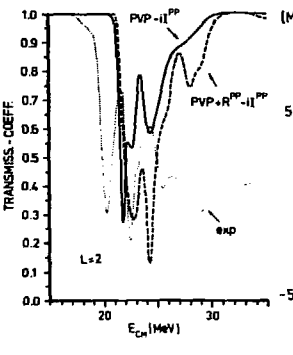


Fig.1

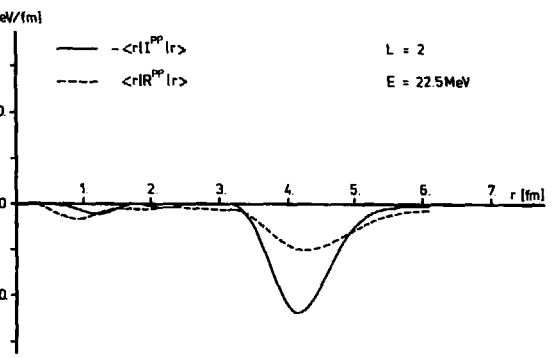


Fig.2

1) H. Feshbach; Ann.Phys. 19 (1962) 287
2) H.R. Fiebig, M.Stingl and W. Timm; J.Phys. G4 (1978) 1291

THE INFLUENCE OF THE PHASE SPACE FACTOR IN THE BREAK UP OF COMPOSITE PARTICLES

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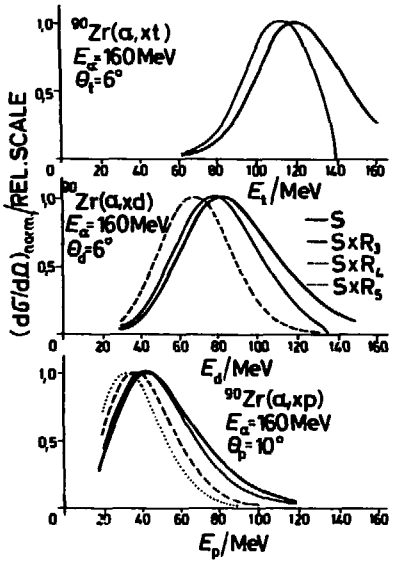
Recently several experiments have been performed studying the break up of composite particles[1].

The theoretical analysis has met with partial success. We propose in the present paper that the theoretical treatment of the data should take into account the number of particles in the final state since it determines the shape of the phase space factor, which has to be introduced. In our opinion the formula derived from the Serber formalism[2] should have the form

$$\frac{d^2\sigma}{d\Omega\, dE} \propto |\Psi(p)|^2 \sum A_i R_i$$

where $\Psi(p)$ is the Fourier transform of the spatial wave function of the observed particle in the original composite projectile, i is the number of particles in the final state, A_i is the probability for each of these final states and R_i is the corresponding phase space factor.

We present calculations of each particular term for the reactions ^{90}Zr (α,xd), ^{90}Zr (α,xd) and ^{90}Zr(α,xt) at E= =160 MeV. The heavy lines show the results of the calculation along the lines of ref. 1 denoted by S. The thin, dashed, and dotted lines show the result of the calculation when a three, four and five body phase space (R_i) is supposed, respectively. The influence of the phase space factor is clearly demonstrated, as well as the additional information on final states that may be gained. Accounting for the different allowed phase spaces also alters the proportions of observed break up cross sections.



1. J.R. Wu et al., Phys.Rev. C20 (1979) 1284 and references therein
2. R. Serber, Phys.Rev. 72,(1947) 1008

QUASI-FREE SCATTERING IN $^{6,7}Li(\alpha,2\alpha)^{2,3}H$, $^{9}Be(\alpha,2\alpha)^{5}He$ REACTION AT LOW ENERGY

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The quasi-free scattering for ^{6}Li, ^{7}Li, $^{9}Be(\alpha,2\alpha)$ reactions has been studied by both angular correlation method and energy sharing method. The energy of incident α particles was 18 MeV. Emitted α_1 and α_2 were detected in coincidence and the differential cross section of quasi-free scattering were obtained. By means of the PWIA and "on shell" approximation the experimantal results were analyzed. The widths of the cluster relative momentum distribution for ^{6}Li, ^{7}Li, ^{9}Be have been found to be 48 MeV/c, 80 MeV/c and 38 MeV/c, respectively.

The shapes of the momentum distribution extracted from the experiments consist with the momentum distribution obtained from the Fourier transformation of the wave function of relative motion of the clusters. The results of ^{6}Li, ^{7}Li are shown in Figs. 1-2. The curves represent PWIA calculation with cut-off radius.

The existence of quasi-free scattering by ^{6}Li, ^{7}Li and ^{9}Be nuclei at such low energy gives evidence of the α cluster substructure in these nuclei and as a first order approximation, PWIA calculation is consistent with experimental results.

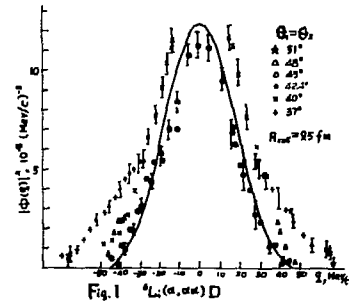


Fig.1 $^{6}Li(\alpha,\alpha\alpha)D$

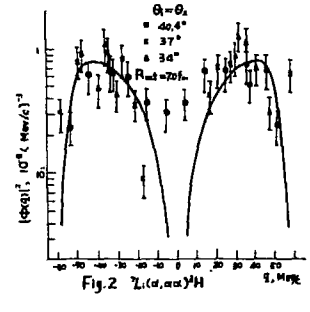


Fig.2 $^{7}Li(\alpha,\alpha\alpha)^{3}H$

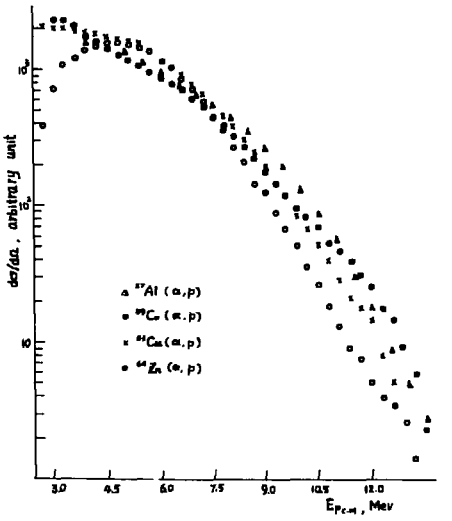
THE STUDY OF PRE-EQUILIBRIUM EMISSION IN ^{27}Al, ^{59}Co, ^{63}Cu, $^{64}Zn(\alpha,p)$ reactions

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Lu Xiu-qin Yang Zhu-qing Jiang Cheng-lie

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The ^{27}Al, ^{59}Co, ^{63}Cu and ^{64}Zn targets were bombarded by 18MeV α-particles. The pre-equilibrium emission was studied by analysing the integrated proton spectra. Selfsupported metallic foils are used as targets and thier thickness varies in the range 1-2mg/cm^2. The isotopic purity of ^{63}Cu and ^{64}Zn is > 99% and 94% respectively. The emitted charged particles were detected by ΔE-E counter telescope. The ΔE and ΔE+E signals fed into a multichannel analyzer-computer system and by means of an on-line ΔE-E particle identification code the two dimensional patterns were transformed into energy spectra of different particles. The energy spectra of emitted protons have been obtained between 30° and 165° in step of 10° in the laboratory system. The integrated proton spectra were obtained by transformation of the coordinate system and integration over the angles.

The integrated spectra were analyzed by the formula based on the theory of Griffin's exciton model and similar to Gadioli's closed form. The preform of α particles and the competition of α particle emission have been taken into account. The fractions of pre-equilibrium emission in (α,p) reactions have been extracted and the initial exciton configuration was discussed.



THE INTERPRETATION OF HIGH ENERGY α - α SCATTERING EXPERIMENT WITH A POOR ENERGY RESOLUTION

R. Dymarz and A. Małecki

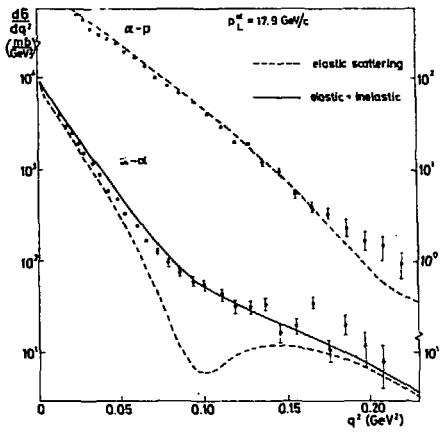
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Differential cross-sections of 17.9 GeV/c α - particles scattered from various nuclei have recently been measured at JINR Dubna[1]. The energy resolution was sufficient to separate production processes but not good enough to distinguish between the elastic events and those where the target nucleus was excited. This almost elastic scattering may be interpreted[2] as a sum of the elastic scattering produced coherently by the whole target nucleus and of the incoherent scattering of the α - particles on the individual nucleons:

$$\sigma^{scatt} = \sigma^{elast} + A_{eff}\,\sigma^{\alpha N} \qquad /1/$$

where A_{eff} is the effective number of nucleons in the target which undergo quasi-elastic collision with the projectile.

In figure we present an example of such an interpretation in the case of α - ^{4}He scattering. The solid curve corresponds to Eq.1 computed with the elastic cross-sections as shown by dashed curves and $A_{eff}=1$, q being the momentum transfer. The cross-sections for the α - nucleus and α - nucleon elastic scattering have been calculated using the Glauber model[3] with Coulomb interaction included. A good agreement with experiment indicates that inelastic component of the α - ^{4}He scattering may effectively be viewed as a collision of the α - particle with one bound nucleon.



1/ V.G. Ableev et al., Dubna report P1-10565 /1977/.
2/ G. Bellettini et al., Nucl.Phys.79 /1966/ 609.
3/ W. Czyż and L.C. Maximon, Ann.Phys.52 /1969/ 59.

FLUCTUATIONS IN EXCITATION FUNCTIONS OF $^{3}He,p$ REACTIONS CONNECTED WITH STATISTICAL MULTISTEP COMPOUND EMISSION

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Excitation function of the reaction $^{3}He,p$ on ^{25}Mg and ^{27}Al shows the existence of fluctuations having an energy correlation width $\Gamma \sim 300$ kev, larger than that expected in connection with compound nucleus formation.

These fluctuations can be explained on the basis of the recently proposed theory of the statistical multistep compound emission (SMCE).

In the frame of this theory, proposed by Feshbach, Kerman and Koonin[1], transitions to different final levels can come from different steps of the chain developing itself in the nucleus, so that different values of the nuclear lifetime and, of course, of the fluctuation width can appear.

The condition for existence of fluctuation effect, that is width Γ much larger than the distance of corresponding excited levels is here certainly verified.

Other characteristics of the reaction here studied, that is emitted particle angular distribution and total spectrum shape are also in agreement with the prediction of the SMCE.

Comparison of the fluctuation width obtained experimentally with the SMCE formulae allows to calculate the value of the two-body residual interaction, acting in the development of the chain in the nucleus.

[1] H. Feshbach, A. Kerman, S. Koonin
In publication on Annals of Physics

TWO-PROTON PICKUP FROM INTERMEDIATE-WEIGHT NUCLEI USING THE (^{6}Li,^{8}B) REACTION*

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The (^{6}Li,^{8}B) reaction is the lightest of the possible two-proton pickup reactions induced by heavy ions, with consequent advantages in the resolution which can be achieved in studies of nuclear structure. Although some of the more interesting possibilities for studies of this type involve the heavier nuclei, previous observations of the (^{6}Li,^{8}B) reaction have been confined to light targets[1]).

In order to investigate the usefulness of the (^{6}Li,^{8}B) reaction as a probe of heavier nuclei, spectra at a forward angle, and in a few cases angular distributions, were measured for ^{56}Fe, ^{66}Zn, ^{90}Zr, ^{94,98}Mo, ^{120}Sn, and ^{122,126,130}Te targets, using a 90 MeV ^{6}Li beam from the Indiana University Cyclotron Facility. The ^{8}B ejectiles were detected in a position-sensitive gridded ionization chamber placed at the focal plane of a magnetic spectrograph.

The features we observe are: (1) The pattern of transition strengths is similar to that of the (p,t) reaction, with the ground state transition usually by far the dominant one in the spectrum. At $\theta_{lab} = 8°$, the ground state cross sections range from 0.3 to 27 μb/sr for ^{120}Sn and ^{66}Zn, respectively. (2) Angular distributions measured for transitions leading to the ground state of ^{64}Ni and the ground and 2_1^+ state of ^{88}Sr are featureless and fall off rapidly with increasing angle. This behavior is qualitatively reproduced by exact finite-range (EFR) DWBA calculations made using the code DWUCK5. (3) In contrast to the general trend, the 2_1^+ state in ^{88}Sr and the first excited 0^+ state in ^{96}Zr are populated almost as strongly as the ground states in these two nuclei.

The strong excitation of the 0_2^+ state in ^{96}Zr can be understood in terms of the systematics of the proton configurations in the Zr isotopes. The strength of this transition relative to the much weaker 0_2^+ transition in ^{92}Zr, and the relative cross sections for populating the ^{92,96}Zr ground states, are well reproduced by EFR DWBA calculations in which the proton configurations are taken explicitly into account.

*Work supported in part by the National Science Foundation.
†Work supported in part by grants from the Rackham Graduate School and the Memorial-Phoenix Project of the University of Michigan.

1. N. A. Jelly et al., Phys. Rev. C9 (1974) 2067; R. B. Weisenmiller et al., Nucl. Phys. A280 (1977) 217.

D- α CLUSTERING PROBABILITY IN ^{6}Li AND ITS EFFECT ON INTERACTION POTENTIAL

Kiran Kumar

Radiochemistry Division, and

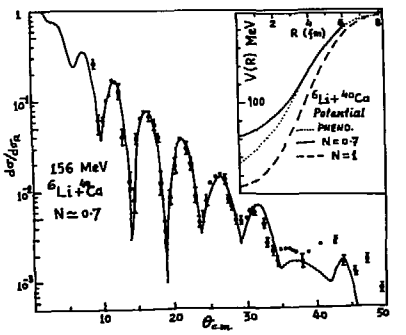
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The folding model potentials for ^{6}Li have been found to have an anomalous behaviour[1,2]. They are found to be consistently larger than the phenomenological potentials. An unexplained normalisation factor, $N \sim 0.7$ is needed for the folding model potential to fit the elastic scattering data. In the present work we describe the interaction potential of 156 MeV ^{6}Li with ^{40}Ca in terms of α-^{40}Ca and d-^{40}Ca optical potentials and an antisymmetrized ^{6}Li cluster model wave function. The ^{6}Li interaction potential is therefore written as:

$$V_{^6Li}(R) = \int \{\phi_\alpha \phi_d \psi_{\alpha-d}(r) \xi(spin)\}^\dagger \left[V_\alpha(|\vec{R}-\tfrac{1}{3}\vec{r}|)+V_d(|\vec{R}+\tfrac{2}{3}\vec{r}|)\right] \mathcal{A} \{\phi_\alpha \phi_d \psi_{\alpha-d}(r) \cdot \xi(spin)\}\, d\tau$$

where ϕ_α, ϕ_d are the internal spatial wave functions of α-and d- clusters, $\psi_{\alpha-d}$ is the relative α-d wave function, ξ(spin) is the 6-nucleons spin function. V_α and V_d are the real parts of α-^{40}Ca and d-^{40}Ca optical potentials respectively(phenomenological potentials at appropriate energy). The multidimentional integral in the equation above is evaluated by expanding the V_α, V_d and $\psi_{\alpha-d}$ in terms of series of Gaussians. The ^{6}Li interaction potential is found to be sensitive to the surface of α-d relative wave function. However, the surface behaviour of ^{6}Li wave function is described by d-α clusters only and with a probability of only 0.6 to 0.7 (determined from cluster knock-out reactions of ^{6}Li(α,2α) and ^{6}Li(d,dα) type[3]. This provides us an answer to the anomalous normalisation factor of the interaction potential. Thus the interaction potential derived from equation above is to be reduced by the d-α clustering probability (~0.6 to 0.7) which is also the required normalisation factor for the ^{6}Li interaction potential.



The net contribution to the interaction potential from the exchange terms is small because of their localisation in the interior of ^{6}Li. It is seen in the inset to figure that with the normalisation of 0.7 the derived cluster model potential agrees very well with the phenomenological potential in the surface region. The figure shows that this reduced cluster model potential gives good agreement with the 156 MeV ^{6}Li-^{40}Ca elastic scattering data.

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EMISSION PROBABILITY OF ALPHA PARTICLES, TRITONS AND PROTONS IN THERMAL AND KEV NEUTRON INDUCED FISSION OF ^{235}U

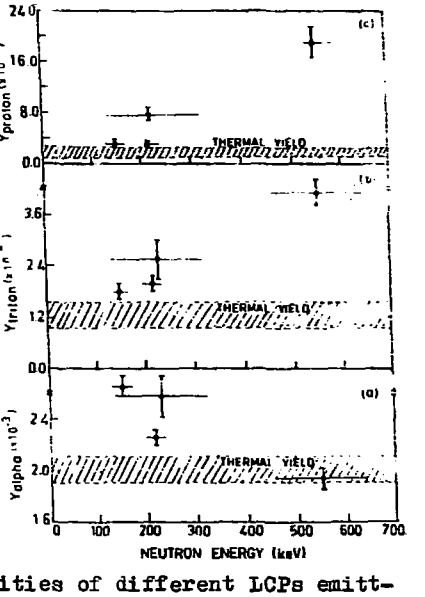
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It is known that light charged particles (LCP) are emitted in fission with a very low probability and that the alpha particles constitute the bulk (~90%) of these particles followed by tritons and protons. In earlier studies[1,2] the total LCP yield in keV neutron induced fission of ^{235}U showed some unexpected variation with the incident neutron energy, E_n. In the present work, the LCP emitted in coincident with fission fragments were identified by means of a ΔE-E semiconductor detector telescope and their yields and energy spectra were measured at incident neutron energies of E_n = 120, 210, 230 and 550 keV. The energy spectra of the different LCPs do not show any significant variation with E_n. However, the dependence of the emission probability on E_n is different for alpha particles, tritons and protons as shown in the figure. It is seen that Y_{alpha} increases by about 20% at $E_n \sim 200$ keV and then decreases to the thermal neutron value at higher neutron energies. Y_{triton} and Y_{proton} are seen to increase significantly with E_n. Y_{triton} increases by about 2.5 to 3 times at E_n = 550 keV as compared to that of the thermal neutron value, whereas the increase in Y_{proton} is still higher. Such striking increases in the emission probabilities of tritons and protons with the incident neutron energy is not explained by the existing models[3] of ternary fission. The present results therefore point out to the need for a theory to calculate the emission probabilities of different LCPs emitted in fission.



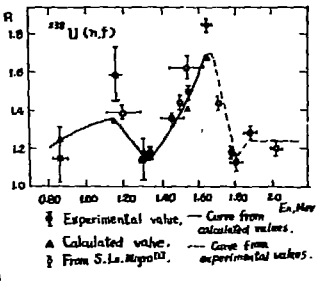
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FISSION FRAGMENT ANGULAR DISTRIBUTION FOR THE $^{238}U(n,f)$ REACTION NEAR THRESHOLD

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The angular distributions for the fission fragments of ^{238}U (n,f) reaction were studied by means of nuclear emulsion loaded with uranium and solid state track detectors between E=0.86 MeV and 1.80 MeV. The measured anisotropies are given in Fig.1. It can be seen that the anisotropy has a gross structure which is in discrepancy with the result of Androsenko [2].



The fission cross-sections and fragment angular distributions were calculated using Hauser-Feshbach theory with width fluctuation correction based on the model of effective single fission barrier. The parameters of fission barrier are given in table 1. The calculated anisotropies are also plotted in Fig.1. From the obtained variation of the anisotropy with neutron energy we can qualitatively envisage that the outer barrier is higher than the inner one for ^{239}U fission. This disagrees with the suggestion of Bjornholm [3], but it agrees with Britt's result.[4]

K^π	$\frac{1}{2}^+$	$\frac{3}{2}^+$	$\frac{3}{2}^-$	$\frac{1}{2}^-$	$\frac{1}{2}^+$
$B_f(K\pi)$ Mev	6.29	6.34	6.3	6.4	6.41
$\hbar\omega_{eff}(K\pi)$Mev	0.55	0.62	0.38	0.385	0.32
$\frac{\hbar^2}{2\vartheta}$ (Mev)	0.005	0.005	0.005	0.005	0.005
α	-.75	0	0	0.75	-.75

Table 1.Parameters of fission barrier

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Charge Distribution in the Fission of ^{232}Th

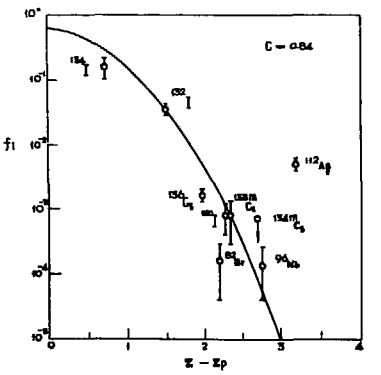
Li Wen-xin, Sun Tong-yu, Sun Xiu-hua, Zhang Tian-mei,
Zheng Man-jiao, Dong Tian-rong and Fu Min

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In the previous work on the charge distribution for the 14.7Mev-neutron induced fission of ^{238}U, the width parameter c of the charge distribution was found to be 0.83[1] and was much smaller than the value of C between 2.0 and 2.5 used for ^{232}Th(n,f) by Rao et al.[2]. It is, therefore, very interesting to extend our investigation to the fission of ^{232}Th.

In the fission of ^{232}Th by 14Mev-neutron, the independent yields of 9 shielded or quasi-shielded nuclides have been determined using radiochmical techniques. The correlation of fractional independent yields in high yield mass chains with a Gaussian function, $fi = (\pi c)^{-\frac{1}{2}} \exp[-(z-z_p)^2/c]$, was investigated using various mass formulae and charge distribution hypotheses. From the result of fitting procedure, it can be concluded that the MPE postulate with Green mass equation gives the best fit to the data. The width parameter C was found to be 0.84. This value agrees well with those obtained elsewhere for the most of the low energy fission. The discrepancy between our value and Rao's in the width parameter seems to originate from the large disagreement of fractional independent yields.

All experimental data based on the MPE postulate were showed in the figure. The fitting is satisfactory with the exception of ^{82}Br and ^{112}Ag. We think, therefore, the low yield in very asymmetric fission can attribute to a narrower width of the Gaussian charge distribution, whereas the high yield in symmetric fission can correlate with a wider width. The similar trend has been confirmed in ^{40}Ar-ion induced fusion-fission of ^{238}U[3] and has been explained in terms of a liquid drop formula. The dependence of the charge distribution width parameter on the fragment mass, which was deduced from the liquid drop formula, seems to be adequate to explain qualitatively all the results obtained in this work.



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MUONIC ATOM FINAL-STATE PROBABILITIES AFTER FISSION

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and J.O. Rasmussen**

By numerically integrating time-dependent coupled Schrödinger equations we calculate the final state probabilities for a μ- meson bound initially to fissioning ^{238}U. We compare well with prior theoretical work[1] on point nuclei, and we go beyond it by using extended charge distributions and a few different values of fission asymmetry. We find that the probability of the muon being bound in the 1s state of the fission fragment of charge Z can be well represented as

$$P_{\mu}(Z) = \{1 + \exp[0.45(46-Z)]\}^{-1} .$$

When folded over the fission yield curve, this expression gives qualitative agreement with the experimental result[2] of ~0.08 fractional attachment of the muon to the light fragment, ~0.92 to the heavy fragment in fission. With somewhat improved accuracy in experiment and theory there is the possibility of testing details (viscosity, etc.) of fission fragment motion from saddle to scission.

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**University of California, Lawrence Berkeley Laboratory, Berkeley, CA
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ON THE QUASIFREE SCATTERING OF ^{6}Li AND ^{7}Li

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We have used the cluster model wave functions of ^{6}Li and ^{7}Li to analyse the quasifree scattering ^{6}Li(p,pd)α , ^{6}Li(d,dd)α, ^{6}Li(d,αd)α , ^{6}Li(α,$\alpha\alpha$)d, ^{7}Li(p,pt)α , ^{7}Li(α,$\alpha\alpha$)t with incident particles of different energies by PWIA and DWIA.

For ^{6}Li, the relative wave function between the α-cluster and the deuteron cluster is

$$\Phi_{rel}(R)=\begin{cases} A_{j_0}(\beta R), & R \le R_0 , \\ B h_0^{(1)}(i\gamma R), & R > R_0 , \end{cases}$$

where β , γ and R_0 are constants, which are taken as

$$R_0=3.5\text{fm},\ \beta=2.282\text{fm}^{-1},\ \gamma=.306\text{fm}^{-1}.$$

For ^{7}Li, the relative wave function between the α-cluster and the triton cluster is

$$\Phi_{rel}(R)=\begin{cases} A'_{j_1}(\beta R), & R \le R_0 , \\ B' h_1^{(1)}(i\gamma R), & R > R_0 , \end{cases}$$

where the constants β, γ and R_0 are taken as

$$R_0=3.5\text{fm},\ \beta=1.837\text{fm}^{-1},\ \gamma=.4542\text{fm}^{-1}.$$

With these functions we have calculated results, which agree with the experiments.

The experiments ^{6}Li(d,dd)α , ^{6}Li(α,αd)α , ^{6}Li(α,$\alpha\alpha$)d and ^{7}Li(α,$\alpha\alpha$)t with E_d=9 MeV, E_α=18 MeV are performed on the cyclotron in the Institute of Atomic Energy. In this abstract, two examples ^{6}Li(d,dd)α with E_d=9MeV and ^{7}Li(p,pt)α with E_p=55 MeV(Fig1-2) are shown as illustration.

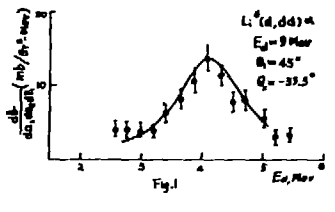


Fig.1

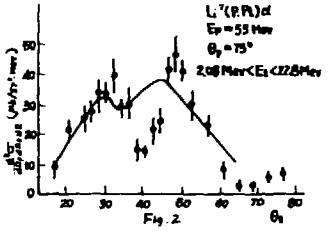


Fig.2

ENTRANCE CHANNEL EFFECTS IN FORMATION OF THE COMPOUND NUCLEUS ^{204}Rn *

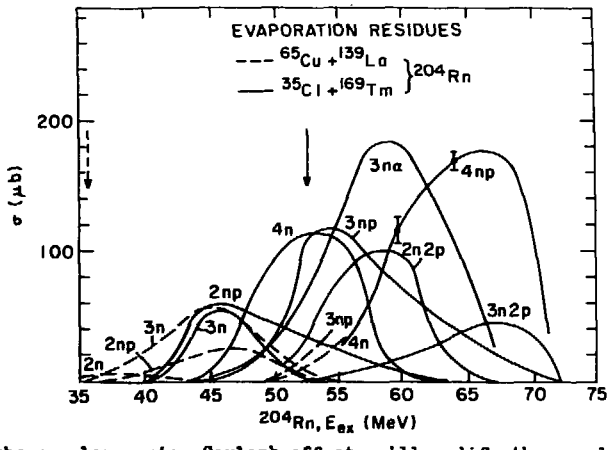
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Excitation functions for evaporation residues formed by multi-nucleon boiloff from the compound nucleus ^{204}Rn were measured over a range of excitation energy E_{ex} from 35 to 70 MeV utilizing the two heavy ion reactions $^{65}Cu + ^{139}La$ and $^{35}Cl + ^{169}Tm$ and the MIT-BNL Recoil Mass Selector. The ^{65}Cu reaction covered an E_{ex} range of 35-53 MeV and the ^{35}Cl reaction 40-70 MeV in approximately 5 MeV steps as shown in the figure. The two vertical arrows indicate the nominal E_{ex} corresponding to the Coulomb barrier for the two reactions. Data points and error bars were left out for clarity except for two to indicate the magnitude. The curves are drawn through the centroids of the data points.

The excitation functions for some of the evaporation residues overlap for the two reactions and consequently indicate the similarity and differencea in the decay of a compound nucleus at a particular excitation energy but with a maximum angular momentum of 40h for ^{35}Cl and 95h for ^{65}Cu. The



2np and 3n excitation functions are similar in shapefor the two reactions, with the 2np yield for the ^{65}Cu reaction approximately half that for the ^{35}Cl reaction; however all of the others in the overlap area are quite different.

The Coulomb barrier cutoff for ^{35}Cl reaction distorts the residue yield curves ascompared to the ^{65}Cu reaction so thatin the overlap region Coulomb effects will modify the angular momentum distribution for the formation of the compound nucleus. These gross effects are all allowed for in various evaporation models and these data have been compared to the predictions of OVERLAID ALICE[1] as well as other evaporation models. It is not surprising that these small (0.01%) of the total fusion crossection) residue yields are poorly predicted and the differences may be due to various kinds of preequilibrium fusion or entrance channel effects.

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1) M. Blann, OVERLAID ALICE COO-3494-29

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551 Bistirlich, J.A.
554 Bistirlich, J.
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82 Bizard, G.
538 Bizard, G.
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392 Blair, J.S.
838 Blair, J.S.
404 Blankenbecler, R.
466 Blankenbecler, R.
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69 Blankleider, B.
264 Blanpied, G.
687 Blanpied, G.S.
692 Blanpied, G.S.
695 Blanpied, G.S.
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727 Blanpied, G.S.
915 Blasi, N.

274 Blasing, C.
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896 Blok, J.
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452 Bochev, B.
570 Bock, R.
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71 Bodyagin, V.A.
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152 Bourgeois, C.
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253 Bousshid, O.
146 Bouyssy, A.
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709 Bowman, J.D.
695 Boyer, K.G.
887 Brady, F.P.
359 Braga, R.A.
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551 Buttke, T.F.
563 Buttlar, H.V.
842 Bybell, D.
309 Byrski, T.
153 Cable, M.
581 Cala, S.E.
388 Calabretta, L.
226 Calarco, J.R.
228 Calarco, J.R.
77 Caloi, R.
101 Cameron, J.M.
148 Camplan, J.
243 Cao, Z.-Q.
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57 Carstoiu, F.
77 Casano, L.
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617 Cecil, R.A.
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372 Chandra, H.
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224 Chew,S.H.
594 Cheynis, B.
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557 Chu, Y.T.
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906 Chung, W.
881 Chupp, T.E.
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148 Clifford, E.T.H.
162 Clough, A.S.
374 Cocu, F.
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911 Cohler, M.D.
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325 Cole, J.D.
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246 D'Erasmo, G.
375 D,hondt, P.
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461 Dacal, A.
577 Dacal, A.
816 Dahiya, H.S.
439 Dahme, W.
251 Dai, N.-X.
284 Dairiki, J.M.
223 Dallin, L.O.
44 Dalton, B.J.
354 Daly, P.J.
361 Daly, P.J.
264 Dam, S.H.
716 Dam, S.H.

907 Dang, Z.-J.
371 Danilyan, G.V.
468 Darves-Blanc, R.
86 Dasgupta, S.S.
713 Datar, V.M.
645 David, P
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410 Davies, K.T.R.
412 Davies, K.T.R.
422 Davies, K.T.R.
283 Davies, W.G.
695 Davis, J.
714 Davis, J.F.
727 Daw, G.H.
232 Dawson, J.F.
47 Day, B.
714 Day, D.
497 Dayras, R.A.
455 de Boer, F.W.N.
457 de Boer, F.W.N.
458 de Boer, F.W.N.
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375 De Frenne, D.
375 De Gelder, P.
189 de Haro, R.
203 De Leo, R.
246 De Leo, R.
915 de Meijer, R.J.
77 De Pascale, M.P.
388 De Pasquale, D.
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124 de Witt Huberts, P.K.A.
875 de Witt Huberts, P.K.A.
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588 Dehnhard, D.
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494 del Campo, J.G.
497 del Campo, J.G.
388 Del Zoppo, A.
643 Delagrange, H.
825 Delagrange, H.
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886 Delaroche, J.P.
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375 Deruytter, A.J.
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152 Desthuilliers-Porquet, M.G.
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591 Deutchman, P.A.
50 Deutsch, J.
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126 Deutschmann, U.
401 Devi, K.R.S.
175 DeVito, R.
418 DeVries, R.M.
423 DeVries, R.M.
306 Dewald, A.
415 Dhar, A.
412 Dhar, A.K.
456 Dhuga, K.S.
867 di Napoli, V.
327 Diamond, R.M.
328 Diamond, R.M.
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381 DiCenzo, S.B.
546 DiCenzo, S.B.
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585 Dietrich, K.
102 Dietzsch, O.
565 Dietzsch, O.
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51 Dillig, M.
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142 Dillig, M.
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70 Dimitrov, Kh.
72 Dimitrov, Kh.
243 Ding, D.-Z.
244 Ding, D.-Z.
613 DiRienzo, A.
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553 Disdier, D.
387 DiToro, M.
293 Divadeenam, M.

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741 Dixon, W.R.
131 Djaloeis, A.
253 Djaloeis, A.
403 Djaloeis, A.
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876 Djilavyan, L.Z.
737 Dobiasch, H.
728 Doerr, M.
122 Dolbilkin, B.S.
262 Doll, P.
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755 Donau, F.
928 Dong, T.-R.
154 Donnelly, T.W.
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354 Dors, C.L.
110 Dorsch, C.
335 Dossing, T.
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221 Dowell, D.H.
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900 Drentje, A.G.
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426 Duck, P.
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825 Dufour, J.P.
852 Duhm, H.H.
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57 Dumitrescu, O.
173 Dumitrescu, R.
439 Dunnweber, W.
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524 Durand, M.
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391 Durell, J.L.
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355 Dworzecka, M.
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667 Egido, J.L.
718 Eisenegger, C.
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132 Ekstrom, C.
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504 El-Masri, Y.
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503 El-Nagdi, M.S.
503 El-Sharkawi, S.M.
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710 El-Shawarbi, A.
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710 El-Sikafi, A.
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843 Emery, G.T.
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334 Emling, H.
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340 Engelbrecht, C.A.
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698 Enyo, H.
154 Epstein, G.N.

160 Epstein, G.N.
203 Erasmo, G.D.
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97 Esat, M.T.
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903 Feigel, A.
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347 Frauendorf, S.
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373 Frehaut, J.
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65 Frick, R.
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166 Fujiwara, M.
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873 Garibaldi, F.
88 Garman, E.F.

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608 Gavron, A.I.
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115 Gazzaly, M.M.
511 Ge, L.-X.
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24 Kuo, T.T.S.
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89 Lawin, H.
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471 Lebrun, D.
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