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Argonne National Laboratory

PHYSICS DIVISION SUMMARY REPORT

January-February 1966

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ANL-7179
Physics
AEC Research and
Development Report

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

PHYSICS DIVISION SUMMARY REPORT

January-February 1966

Lowell M. Bollinger, Division Director

Preceding Summary Reports:

- ANL-7029, January-March 1965
- ANL-7081, Annual Review, April 1964—March 1965
- ANL-7108, April-December 1965

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FOREWORD

Starting with this issue, the character of the ANL Physics Division Summary Report will be changed somewhat to emphasize not-yet-published results and work still in progress, and to reduce the labor of preparing the reports. The comments of readers will be welcomed.

The Physics Summary is issued at approximately monthly intervals for the information of the members of the Division and a limited number of other persons interested in the progress of the work. It includes short reports on highlights of the research, abstracts or short summaries of oral presentations at meetings, abstracts of papers recently accepted for publication, and publication notices of papers appearing in recent journals and books. Many of these cover work still in progress; the results and data they present are therefore preliminary, tentative, and often incomplete.

The research presented in any one issue of the Summary is only a small random sample of the work of the Physics Division. For a comprehensive overview, the reader is referred to the ANL Physics Division Annual Review issued each summer, the most recent being Argonne National Laboratory Report ANL-7081 which reports research in the year ending 31 March 1965.

The issuance of these reports is not intended to constitute publication in any sense of the word. Final results will be either submitted for publication in regular professional journals, or, in special cases, presented in ANL Topical Reports.

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TABLE OF CONTENTS

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I. RESEARCH HIGHLIGHTS

NEUTRON CROSS SECTIONS OF B^{10} FOR ENERGIES BETWEEN 10 AND 500 KEV* (51312-01)

F. P. Mooring, J. E. Monahan, and C. M. Huddleston†

Values of the $B^{10}(n,\alpha)Li^{7}$ cross section measured by Bichsel and Bonner[1] for neutron energies between 0.02 and 4.80 MeV are used frequently as a secondary standard for the measurement of neutron flux. These values are used also in shielding and reactor-design calculations where it is further assumed that the (n,α) cross section is equal to the absorption cross section of B^{10} for neutron energies below 1.0 MeV. Recently we have measured the neutron total and absorption cross sections of B^{10} for energies between 10 and 500 keV. Our values of the absorption cross section are larger (by an average of about 275 mb over the neutron-energy interval from 160 to 500 keV) than the values of the (n,α) cross section obtained from Ref. 1. These measurements are compared in Fig. 1.

Other measurements[2—4] of the other energetically allowed neutron-absorbing processes indicate that the (n,α) and the absorption

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*The full report has been accepted for publication in Nuclear Physics.

†Present address: U.S. Navy Civil Engineering Laboratory, Port Hueneme, California.

[1] H. Bichsel and T. W. Bonner, Phys. Rev. 108, 1025 (1957).

[2] P. D. Klein and F. P. Mooring (private communication).

[3] J. A. Biggerstaff, Some Recent Nuclear Cross Section Measurements at ORNL, edited by P. H. Stelson, ORNL-TM-1271 (1965), p. 8 (unpublished).

[4] C. Eggler, D. J. Hughes, and C. Huddleston, Phys. Rev. 74, 1239 (1948).

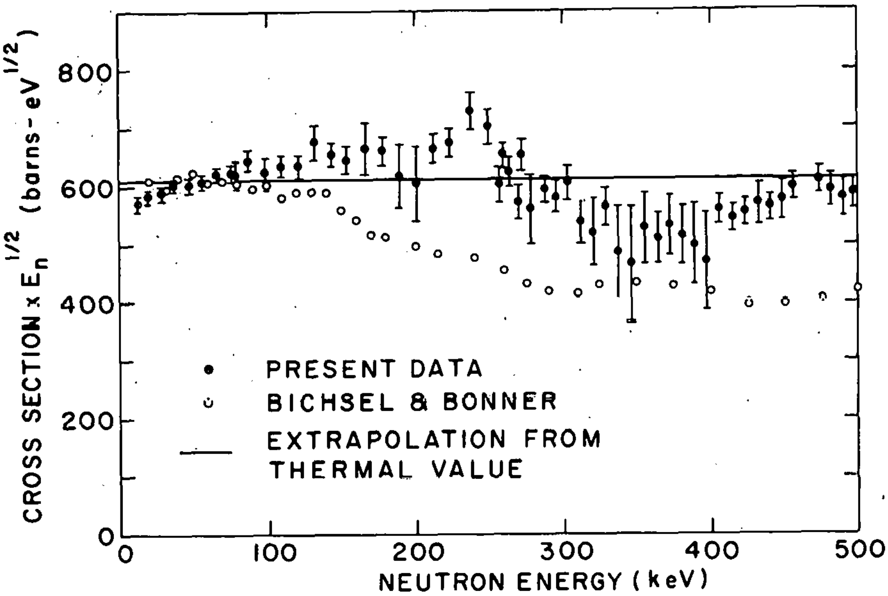

Fig. 1. A comparison of the present measurements of the reduced absorption cross section and the reduced (n, α) cross section of B^{10} obtained from Ref. 1. The horizontal line is a 1/v extrapolation of the thermal value of the (n, α) cross section. The measurements of Ref. 1 have been normalized to this 1/v extrapolation at the lowest energies.

cross sections of B^{10} are indeed very nearly equal in this energy interval. There is substantial confirmation of the accuracy of the present results from other measurements[5—7] of related cross sections. We believe, therefore, that the values of the B^{10}(n, α) cross section obtained from Ref. 1 are in error—by as much as 30%—in the interval from 160 to 500 keV.

In addition to (n, α), the possible neutron absorbing processes in B^{10} are (n, t), (n, p), and (n, γ). These alternative reactions have been investigated respectively by Klein and Mooring,[2] Biggerstaff,[3]

[5] S. A. Cox, Status Report to Nuclear Cross Section Advisory Group, Argonne National Laboratory, compiled by A. B. Smith (4 October 1965), p. 4 (unpublished).

[6] C. K. Bockelman, D. W. Miller, R. K. Adair, and H. H. Barschall, Phys. Rev. 84, 69 (1951).

[7] R. O. Lane, A. Elwyn, F. P. Mooring, and A. Langsdorf, Jr. (to be published).

and Eggler *et al.*[4] From these measurements it is possible to assign an upper limit of less than 100 mb for the average contribution from all of these alternative reactions in the energy interval from 160 to 500 keV. Thus it is improbable that the difference between the present B^{10} absorption results and the (n, α) measurements is the result of neutron-absorbing processes other than (n, α).

The present results and recent measurements of the B^{10} absorption cross section by Cox[5] are in good agreement over the interval (10—200 keV) common to both measurements. Further, our measurement of the total neutron cross section of B^{10} agrees with the measurement of Bockelman *et al.*[6] and our scattering cross section (obtained by subtracting the absorption from the total cross section) agrees with the scattering cross section obtained by integrating the differential-scattering measurements of Lane *et al.*[7]

PROTON REACTION CROSS SECTIONS AND STRENGTH FUNCTIONS

A. J. Elwyn, A. Marinov,* and J. P. Schiffer (51313-01)

When a (p,n) reaction on a given target element is induced by protons with energies sufficiently below the Coulomb barrier, the emission of charged particles is inhibited and the compound nucleus decays almost entirely by neutron emission. Under these circumstances, therefore, the total neutron yield integrated over all angles of emission is a good approximation to the total reaction cross section. In a recent series of experiments, about 33 elements in the region of atomic weight $90 \lesssim A \lesssim 209$ were bombarded by monoenergetic protons from the Argonne tandem accelerator. Total (p,n) reaction cross sections were obtained from the measured neutron yields and "reduced cross sections,"[1] which are closely related to the proton strength function, were determined by dividing the total neutron yields by the weighted sum of the penetrability factors of the Coulomb and centrifugal barriers. An optical-model description of the interaction of nucleons with nuclei predicts that the proton strength function should show resonances as a function of A, much as the neutron strength function does. Previous measurements[1,2] of the neutron yields from (p,n) reactions on elements from A = 37 to A = 130 have established the existence of a peak in the S-wave strength function near $A \approx 68$. The present experiment reveals a P-wave peak at about A = 105 and assesses the relative importance of S-, P-, and D-wave contributions in the various mass regions. It furthermore shows relatively good agreement between measured (p,n) cross sections and optical-model calculations of proton reaction cross sections up to $A \approx 200$.

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*Present address: The Hebrew University, Jerusalem, Israel.

[1] J. P. Schiffer and L. L. Lee, Jr., Phys. Rev. 109, 2098 (1958).

[2] C. H. Johnson, A. Galonsky, and J. P. Ulrich, Phys. Rev. 109, 1243 (1958).

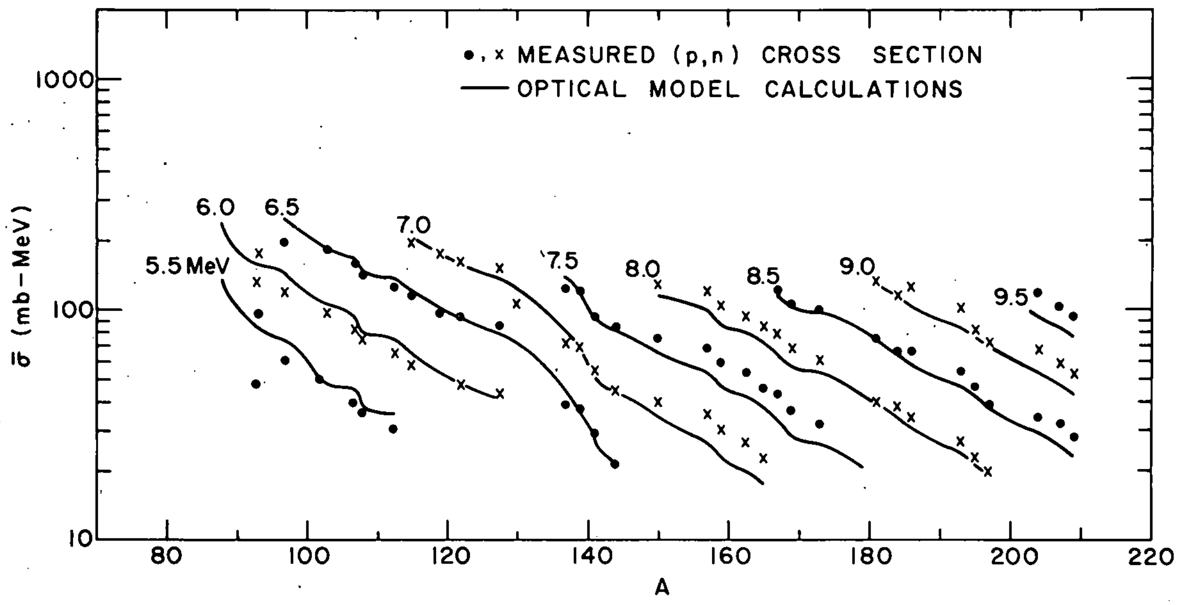

Fig. 2. The cross sections (at each of the indicated incident proton energies) as a function of atomic weight A. The points (circles and x's) are measured (p,n) reaction cross sections. The compound-nucleus cross sections (curves) were calculated on the basis of the optical model of Ref. 3.

These measured and calculated cross sections are compared in Fig. 2. The calculations were based on the surface-absorption optical potential of Perey,[3] which had been obtained from a systematic analysis of proton elastic-scattering data in the energy range between 9 and 22 MeV. As can be seen, the agreement between the calculations and the measurements is remarkably good—especially in the mass regions $100 \lesssim A \lesssim 150$ and $180 \lesssim A \lesssim 195$. But as might be expected, in the intervening range from $A \approx 150-180$ (a region of strongly deformed nuclei) the data are in less good agreement with calculations based on a spherical optical model.

Figure 3 shows the A dependence of the mean reduced cross sections, the points being the measured values and the curves the result of an optical-model calculation. Although some of the actual details

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[3] F. G. Perey, Phys. Rev. 131, 745 (1963).

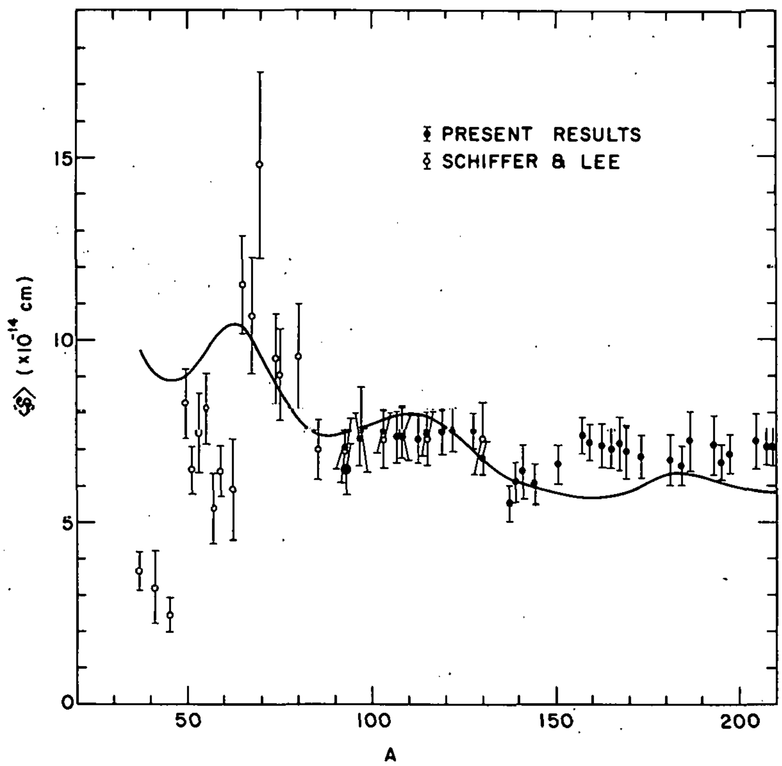

Fig. 3. The mean "reduced cross sections" measured in the present experiment and that of Ref. 1 as a function of A (points) compared with calculations based on the optical model of Ref. 3. The calculated curves result from dividing the computed compound-nucleus cross sections by the weighted sum of the Coulomb and centrifugal penetrability factors.

in the data are not reproduced by the calculations (notably in the region of strongly deformed nuclei), the disagreement between calculations and measurements is not worse than 10—15%, at least for $A \geqslant 90$.

On the basis of further calculations, in which the optical-model results were decomposed into their partial-wave components, we find that the fall-off in the "reduced cross sections" for A = 120 to A = 140 (in Fig. 3) can be associated with a large decrease in the P-wave transmission coefficients. Further, at the higher atomic weights, the calculations indicate that S- and D-wave proton captures predominate. We conclude, then, that the P-wave proton strength function peaks at about A = 105, and that S- and D-wave strength functions dominate near $A \approx 65$ and for $155 \leqslant A \leqslant 200$. In the mass region between $A \approx 150$ and $A \approx 180$, it is likely that specific properties of deformed nuclei play an important role for the proton strength function, as has previously been shown to be the case for the neutron strength function.[4]

[4] F. S. Troubetskoy and B. Margolis, Phys. Rev. 106, 105 (1956); D. M. Chase, L. Wilets, and A. R. Edmonds, Phys. Rev. 110, 1080 (1958).

A NEW METHOD FOR DETERMINING CHARGE RADII OF NUCLEI

K. W. Jones,* L. L. Lee, Jr., A. Marinov, and J. P. Schiffer (51312-01)

The existence of sharply defined isobaric-analog states in highly excited nuclei is one of the more interesting recent discoveries in experimental nuclear physics. Recently, in experiments on the Argonne tandem Van de Graaff accelerator, such states were studied in the scattering of protons from a Ca^{48} target. The energies of these resonant states in Sc^{49} can then be compared with the states in the $Ca^{48} + n \rightarrow Ca^{49}$ system and the difference in their energies can be obtained. This difference in energy should arise entirely from the Coulomb energy E_c of a proton interacting with the charge distribution of Ca^{48}; the states are otherwise identical. If the wave function of a state is well known, the radius of the charge distribution can therefore be obtained if one assumes a specific shape (such as a uniform sphere) for the distribution.

The structure of the Ca isotopes is reasonably well known. We have used single-particle wave functions in a Woods-Saxon potential well to calculate a charge radius for Ca^{48}, and have done similar calculations for the other even-A Ca isotopes. The results are shown in Table I. As a check on the calculation, it was repeated for states other than the ground state in two cases in which the energies of other single-particle states were known. The results are in excellent agreement with the calculations for the ground state.

The ratio of the charge radius of Ca^{40} to that of Ca^{44} has recently been determined from a combination of electron-scattering and muonic x-ray measurements.[1] The result was 1.008 ± 0.003 which can

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*Brookhaven National Laboratory.

[1] R. Hofstadter, G. K. Nöldeke, K. J. van Oostrum, L. R. Suelzle, M. R. Yearian, B. C. Clark, R. Herman, and D. G. Ravenhall, Phys. Rev. Letters 15, 758 (1965).

be compared with the present result of 0.998 ± 0.007. The agreement seems reasonable in view of the approximations made in the present calculations.

TABLE I. Summary of Coulomb energies and charge radii for the even-A calcium isotopes.

Nucleus	Observed E_c (MeV)	Charge radius (F)
Ca^{40}	7.302	4.189
Ca^{42}	7.164	4.293
Ca^{44}	7.125	4.183
Ca^{48}	6.701	4.129

II. PAPERS PRESENTED AT MEETINGS

Symposium on Research and Industrial Applications of the Mössbauer Effect

New York City, 25 January 1966

MÖSSBAUER ANALYSIS OF IRON IN STONE METEORITES

E. L. Sprenkel-Segel and S. S. Hanna*

The absorption of resonant gamma rays by Fe^{57} has been used in the analysis of iron in stone meteorites. By comparison with absorption patterns of terrestrial reference minerals, the meteoritic compounds may be identified and the relative amount of iron in each mineral determined. Typical minerals analyzed (Fig. 4) are olivine and pyroxene (ferromagnesian silicates), troilite (a sulfide), and kamacite (an iron-nickel alloy). Iron analysis plays an important role in both the classification of meteorites and the investigation of their preterrestrial history. Important inferences concerning the evolution of meteorite bodies can be deduced from the relative proportions of oxidized and reduced iron in stone meteorites.

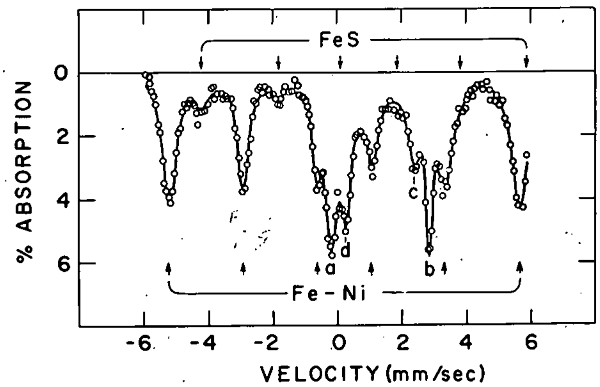

Fig. 4. Mössbauer spectrum of the magnetically separated fraction of the Plainview meteorite. Absorption lines a and b are from olivine, c is from pyroxene, and d is mainly from pyroxene but also includes some absorption by FeS.

*Stanford University.

American Physical Society Meeting

New York, 26—29 January 1966

INTERNAL SYMMETRIES ALLOWED IN A MANY-CHANNEL MODEL

James T. Cushing

Bull. Am. Phys. Soc. 11, 22 (January 1966)

Numerical ratios of coupling constants produced by crude N/D calculations are sometimes interpreted as indicating that a particular internal symmetry group is favored, or possibly chosen uniquely, by strong interactions, the general philosophy being that a particular symmetry group may be the only one compatible with a unitary, crossing-symmetric, self-consistent set of scattering amplitudes. However, in practice crossing symmetry is badly violated in constructing approximate solutions so that it is unclear to what extent a symmetry generated in this manner is indicative of a symmetry possessed by the actual scattering amplitude. Therefore, a model has been considered in which two types of particles, each carrying internal quantum numbers and embedded in a two-dimensional world, scatter from each other. All two-particle intermediate states, both elastic and inelastic, are treated without approximation. The nonlinear integral equations coupling the four possible scattering amplitudes are solved exactly. Analytic, unitary, crossing-symmetric solutions are obtained independent of the nature of the unspecified internal symmetry group. Therefore, in this model at least, the usual assumptions of unitarity and crossing are not sufficient to explain the origin of an internal symmetry.

$Ti^{48}(d,d)Ti^{48}$ FROM 6 TO 11 MEV

C. Mayer-Böricke* and R. H. Siemssen

Bull. Am. Phys. Soc. 11, 82 (January 1966)

In order to study the variation of the deuteron optical-model parameters with decreasing bombarding energies, we have measured

*Present address: Max Planck Institut für Kernphysik, Heidelberg.

the elastic scattering of deuterons from Ti^{48} in the energy range from 6 to 11 MeV. The scattered deuterons were detected with a solid-state counter telescope for particle identification. Angular distributions have been obtained at 6, 7, 8, 9, 10, and 11 MeV. The data have been analyzed in terms of the nuclear optical model and comparison is made with the results of other deuteron scattering experiments in the same energy range.

x RAYS FROM MUONIC BISMUTH

S. Raboy, R. E. Coté, R. Guso,* R. A. Carrigan, Jr.,† A. Gaigalas,† R. B. Sutton,† and C. C. Trail‡

Bull. Am. Phys. Soc. 11, 129 (January 1966)

The x rays from atoms of muonic bismuth have been studied with the aid of the muon channel at the synchrocyclotron of the Carnegie Institute of Technology and a lithium-drifted germanium gamma-ray spectrometer. All of the lines reported by Acker et al.[1] have been observed and their fine-structure splittings and the absolute values of their energies have been measured. Both of these are in excellent agreement with the earlier values. In addition, the $2p_{3/2} \rightarrow 1s_{1/2}$ transition has been resolved into two components whose separation is compatible with the rather small intrinsic quadrupole moment of bismuth. The separation of these two components is about 10 keV. An approximate theoretical treatment of the relative intensities of the components of the $2p_{3/2} \rightarrow 1s_{1/2}$ transition

*Special Materials and Services.

†Carnegie Institute of Technology.

‡Brooklyn College.

[1] H. L. Acker, G. Backenstoss, C. Daum, J. C. Sens, and S. A. DeWit, Phys. Letters 14, 317 (1965).

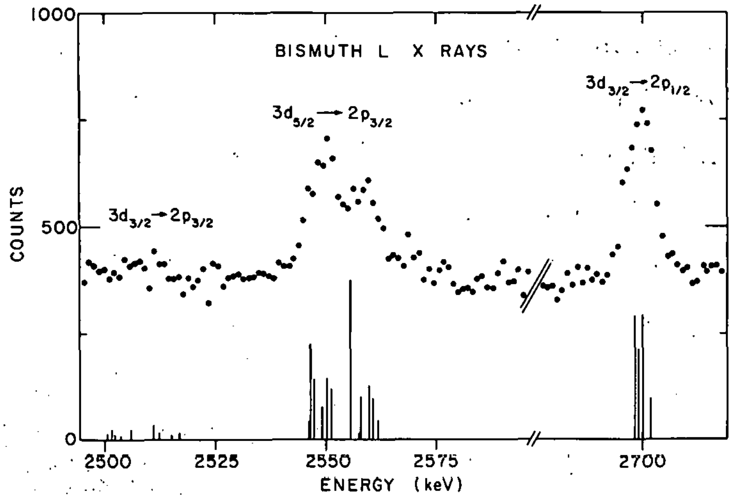

Fig. 5. The L x-ray spectrum of bismuth and a computed spectrum based on magnetic-dipole and electric-quadrupole interactions between the muon and the nucleus.

predicts two pairs of lines of roughly the same intensity separated by about 7 keV. The L x-ray spectrum for bismuth shows this structure, caused mainly by the hyperfine splitting of the $2p_{3/2}$ level, much more clearly. Furthermore, the K line associated with $2p_{1/2} \rightarrow 1s_{1/2}$ transitions is broader than the corresponding calibration line. This extra width is caused by the magnetic-dipole interaction between the nucleus and the muon. A computed spectrum for the L x rays in bismuth, which includes the effects of both the magnetic-dipole and electric-quadrupole interactions, is shown with the observed spectrum in Fig. 5. The spectra from nine other atoms with nearly spherical nuclei have been studied.[2]

[2] See the report below entitled "x Rays from Muonic Atoms with Spherical, Nearly Spherical, and Nonspherical Nuclei," presented at the Williamsburg Conference on Intermediate Energy Physics.

(d, p) REACTIONS ON $Zn^{64,66,68}$

J. P. Schiffer, D. von Ehrenstein, and L. L. Lee, Jr.

Bull. Am. Phys. Soc. 11, 100 (January 1966)

Angular distributions have been measured between 20° and 160° in steps of 5° for the (d, p) reactions on $Zn^{64,66,68}$ with 10-MeV deuterons from the Argonne tandem Van de Graaff in order to determine spins and parities of the final states with the help of the previously established J-dependence rules.[1] The data were acquired with a solid state detector and—in forward direction—with the magnetic spectrograph. We found a number of new levels, were able to determine unknown spins, and to verify or correct previously assigned spin values.[2] Most striking examples for corrections on the basis of the J dependences[1] are the spins of the low-lying levels 0.09 MeV and 0.18 MeV of $Zn^{66}(d,p)Zn^{67}$ to which we assign $J = \frac{1}{2}^-$ and $\frac{3}{2}^-$, respectively, instead of the previous $J = \frac{3}{2}^-$ and $\frac{5}{2}^-$.

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[1] L. L. Lee, Jr., and J. P. Schiffer, Phys. Rev. 136, B405 (1964).

[2] Nuclear Data Tables; and E. K. Lin and B. L. Cohen, Phys. Rev. 132, 2632 (1963).

MÖSSBAUER QUADRUPOLE RESONANCE IN Sb^{121}

R. E. Snyder,* G. B. Beard,* S. L. Ruby, and G. M. Kalvius†

Bull. Am. Phys. Soc. 11, 51 (January 1966)

Following the discovery that the $\frac{7}{2}^+ \rightarrow \frac{5}{2}^+$ transition in Sb^{121} can be studied via Mössbauer techniques,[1] we have taken spectra from several compounds with large electric field gradients. The resulting 8-line spectra are partially resolved and can be interpreted in terms of the ground-state interaction constant e^2qQ, the ratio R of the excited-state to ground-state quadrupole moment, and the isomer shift s. For the favorable case of Sb_2O_3, where conventional EQR has given $e^2qQ = 551.38$

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*Wayne State University.

†Solid State Science Division.

[1] R. E. Snyder and G. B. Beard, Phys. Letters 15, 3 (1965).

Mc/sec and $\eta = 0$ at $300^{\circ}K$,[2] our computer fitting techniques give the two results R = 1.38 or 0.59, with the former more likely. A second compound, potassium antimono-tartrate (unfortunately not yet examined by EQR), gives spectra which can be well fitted only by the first value of R and using $\eta \approx 0.5$. Our final results for Sb_2O_3 at $4.2^{\circ}K$ using an Sb in Sn source are: $e^2qQ = +(18.5 \pm 0.4)$ mm/sec = +(551 ± 12) Mc/sec; R = 1.38 ± 0.03; and s = -0.47 ± 0.03 mm/sec. Q^{121} $(\frac{7}{2}^{+})$ is 8.5% larger than Q^{123} $(\frac{7}{2}^{+})$ which differs from it only by a pair of neutrons.

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[2] S. L. Segal and R. G. Barnes, Catalogue of Nuclear Quadrupole Interactions, TID 4500, 1962.

CONCEALED CONFIGURATION MIXING IN THE NUCLEAR SHELL MODEL

J. M. Soper* and R. D. Lawson

Bull. Am. Phys. Soc. 11, 102 (January 1966)

We have examined the extent to which various types of configuration admixture, which might reasonably be expected to occur in nature, affect the commonly measured properties of nuclear states. We construct wave functions with mixed configurations by means of a shell-model calculation in a basis containing more than one shell. For this purpose we use a simple potential which has, however, many of the properties of the free two-nucleon interaction. We dub the resulting states "pseudo-nature," and proceed to fit their properties within the framework of a single shell, exactly as if they were experimental quantities. We find that certain types of admixture can be present in overwhelming amounts (over 80% for example) and yet be scarcely

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*A. E. R. E., Harwell, England. On leave of absence at Argonne National Laboratory.

detectable in their effects on spectra, moments, transitions, or spectroscopic factors. These "pseudo-nuclei" behave largely as unmixed simple shell-model systems.

ENERGIES OF x RAYS FROM MUONIC TANTALUM

C. C. Trail,* R. A. Carrigan,† A. Gaigalas,† R. B. Sutton,† R. E. Coté, S. Raboy, and R. Guso‡

Bull. Am. Phys. Soc. 11, 129 (January 1966)

The spectrum of x rays from muonic tantalum produced with muons from the muon channel at the synchrocyclotron of the Carnegie Institute of Technology has been studied with a lithium-drifted germanium gamma-ray spectrometer. The spectrum of x rays is expected to be quite complex (about 22 components for the K lines) because of the large intrinsic quadrupole moment of Ta^{181} and the consequent mixing of the nuclear states and of the various muon states. While the resolution and sensitivity of the present experiments do not permit observation of all of these components, they are good enough to

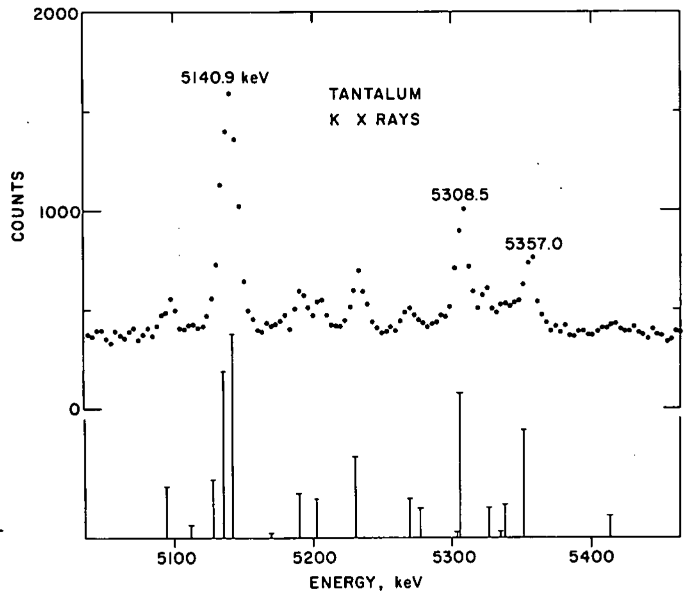

Fig. 6. The K x-ray spectrum of tantalum and a computed spectrum based on an intrinsic quadrupole moment Q_0 = +9.0 and rotational levels at 136.1 and 301.3 keV.

*Brooklyn College.
†Carnegie Institute of Technology.
‡Special Materials and Services.

produce a spectrum with enough lines to allow a meaningful detailed comparison with a theoretical spectrum. Such a comparison of the present results with a theoretical spectrum is shown in Fig. 6. The muonic x-ray spectra from ten other atoms with deformed nuclei have been studied.[1]

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[1] See the report below entitled "x Rays from Muonic Atoms with Spherical, Nearly Spherical, and Nonspherical Nuclei," presented at the Williamsburg Conference on Intermediate Energy Physics.

Williamsburg Conference on Intermediate Energy Physics

Williamsburg, Virginia, 10—12 February 1966

x RAYS FROM MUONIC ATOMS WITH SPHERICAL, NEARLY SPHERICAL, AND NONSPHERICAL NUCLEI*

R. E. Coté, S. Raboy, R. A. Carrigan, Jr., † A. Gaigalas, †
R. B. Sutton, † and C. C. Trail

Of the atoms discussed, those with nearly spherical nuclei were $Ag^{107-109}$, In^{115}, I^{127}, Pr^{141}, $Ce^{140-142}$, Au^{197}, and Bi^{209}; those with deformed nuclei were Tb^{159}, Ho^{165}, and Ta^{181}.[1] An additional twelve elements have been studied but are not discussed.

For the most part, monoisotopic elements were chosen for this series of measurements since these offer the best chances for unambiguous interpretation. Of the elements discussed, only two (silver and cerium) had appreciable amounts of more than one isotope. Both of these are composed almost entirely of only two isotopes, so that a reasonably unambiguous interpretation can be made. The K x-ray spectra of both elements showed a splitting caused by the presence of the two isotopes. In the cerium spectrum (Fig. 7), the full-energy peaks of the K_α lines are seen at the left of the figure; the double-escape peaks of the K_β lines are seen on the right. The natural abundance of Ce^{142} is about one eighth that of Ce^{140}, so the K_α lines of Ce^{142} appear as low shoulders on the low-energy side of the K_α lines of Ce^{140}. The splitting of the K_β lines is a measure of the fine-structure splitting of the 3p levels.

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*Two papers, "x Rays from Muonic Atoms with Spherical or Nearly-Spherical Nuclei" and "Studies of Muonic Atoms with Nonspherical Nuclei," were listed in the program but were presented together as a single 20-minute paper at the meeting.

†Carnegie Institute of Technology.

[1] Spectra for bismuth and tantalum are shown in Figs. 5 and 6 (in the abstracts for the New York meeting of the American Physical Society).

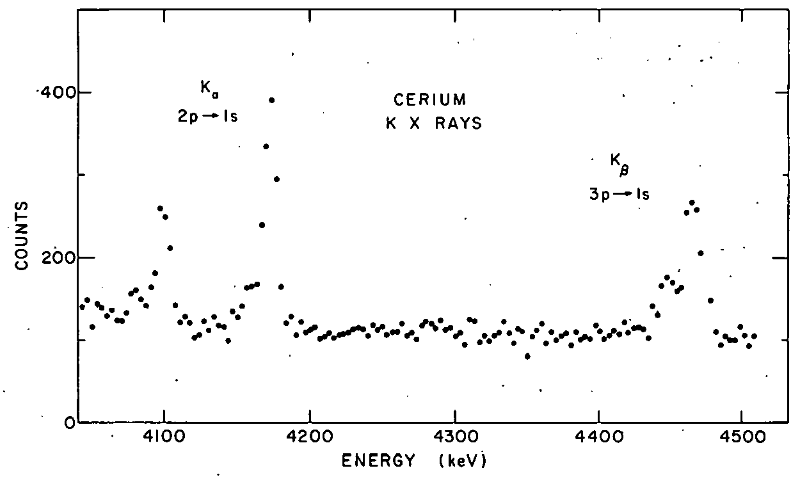


Fig. 7. The K_α and K_β x rays from natural cerium. The K_α lines are represented by full-energy peaks, the K_β lines through their double-escape peaks.

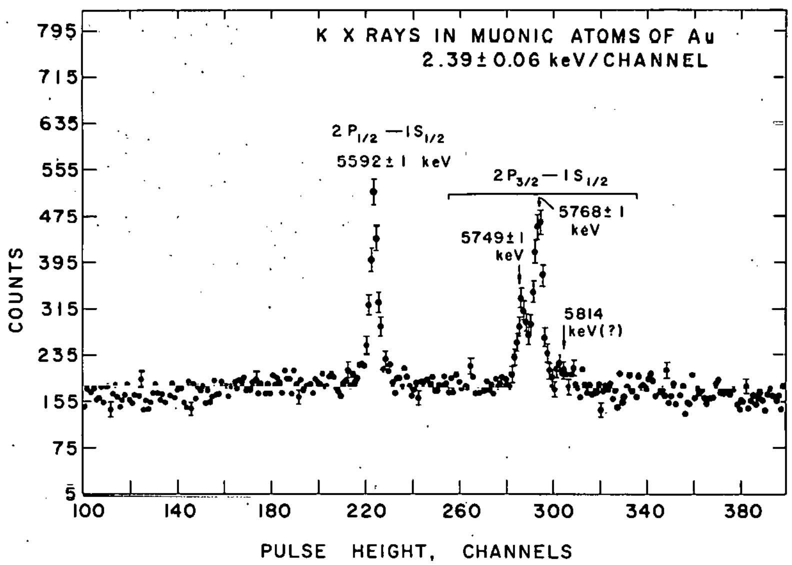
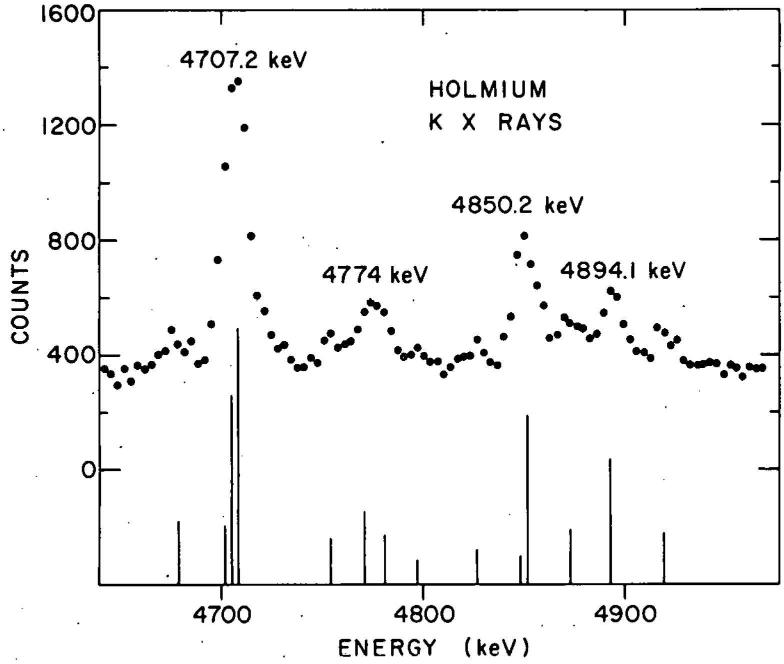


Fig. 8. The K x-ray spectrum of gold.

Definite splitting of the K and L lines, caused by hyperfine splitting of the muonic levels, was observed for gold, bismuth, iodine, and indium. The K x-ray spectrum of gold is shown in Fig. 8. The splitting of the $2p_{3/2} \rightarrow 1s_{1/2}$ transition is quite obvious. The ratio of the intensities of these three components is very close to that expected on the basis of statistical populations of the p levels; i.e., 5:10:1. The ratio of the sum of these three components to the $2p_{1/2} \rightarrow 1s_{1/2}$ line is 1.6:1, not the nearly 2:1 expected on the basis of statistical populations of the 2p levels. Similar discrepancies are found for bismuth and iodine.

The highly deformed nuclides produce further splitting of the x-ray lines. The spectrum of K x rays observed for Ho^{165} is shown

Fig. 9. The K x-ray spectrum for holmium. The line spectrum shown below the experimental spectrum is based on an intrinsic quadrupole moment $Q_0 = +7.8$ b and the excitation of four nuclear levels.



in Fig. 9. The main breadth of the pattern is a rough measure of the fine-structure splitting of the 2p levels, the separation of the peaks at 3828.5 and 3871.4 keV is a measure of the quadrupole interaction, and the lines near the center of the spectrum depend on the excitation of nuclear levels. For holmium, emission of a K x ray leaves the nucleus in the first excited state about 23% of the time and in the second excited state about 4% of the time.

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III. ABSTRACTS OF PAPERS ACCEPTED FOR PUBLICATION

PHENOMENOLOGICAL α-α POTENTIALS

S. Ali* and A. R. Bodmer

Nucl. Phys.

Phenomenological ℓ-dependent α-α potentials are obtained for ℓ = 0, 2, and 4 from fitting the relevant phase shifts for c.m. energies $\lesssim$ 12 MeV. For the nuclear part of the potentials, a superposition of repulsive and attractive Gaussian shapes was used. Following theoretical indications, we try to obtain fits with an ℓ-independent attractive part having a longer range than the repulsive parts. Further, we attempt to obtain, at first, the attractive part from just the ℓ=4 phase shift in view of the effect of the large ℓ=4 centrifugal barrier in masking the inner repulsive part. It is, in fact, found possible to obtain acceptable potentials with a common attractive part. These potentials are, however, strongly ℓ dependent through the repulsive part which becomes weaker as ℓ increases. For ℓ = 4, only a quite weak repulsive part is found to be permissible. Our potentials are in good agreement with those recently obtained by Darriulat et al. The possible importance of the attractive tail of the α-α potential as a selective probe into just the central, spin-independent, isospin-independent part of the nuclear force is pointed out and discussed.

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*The University, Manchester, England.

NUCLEAR RESONANCE FLUORESCENCE IN Kr^{82}

G. B. Beard

Phys. Rev.

The 777-keV excited state of Kr^{82} has been investigated by means of nuclear resonance-fluorescence scattering experiments. The level width was found to be $(9.6 \pm 1.5) \times 10^{-5}$ eV corresponding to a mean

life of $(6.9 \pm 1.1) \times 10^{-12}$ sec. From this result and the relative reduced transition probabilities determined previously by Heydenberg, Pieper, and Anderson, the mean lives for first excited states of other even-even Kr isotopes can be obtained. No resonant scattering from the 1.475-MeV state of Kr^{82} was observed and its mean life was estimated to be $> 1.2 \times 10^{-12}$ sec.

PROTON REACTION CROSS SECTIONS AND STRENGTH FUNCTIONS

A. J. Elwyn, A. Marinov, and J. P. Schiffer

Phys. Rev. (20 May 1966)

The average yields of neutrons from proton-induced reactions in thick targets have been measured for about 33 elements in the mass region $90 \lesssim A \leqslant 209$ at incident proton energies between 5.5 and 9.5 MeV. In this region of energies and masses, the (p, n) reaction overwhelms competing reactions so that, except in a few cases, the average (p, n) cross sections deduced from the measured yields are equal to the total reaction cross sections for protons. Reduced cross sections, which are directly related to the proton strength function, were obtained from the measurements. These results, as well as the results of previous measurements for $A < 90$, were compared with optical-model calculations. Proton reaction cross sections calculated from the optical potential of F. G. Perey are in remarkably good quantitative agreement with the measurements. The data are consistent with a resonance in the P-wave proton strength function at $A \approx 105$, and with dominant contributions from S- and D-wave protons at $A \approx 65$ and for $155 \leqslant A \leqslant 200$. The measured angular distributions for some of the nuclei showed symmetry about 90° to about 2%, indicating no measurable direct-interaction component. The maximum anisotropy observed was about 7%.

MEASUREMENT OF THE SPINS OF SOME STATES IN Fe^{55}

D. S. Gemmell, L. L. Lee, Jr., A. Marinov, and J. P. Schiffer

Phys. Rev.

The p-γ angular correlations in the reaction $Fe^{54}(d, p\gamma)Fe^{55*}$ have been measured for several proton groups. The groups chosen correspond to states for which the proton angular distribution shows formation by $\ell = 1$ neutron capture. These states must therefore have spins $\frac{1}{2}^-$ or $\frac{3}{2}^-$. A state

with spin $\frac{1}{2}^-$ must exhibit an isotropic angular correlation while a state of spin $\frac{3}{2}^-$ will ordinarily show some anisotropy. The results indicate spin $\frac{1}{2}^-$ for the first excited state of Fe^{55} at 413 keV and spin $\frac{3}{2}^-$ for states at 2.490, 3.556, and 3.800 MeV excitation. The conclusions are compared with previous results and with theoretical predictions.

SUPPRESSION OF MULTIPACTING IN PARTICLE ACCELERATORS

Albert J. Hatch

Nucl. Instr. Methods

A new method of suppressing the multipacting breakdown between conductors in evacuated high-frequency systems such as in cyclotrons and linacs is described. Thin metallic or insulating baffles are used to subdivide the interconductor space into gaps narrower than that for multipacting cutoff. Measurements in a system with plane-parallel electrodes show the method to be effective and electrically nonperturbing. The experimental results are correlated with an "average electron" theory of multipacting developed previously and presented here in a form suitable for use by the accelerator designer.

STUDIES OF ELASTIC SCATTERING OF PROTONS AND DEUTERONS BY CALCIUM ISOTOPES

A. Marinov, L. L. Lee, Jr., and J. P. Schiffer

Phys. Rev. (22 April 1966)

Angular distributions of elastically scattered protons and deuterons from enriched isotopic targets of Ca^{42}, Ca^{44}, and Ca^{48} have been measured at bombarding energies of 9 and 12 MeV, between 30° and 168°. The data are analyzed in terms of the optical model, with particular emphasis on the importance of a symmetry term in the proton potential. The energy dependence of the parameters is also discussed. The results are compared with those obtained from earlier work on isotopes of nickel and copper. An attempt is made to find systematic trends in the deuteron potential and a comparison is made with earlier measurements of deuteron scattering from Ca^{40} and from Ni and Cu isotopes.

NEUTRON CROSS SECTIONS OF THE BORON ISOTOPES FOR ENERGIES BETWEEN 10 AND 500 KEV

F. P. Mooring, J. E. Monahan, and C. M. Huddleston

Nucl. Phys.

The total neutron cross sections of ^{10}B, ^{11}B, C, and O and the absorption cross section of ^{10}B have been measured for neutron energies between 10 and 500 keV. The ^{10}B absorption cross section does not deviate appreciably from a 1/v dependence in this interval of neutron energies. The present values of the ^{10}B absorption cross section are systematically larger than previously measured values of the $^{10}B(n,\alpha)$ cross section; but the evidence presented indicates that this excess cannot be explained in terms of other neutron-absorbing reactions.

GAMMA DECAY OF THE 5.16-MEV STATE IN B^{10}

R. E. Segel and R. H. Siemssen

Phys. Letters (15 February 1966)

A transition from the 5.16-MeV state to the 3.58-MeV state in B^{10} was sought and found; the strength of this transition is in agreement with the theoretical predictions of Cohen and Kurath. It is shown that the entire gamma decay scheme from the 5.16-MeV level is consistent with the theory.

STUDY OF THE $K^{39}(p,\alpha)Ar^{36}$ REACTION

D. von Ehrenstein, L. Meyer-Schützmeister, and R. G. Allas

Nucl. Phys.

The reaction $K^{39}(p,\alpha)Ar^{36}$ was investigated in the incident-proton energy range 10.0—13.0 MeV in steps of 20 keV and 100 keV at eight angles from 25° to 160°. The excitation functions of the α groups leading to different final states in Ar^{36} exhibit strong fluctuations in forward and backward angles. These fluctuations usually are not correlated. The analysis was made in terms of Ericson's statistical model. The coherence width Γ is around 10—15 keV. There are some indications for nonfluctuating contributions (direct interaction). Tentative spin assignments of the first two excited states in Ar^{36} are discussed on the basis of the (2I + 1) rule.

IV. PUBLICATIONS SINCE THE LAST REPORT

PAPERS

HYPERTRITON WITH S' STATE AND THE Λ-N INTERACTION
A. R. Bodmer
Phys. Rev. 141, 1387-1397 (January 1966)

THE MASS-SEVEN HYPERNUCLEI AND THE MASS-SIX NUCLEI
A. R. Bodmer and J. W. Murphy*
Nucl. Phys. 73, 664-680 (November 1965)

ELECTRON-SPIN RELAXATION AND THE MÖSSBAUER EFFECT IN FERRIC AMMONIUM SULPHATE
A. J. F. Boyle and J. R. Gabriel (Applied Mathematics and Solid State Science Divisions)
Phys. Letters 19, 451-452 (1 December 1965)

ELECTRONIC g FACTORS OF THE LOW LEVELS OF Ni I
W. J. Childs, M. S. Fred (Chemistry), and L. S. Goodman
Phys. Rev. 141, 44-47 (January 1966)

HYPERFINE STRUCTURE OF Ge^{73} IN THE $^3P_1$ AND $^3P_2$ ATOMIC STATES AND THE NUCLEAR MAGNETIC DIPOLE MOMENT OF Ge^{71}
W. J. Childs and L. S. Goodman
Phys. Rev. 141, 15-21 (January 1966)

HYPERFINE STRUCTURE OF THE 9161-cm^{-1} $^2D_{5/2}$ STATE OF Au^{197} AND THE NUCLEAR ELECTRIC-QUADRUPOLE MOMENT
W. J. Childs and L. S. Goodman
Phys. Rev. 141, 176-180 (January 1966)

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*The University, Manchester, England.

GAMMA RAYS FROM THE DECAY OF 35-DAY Nb^{95}

L. B. Church,* A. Gaigalas,* R. B. Sutton,* R. E. Coté, S. Raboy, and C. C. Trail†

Phys. Rev. <u>142</u>, 690-691 (18 February 1965)

RELATIVISTIC COMBINATION OF INTERNAL AND SPIN SYMMETRIES IN S-MATRIX FORMULATION

H. Ekstein

Phys. Rev. <u>141</u>, 1560-1571 (January 1966)

POLARIZATION AND DIFFERENTIAL CROSS SECTIONS IN THE SMALL-ANGLE SCATTERING OF NEUTRONS BY URANIUM

A. J. Elwyn, J. E. Monahan, R. O. Lane, A. Langsdorf, Jr., and F. P. Mooring

Phys. Rev. <u>142</u>, 758-767 (18 February 1966)

ENERGY LEVELS IN Sc^{49} FROM $Ca^{48}(He^3,d)Sc^{49}$, AND OTHER REACTIONS PROCEEDING FROM Ca^{48}

J. R. Erskine, A. Marinov, and J. P. Schiffer

Phys. Rev. <u>142</u>, 633-637 (18 February 1966)

INELASTIC ALPHA SCATTERING AND ASSOCIATED GAMMA RADIATION. II

D. R. Inglis

Phys. Rev. <u>142</u>, 591-598 (18 February 1966)

THE DYNAMO MODEL, FIELD REVERSAL, AND POLAR WANDERING

D. R. Inglis

J. Geomagnetism and Geoelectricity (Japan) <u>17</u>, 517-529 (1965)

MEASUREMENTS OF NEUTRON CROSS SECTIONS OF Fe, Al, AND CF_2 BY A RATIO METHOD

A. Langsdorf, Jr., J. E. Monahan, R. O. Lane, and A. J. Elwyn

Phys. Rev. <u>142</u>, 643-656 (18 February 1966)

^{47}K MASS FROM THE REACTION $^{48}Ca(d,^3He)^{47}K$

E. Newman,‡ J. C. Hiebert,‡ and B. Zeidman

Phys. Rev. Letters <u>16</u>, 28-30 (3 January 1966)

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*Carnegie Institute of Technology.

†Brooklyn College.

‡Oak Ridge National Laboratory.

PAPERS AT MEETINGS

American Physical Society meeting, New York, 26—29 January 1966.

INTERNAL SYMMETRIES ALLOWED IN A MANY-CHANNEL MODEL
J. T. Cushing
Bull. Am. Phys. Soc. 11, 22 (January 1966)

$Ti^{48}(d,d)Ti^{48}$ FROM 6 TO 11 MEV
C. Mayer-Böricke and R. H. Siemssen
Bull. Am. Phys. Soc. 11, 82 (January 1966)

x RAYS FROM MUONIC BISMUTH
S. Raboy, R. E. Coté, R. Guso (Special Materials and Services), R. A. Carrigan, Jr.,* A. Gaigalas,* R. B. Sutton,* and C. C. Trail†
Bull. Am. Phys. Soc. 11, 129 (January 1966)

$Zn^{64,66,68}(d,p)$ REACTIONS
J. P. Schiffer, D. von Ehrenstein, and L. L. Lee, Jr.
Bull. Am. Phys. Soc. 11, 100 (January 1966)

MÖSSBAUER QUADRUPOLE RESONANCE IN Sb^{121}
R. E. Snyder,‡ G. B. Beard,‡ S. L. Ruby, and G. M. Kalvius (Solid State Science)
Bull. Am. Phys. Soc. 11, 51 (January 1966)

CONCEALED CONFIGURATION MIXING IN THE NUCLEAR SHELL MODEL
J. M. Soper| and R. D. Lawson
Bull. Am. Phys. Soc. 11, 102 (January 1966)

ENERGIES OF x RAYS FROM MUONIC TANTALUM
C. C. Trail,† R. A. Carrigan,* A. Gaigalas,* R. B. Sutton,* R. E. Coté, S. Raboy, and R. Guso (Special Materials and Services)
Bull. Am. Phys. Soc. 11, 129 (January 1966)

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*Carnegie Institute of Technology.

†Brooklyn College.

‡Wayne State University.

|A. E. R. E., Harwell, England.

STUDENT REPORTS

A MASS SPECTROMETRIC STUDY OF TELLURIUM AND THE THERMODYNAMICS OF Te_5^-

D. Bayer

ACM student report to Knox College (December 1965)

MANUAL FOR REDUCTION OF NUCLEAR-REACTION DATA

R. J. Henninger

Co-op student report to Northwestern University (15 December 1965)

EXPLANATION OF EQUIPMENT USED IN SECONDARY ELECTRON AND SECONDARY ION EMISSION FROM MONOCRYSTAL METALS UNDER HIGH-ENERGY ION BOMBARDMENT

K. Swenson

Co-op student report to the University of Michigan (February 1966)

THE USE OF LANGMUIR dc PROBES IN HIGH-FREQUENCY DISCHARGE PLASMAS

N. M. Uss

ACM student report to Knox College (23 December 1965)

V. PERSONNEL CHANGES IN THE ANL PHYSICS DIVISION

NEW MEMBERS OF THE DIVISION

Resident Research Associate (Post-Doctoral)

Dr. Norman Williams, Manchester University. Experimental charged-particle reactions. Came to Argonne on 8 February 1966.

University Users of the ANL Tandem

Mr. Gordon P. Eckley, Mr. Charles C. Foster, Mr. Alvin Sauter, Indiana University. Alpha-gamma correlation studies of the reaction $C^{12}(O^{16},\alpha)Mg^{24*}$. Started work at ANL on 6 January 1966.

Student Aides (ACM)

Mr. Douglas Hunt, Knox College, Galesburg, Illinois. Working with W. A. Chupka on photoionization of molecules. Came to ANL on 31 January 1966.

Mr. Robert G. Peterson, St. Olaf College, Northfield, Minnesota. Working with G. J. Perlow on the Mössbauer effect in an yttrium-iron garnet. Came to ANL on 14 February 1966.

Co-op Technician

Mr. Roman Kuc, Illinois Institute of Technology, Chicago, Illinois. Working with Manfred Kaminsky on sputtering experiments in the Rutherford collision region. Came to ANL on 24 January 1966.

CSUI-ANL Honor Students

Mr. Russell A. Bennett, Northern Illinois University, DeKalb, Illinois. Working with G. T. Wood on beta-ray spectroscopy. Came to ANL on 24 January 1966.

Mr. Richard H. Braun, Wisconsin State University at Platteville. Working with L. Meyer-Schützmeister on analysis of nuclear spectra and modifications of the associated computer program. Came to ANL on 14 February 1966.

Mr. Richard J. Gotz, Wisconsin State University, Superior, Wisconsin. Working with F. P. Mooring on ion-source development. Came to ANL on 14 February 1966.

Mr. Dwight Hinds, Eastern Michigan University, Ypsilanti, Michigan. Working with G. C. Morrison on reduction of data from proton scattering on Ba isotopes. Came to ANL on 14 February 1966.

Mr. Ronald A. Knief, Albion College, Michigan. Working with S. L. Ruby on Mössbauer experiments. Came to ANL on 14 February 1966.

Mr. Larry L. Learn, Western Michigan University, Kalamazoo, Michigan. Working with R. O. Lane on neutron cross-section experiments with the 4.5-MeV Van de Graaff. Came to ANL on 3 January 1966.

Mr. Richard E. Menninger, Xavier University, Cincinnati, Ohio. Working with J. R. Erskine on automation of the scanning of nuclear emulsion plates. Came to ANL on 14 February 1966.

Mr. Edwin S. Smith, Jr., Heidelberg College, Tiffin, Ohio. Working with L. S. Goodman on various problems associated with atomic-beam measurements. Came to ANL on 14 February 1966.

Technician

Mr. Victor J. Malasauskas joined the Physics Division on 4 January 1966 as a Scientific Technician, Sr., to work with R. E. Holland.

Secretary

Mrs. Nancy Smith joined the Physics Division on 21 February 1966 as secretary in H wing.

DEPARTURES

Dr. Donald Lang has been on the staff of the Physics Division since 17 February 1964. He has worked on Ericson fluctuations and experimental resolution, level densities with high angular-momentum, and synthetic cross sections for correlation studies. He terminated at ANL on 2 February 1966 to go to the Department of Physics and Astronomy, University of Kansas, Lawrence, Kansas 66045. (After 1 June 1966, his address will be Theoretical Physics Division, A. E. R. E., Harwell, Didcot, Berks., England.)

Mr. Vladimir W. Nemec, technician, has been in the Physics Division since 14 October 1963. He terminated at ANL on 17 January 1966.

Mr. Walter L. Schubert, technician, has been in the Physics Division since 20 September 1965. He terminated at ANL on 25 February 1966.

Mrs. Josephine Snyder, secretary to H wing, has been in the Physics Division since 18 December 1961. She terminated at ANL on 15 February 1966.