COO-720-058

DEPARTMENT OF PHYSICS

NUCLEAR PHYSICS LABORATORY

PROGRESS REPORT

FOR THE PERIOD

NOV. 1, 1964 to OCT. 31, 1965

CASE INSTITUTE OF TECHNOLOGY
CLEVELAND, O.
1880

DEPARTMENT OF PHYSICS

CASE INSTITUTE OF TECHNOLOGY

NUCLEAR PHYSICS LABORATORY

PROGRESS REPORT

COO-720-058

For the period

November 1, 1964 to October 31, 1965

The researches described in this report have been supported in part by the U. S. Atomic Energy Commission under Contract No. AT-11-1-720.

TABLE OF CONTENTS

EXPERIMENTAL RESEARCH PROGRAM

EXPERIMENTAL RESEARCH PROGRAM

1. Van de Graaff Accelerator Operation and Research Instrumentation

a) Operation

As of this report the Van de Graaff accelerator has operated without breakdown for the last three to four months and its performance has not deteriorated during this time. There seems to be no indication that this situation should not continue for sometime. The presumed reason for this fortunate condition is a slight but important change in the R.F. source design.

It had been our experience that R.F. sources as supplied by High Voltage Engineering Corporation had useful lives much less than 200 hours and this required opening the accelerator to replace the source every few weeks. This short life was presumably due to excessive erosion of the extraction canal and metallic sputtering onto the bottle. Accordingly the HVEC design was changed by HVEC from an all aluminum canal to a composite of stainless steel and aluminum. Unfortunately the poorer heat conductivity of the stainless steel resulted in the melting closed of this canal in the first few sources tried. This laboratory therefore went back to an essentially all aluminum canal with a small stainless steel insert to protect the canal from erosion by back-streaming electrons. This new modification has now been in the machine since the beginning of June with essentially no deterioration of its performance. Average beam currents on target of 3-4 μamp at a duty cycle of 0.1% (i.e. 1ns pulses every 1000 ns) are being obtained. The fact that the machine has not had to be opened for source replacement has undoubtedly had beneficial effects on other aspects of machine operation e.g. voltage conditioning is needed only infrequently and electronics component failure has essentially stopped perhaps due to absence of pressure cycling and of corrosion from exposure to high humidity conditions.

The construction of the terminal component test stand mentioned in last years progress report has consequently lost its high priority but is still proceeding at a reduced rate. It is still planned to double the output pulse repetition rate from 1 mHz to 2 mHz with a consequently doubling of the average beam current. The vacuum system and the newly designed terminal deflection system hardware has been completed and the new terminal electronic systems are now under construction.

L. Hinkley and E. F. Shrader

b) Zero crossing fast discriminator

A zero-crossing fast discriminator circuit has been designed and constructed. This circuit which is used to eliminate pulse height dependence ("walk") in timing pulses in neutron time-of-flight research. The description of this circuit was given in a paper delivered at the 12th Nuclear Symposium of the IEEE held in San Francisco, California, October 18-20, 1965. This paper will be published in the January 1966 NSG Transactions of the IEEE and the introduction to the paper is quoted below.

"In principle the time of a nuclear event in a detector can be measured independently of the pulse size by observing the time invariant zero-crossing of a doubly-differentiated signal. However, it is not practical to set the trigger level of the pulse height selector to "zero" volts because noise pulses or detector pulses which do not meet the minimum pulse height criterion will generally result in excessive dead time. Devices which sense the leading edge of a signal either suffer from excessive counting rate and require additional "slow" gating if they are made very sensitive, or have an inherent time shift with pulse height if they are set at a higher threshold. The circuit described here incorporates both a pulse height threshold and a true zero-crossing time detector. Thus only signals greater than a predetermined level are accepted, and the output pulse produced is accurately timed from the actual zero-crossing of the input signal. This circuit was developed for use with a fast neutron time-of-flight spectrometer for a pulsed Van de Graaff accelerator facility. Proton recoil liquid scintillation counters incorporating pulse shape neutron-gamma discrimination are the primary source of signals.

A block diagram of the circuit is shown in figure 1. The negative signal from a photomultiplier tube anode is coupled to a tunnel diode pulse height discriminator and also, after about a seven nanosecond delay, to the base of an avalanche transistor. The signal is differentiated here by a five nanosecond clipping cable. Thus the signal at the avalanche transistor base passes through zero volts approximately 17 nanoseconds after its leading edge arrived at the tunnel diode discriminator. This is sufficient time for the tunnel diode to fire and, through the pedestal generator, to produce a negative, flat-topped, constant size pulse. This pedestal pulse is applied to the emitter of the avalanche transistor and it has reached its final amplitude while the delayed and differentiated avalanche transistor base signal is still negative. The avalanche transistor is initially biased off, but the pedestal is of such a size that the transistor will now avalanche when its base returns to zero volts. It does so at the zero-crossing point of the differentiated input signal. The large pulse produced at the emitter by the avalanching process is used after buffering as the "start" signal of a time-to-pulse height converter. A portion of the avalanche collector signal

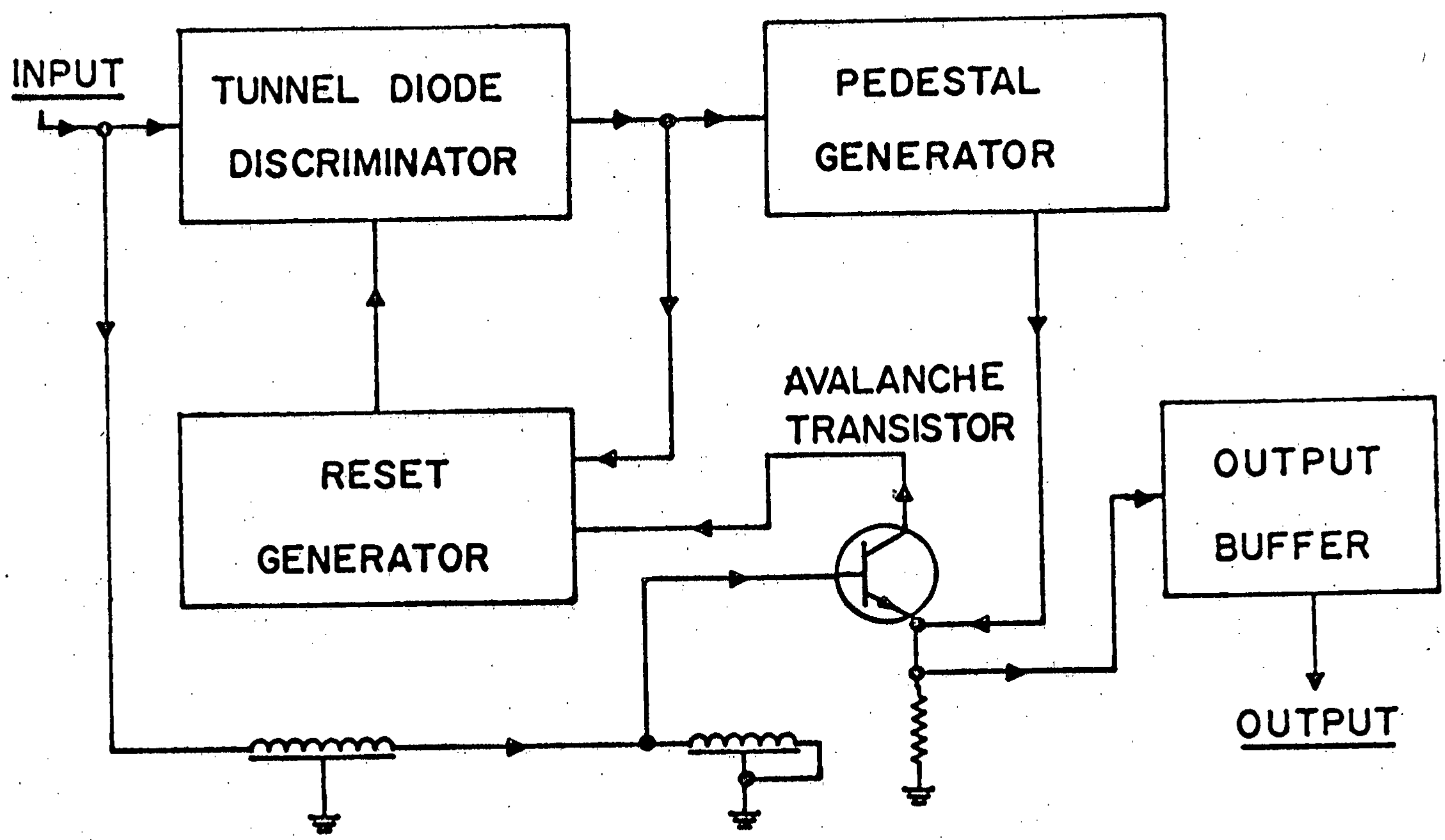


Figure 1. Block Diagram of Zero-Crossing Discriminator

is used to reset the tunnel diode discriminator, with a back-up reset also coming from the pedestal generator, in case the avalanche transistor fails to fire."

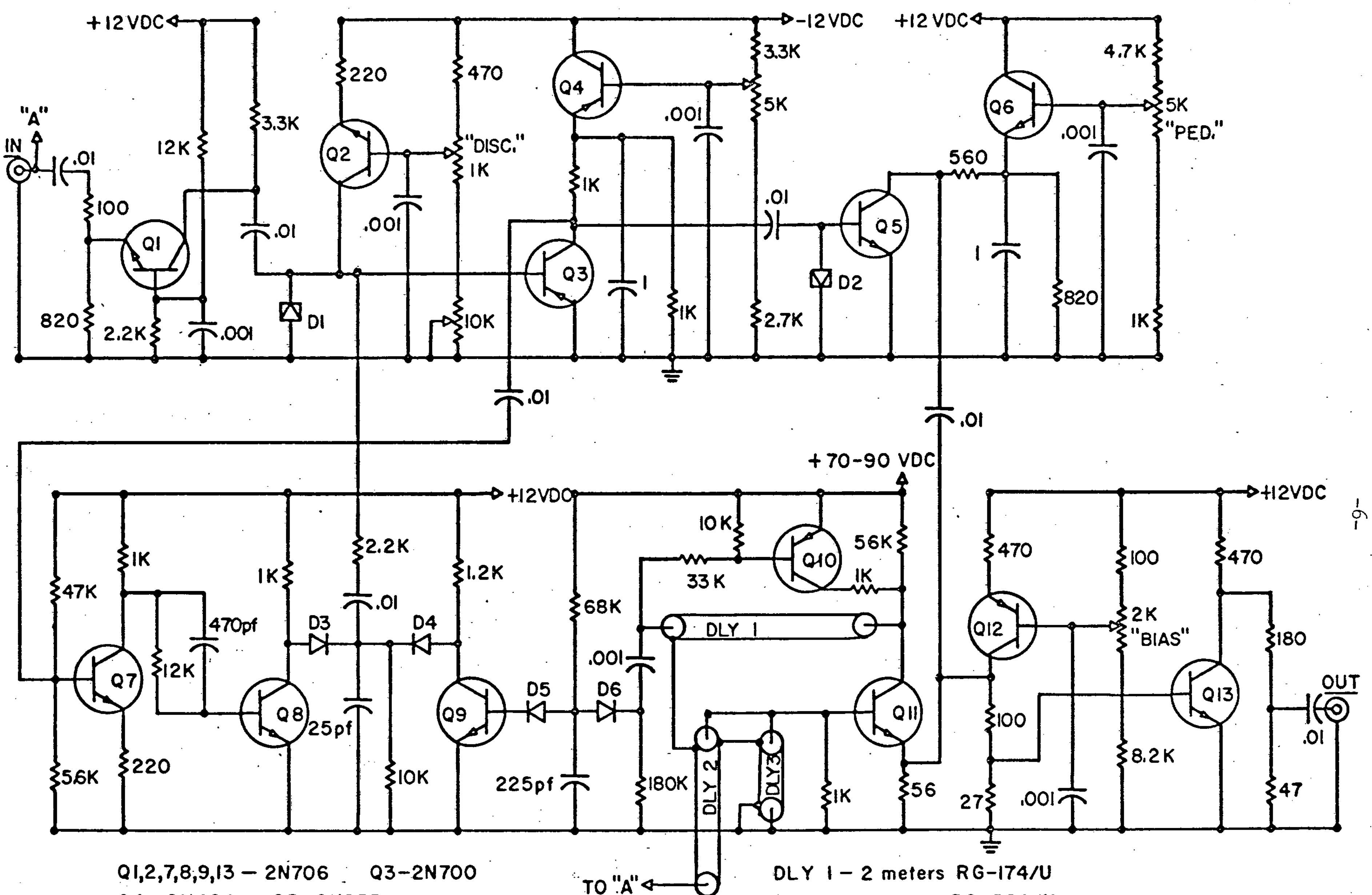
The circuit schematic of the discriminator is shown in Figure 2. The discriminator shows a "walk" of less than 200 picoseconds from the pulse threshold of 0.17 volts to 8 volts - a range of approximately 50 to 1 in input pulse height.

c) Beam current integrator — B. M. Shoffner and E. F. Shrader

A new all transistorized beam current integrator system has been constructed which has several desirable features not present in the previous system. The basic element of the integrator is the charge pump commonly employed in digital voltmeters with the integration being accomplished by counting the number of charge increments required to balance the beam charge. The charge increment or "least count" of the system is 0.01 coulomb. The maximum rate of the charge pump corresponds to currents of 40 amp. The charge increment counter is a Computer Measurements Co. Model 601A Electronic Counter which has been modified so that it may be controlled by an external control circuit. By using the time base scalers of the counter as prescalers the displayed least count may be chosen to be 0.01, 0.1 or 1 μcoul with the possibility of accumulating 10^5 μcoul. The five digit read out is both visual ("Nixie" type) and BCD voltage levels. It is planned to read out the integrated charge on command to a paper tape punch. The start-stop function may be controlled either remotely or by a selectable preset charge from 100μc to 100,000 μc in 10 steps. A signal level is available for the control of ancillary equipment. There is an option which permits the counter to be interrupted by an external signal thereby making it possible to determine the "live" charge i.e. the charge falling on the beam target during only that time when the experimental detection and data handling systems are sensitive. This will relieve one of the necessity of correcting for the percentage live time of the detection system - one need only to normalize to the "live" charge.

A technical report describing this system in detail is presently being prepared.

B. M. Shoffner and E. F. Shrader



Q1,2,7,8,9,13 — 2N706 Q3—2N700
Q4—2N404 Q5—2N955
Q6—2N3391 Q10—2N398B
Q11—2N3035 Q12—2N964
D1,2—1N3716 D3,4,5,6—1N4148

DLY 1 — 2 meters RG-174/U
DLY 2 — 140 cm RG-58A/U
DLY 3 — ~100 cm RG-58A/U

All fixed resistors 1/2w, 10%, composition
All capacitors in microfarads unless marked

Figure 2. Schematic diagram of Zero-Crossing Discriminator

2. The $C^{13}(d,n)N^{14}$ Reaction

The motivation for the study of the $C^{13}(d,n)N^{14}$ reaction has been 1) to assign parities to the states of N^{14} which are populated by this reaction and 2) to determine to what extent the more sophisticated forms of direct reaction calculations can successfully describe the observed reaction.

On the basis of the plane wave Born approximation treatment of the stripping reaction parity assignments can be made with reasonable certainty. These assignments which have been made in earlier progress reports, while in some cases are in disagreement with earlier assignments, agree with all the latest assignments made from the study of deexcitation gamma rays. This phase of the work on this reaction is essentially closed.

During the past year, however, attempts have been made to fit the observed neutron angular distributions with the DWBA relativistic direct reaction calculation of Tobocman. These are available experimental observations at six different deuteron energies of distributions for up to 11 different levels in N^{14}. The fit of the 4.91 MeV (ℓ =0) level has been investigated at all energies and the 4.91, 5.10, ^{P}5.83 and 6.23 MeV levels have been investigated at a deuteron energy of 2.28 MeV and the ground state level at E_d= 1.685 MeV. The fits to the 4.91 MeV have been reasonably good but the fit to the other levels investigated so far have been only moderate with the principal difficulty being the cross section at large angles. It may be that there is a significant compound nucleus effect which prevents better fitting of the observations.

The experimental angular distributions have been expressed as an expansion in Legendre Polynomials. Polynomials up to order 6 or 7 are generally sufficient to fit the distributions within the experimental errors. Table I lists the expansion coefficients of the levels distributions thus far expressed in this manner.

Table II gives the values of the parameters used in the RDRC fit to the experimental data. VD and WD are the well depths (MeV) for deuterons for the real and imaginary parts, RD and AD the radius and diffuseness (fermis) of the Saxon potential. VP, WP, RP and AP are similar quantities for the proton-nuclear potential.

The present calculation program does not include the spin-orbit interaction and steps are now being taken by the theorectical group to include this in the computer program. Even though this is not expected to effect the predicted angular distributions it seems to be highly desirable in view of the inability of the present form to account for the observed polarization of the neutrons[1] from this reaction. Experimental work is in progress to extend the polarization studies to other levels and deuteron energies (see section 3).

E. F. Shrader

[1] D. I. Garber and E. F. Shrader, Bull. Amer. Phys. Soc. 10, 510, (1965).

Table I

Angular distribution of neutrons from the $C^{13}(d,n)N^{14}$ reaction expressed in the expansion

$$\sigma(\theta) = \sigma_{tot} \left(1 + \sum_{i=1}^{n} a_i J_i(\theta)\right)$$

E_x(MeV)	E_d(MeV)	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8
g.s.	1.685	-.304	.505	.032	-.209	-.084			
"	2.20	-.285	.202	-.152	-.033	-.070			
"	2.285	-.642	.689	.503	.155	.057	.133		
"	2.90	.342	.345	.048	-.091	-.271	-.247		
2.315	2.285	-.088	.891	-.088	.379	-.083	-.320	-.147	-.172
"	2.90	.877	.366	.342	.111	-.273	-.782	-.649	
3.95	1.685	-.132	.907	.164	-.308	-.328			
"	2.20	.127	.350	-.041	-.239	-.245	-.301	-.086	
"	2.28	.012	1.020	-.225	-.093	-.406	.441	-.183	
"	2.52	.243	.325	-.042	-.399	-.392	-.154	-.060	
"	2.90	-.131	.120	.334	-.284	-.340	-.133		
4.91	1.685	.832	.788	2.086	1.450	.964	.681	.015	
"	2.20	.676	1.584	1.969	1.760	1.234	.822	.391	
"	2.28	.720	1.732	1.941	1.939	1.372	.795	.433	
"	2.52	2.819	4.040	4.512	4.067	3.214	1.435	-.102	
"	3.05	.862	1.114	.731	.781	.747	1.020	.614	
"	3.23	1.891	1.120	.324	.577	1.000	.879	.390	
5.10	1.685	.552	-.383	-.250	-.007	.016			
"	2.20	.466	-.243	-.195	-.042	-.031	-.033		
"	2.28	.571	.163	-.274	-.150	-.073			
5.83	1.68	.577	-.476	-.357	-.197	.143			
"	2.20	.396	-.305	-.368	-.214	-.023	.096		
"	2.28	.769	.050	-.355	-.219	-.074			
6.23	1.68	1.013	-.010	.142	.048	-.104			
"	2.20	.506	.378	.251	-.009				
"	2.28	.633	.240	.180	-.080	-.066			
"	2.52	.033	-.150	-.050	-.035	.096			
"	2.90	.209	-.183	.165	.077	.080			
"	1.685	1.013	-.010	.142	.048	-.104			
"	2.20	.506	.378	.251	-.009	-.180			
"	3.05	.220	-.203	.110	.019	-.022			
"	3.23	.068	-.638	.051	.123	0.135	-.053		
6.44	2.52	.258	-.174	-.279	-.110	.014			
"	2.90	.521	.127	.070	-.151	-.030			
"	3.05	.313	.250	-.204	.040	-.037			
"	3.23	.351	.064	-.082	-.163	-.033			
7.03	3.05	.755	.554	.145	-.004	.011			
"	3.23	2.194	1.754	.489	-.398	-.322	-.374	-.473	
7.40	3.05	1.204	1.025	.908	.617	.418			

Table II

The RDRC parameters for the best fit to the $C^{13}(d,n)N^{14}$ (4.91 MeV) reaction.

E_d	VD	WD	RD	AD	VP	WP	RP	AP
3.23	135	8	3.4	0.5	70	3	2.85	0.5
3.05	140	8	3.4	0.4	70	5	2.85	0.5
2.52	130	8	3.4	0.6	65	3	2.85	0.5
2.28	130	8	3.4	0.6	65	3	2.85	0.5
2.20	130	8	3.4	0.6	65	3	2.85	0.5
1.685	120	15	3.4	0.7	70	5	2.85	0.5

Table III

The RDRC parameters for the best fit to the $C^{13}(d,n)N^{14}$ reaction at a deuteron energy of 2.28 MeV.

E_x	VD	WD	RD	AD	VP	WP	RP	AP
4.90	130	8	3.4	0.6	65	3	2.85	0.5
5.10	140	8	3.4	0.6	65	8	2.85	0.5
5.83	130	10	3.4	0.6	65	5	2.85	0.5
6.23	130	5	3.4	0.6	65	5	2.85	0.5

3. Polarization of Neutrons from the $C^{13}(d,n)$ Reaction

In the previous study,[1] which involved the measurement of polarization of the neutrons produced in the $C^{13}(d,n)N^{14*}$ reactions, the $C^{12}(n,n)$ reaction was used as the analyzer. While the analyzing power of the $C^{12}(n,n)$ was large (70%) at some incident neutron energies and allowed quoting of polarizations of some neutron groups, the C^{12} analyzing power fluctuated with energy in other energy regions. Neutron groups which were produced by leaving the N^{14} nucleus in the excited states E =3.95 MeV and E =0 were resolved and their right-left asymmetries were measured. However, uncertainties in the $C^{12}(n,n)$ analyzing power prohibited quotation of the polarization from these levels.

The analyzing power of helium for neutrons scattered at 130° is virtually 100% for all energies above 2 MeV.[2] For polarization studies helium is a far better analyzer than carbon. In addition the helium nucleus, which recoils when a neutron is scattered, produces an emission of a scintillation light output. This light output, if viewed, could be used to gate the usual time-of-flight spectrum produced by the right and left detectors resulting in improved signal to noise by reducing the time-random background and discriminating against the neutrons scattered by the helium container.

A choice was made as to whether gaseous or liquid helium would be better to use. The density of liquid helium is but five times the density to helium gas at 150 atm. Since neutron mean free path considerations (i.e.% transmission) dictates the maximum amount of helium (i.e. number of nuclei) which can be used, the volume of a gaseous helium bomb can be made five times larger than a liquid helium cryostat having the same per cent transmission and therefore, similar multiple scattering.

A thin wall high pressure bomb for containing gaseous helium has been designed, built, and pressure tested to 4,000 psi. The bomb is cylindrical, of stainless steel, with a thin wall (90 mil) middle section to serve as a neutron window. The active volume is 2" in dia. and 4" long. At each end of the bomb is an optical window to enable a photomultiplier tube to view the gas scintillation. The windows are constructed of 3/4" thick tempered glass discs backed by 1/4" thick lucite discs to relieve stress.

Two windows and two P.M. tubes were chosen to improve the uniformity of the optical response to a helium recoil. With two P.M. tubes the summed light output should not vary too strongly with where in the bomb the scattering event takes place.

Since the spectrum of light produced in the helium scintillation is less than 1600 Å, wavelength shifters must be used to enhance the S-11 response of the P.M. tube. The inside to the bomb body has been coated by

(1) An aluminum flash (1 micron), for reflectivity
(2) A MgO smoke (approx. 1 mm), for reflectivity in the U. V. range
and (3) a P-P Diphenyl-stilbene evaporation approx. 50 $\mu g/cm^2$, which serves as a wavelength shifter.

The above coatings were performed by the Harshaw Chemical Company. The insides of the glass windows were coated here at Case with an evaporation of pp-diphenyl stilbene (25 $\mu g/cm^2$)

The entire bomb has been baked out for a three day period previous to coating and has been pumped on extensively (i.e. three weeks) since coating. The pressure in the bomb when sealed for a two day period remains less than 10^{-5} mm Hg. This is encouraging since it is desired to run the bomb as a static system.

The bomb has been charged to a pressure of 6-1/2 atm with Xenon, which serves as wavelength shifter, and 26 atm of helium. Resolution studies are presently underway. Should the bomb have adequate pulse height resolution and show no tendency to lose its light output efficiency with time, it will be fully charged (i.e. 150 atm) and measurements of neutron polarizations from C^{13}(d,n) reactions shall commence.

D. I. Garber, W. W. Lindstrom and E. F. Shrader

4. The Na^{23}(d,n)Mg^{24} Reaction

Neutrons from the Na^{23}(d,n)Mg^{24} at E = 2.42 MeV have been observed using the pulsed deuteron beam of the Van de Graaff. Of particular interest were those neutron groups arising from leaving Mg^{24} with excitation energies from 8 to 11 MeV. No parity assignments have been made in this region and it was hoped that the stripping reaction would shed light on this question. Earlier work[3-4] on this reaction had shown neutron groups at excitation energies of 8.48 MeV and 10.46 MeV with an additional possible group corresponding to 9.85 MeV. The presence of the two groups corresponding to the two higher excitation groups has been confirmed.

[3] J. M. Calvert et al, Proc. Phys. Soc. A68, 1008, (1955).

[4] F. A. El Bedewi and M. A. El Wahah, Nuc. Phys. 3, 385, (1957).

The best knowledge[5] of the energies of the levels of Mg^{24} comes from use of the reaction $Na^{23}(He^3,d)Mg^{24}$. Some 20 or more levels have been identified in the region of excitation from 8 to 11 MeV. Quoted errors on the energies are of the order of ≠ 10 to 20 keV. Since only 3 of these levels are populated to any detectable degree by the (d,n) reaction it is of importance to ascertain to which levels they correspond. The energy resolution of the time-of-flight system in this range is comparable to that of a charged particle spectrometer i.e. ≠ 20 keV. The present work confirms that in fact only three levels contribute to measurable d,n yield and that the two higher levels are determined to be 10.030 MeV and 10.732 MeV (in contrast to the earlier quoted values). These undoubtedly correspond to the excitation levels of 10.025 MeV and 10.723 MeV quoted in the $Na^{23}(He^3,d)Mg^{24}$ work.

The angular distributions of neutrons from these two groups were measured and found to be highly forward peaked indicative of $\ell=0$ capture establishing that the two levels to be of even parity.

M. A. Berger and E. F. Shrader

5. Depolarization of neutrons by scattering.

The measurements of left-right assymmetrices observed in elastic and inelastic scattering of partially polarized neutrons is continuing. To improve the solid angle of the neutron recoil detectors without recourse to a larger 5" photomultiplier two 3" diameter scintillation detectors were constructed using NE 213 liquid scintillator and 7850 photomultipliers. Pulse height resolution was improved by making the scintillator cells with a concave window which fit the curved face of the photomultiplier allowing it to see the corners of the cell and eliminating the lucite glass interfaces which arise with the use of a lucite light pipe. Neutron-gamma pulse-shape discrimination was incorporated into these detectors and a rejection ratio for gamma rays of 100 to 1 was obtained with no loss of neutron detection efficiency when the detector was biased to cut off neutrons below 600 keV.

5 Hinds and Middleton, Proc. Phys. Soc. 76, 553, (1960).

A second mobile collimator has been constructed using a combination of borated paraffin blocks and water for neutron shielding. In addition a system of shadow cones has been built and the signal-to-background ratio for a scattering geometry has been determined. Using a flight path of 3m to look at the elastic scattering from C^{12} of 2 MeV neutrons produced from the $C^{12}(d,n)$ reaction, the signal to background ratio varied from 8 to 1 to 25 to 1 depending on the scattering angle. The background was random in time.

Separated isotopes of Cu^{65}, Fe^{54}, Fe^{56}, Ni^{58}, and Ni^{60} have been obtained from the AEC Stable Isotope Pool, and measurement of the left-right asymmetry of the elastic and inelastic scattering of polarized neutrons is to begin immediately.

In order to locate the detectors symmetrically about the 0° scattering angle in the above measurement, the shadow of the scatterer in the direct neutron beam will be used as a reference. The measurement of asymmetry will be made for elastic scattering from a C^{12} scatterer as a check on the method. The contributions of finite geometry to false left-right asymmetry has been calculated according to the method of J. E. Monahan and A. J. Elwyn.[6] The Fortran II program for the numerical integration necessary to calculate this correction has been modified to make it compatible with the Univac 1107 computer and has been extended to calculate the actual correction factor itself. Calculations have also been performed which tabulate the run length required to obtain a given statistical accuracy in the polarization being measured in terms of P_1, the uncertainty in P_1, P_2, and the signal to background ratio.

W. L. Rogers and E. F. Shrader

6. Inelastic Neutron Scattering

Data has been obtained on the differential inelastic neutron scattering cross section for Co^{59} at 5.2 MeV. Angles of 30°, 40°, 50°, 60°, 70°, 80°, 90°, 110°, 130°, and 140° were used. Deuteron bursts ($\sim$ 1/nS) on a gas target produced monoenergetic neutrons from the $D(d,n)He^3$ reaction. These neutrons were scattered from a 3/4" high by 5/8" diameter right cylinder of 99.8% pure Co^{59}.

[6] J. E. Monahan and A. J. Elwyn, Argonne National Laboratory Report ANL 6420.

The level structure of Co^{59} is so dense that no single levels are resolvable with the present techniques. A typical time-of-flight spectrum corrected for background is shown in figure 3. The flight path is 284cm. The theoretically calculated positions of neutron groups corresponding to the known levels are shown by the arrows. Resolution is 4 ns or 16 channels. The data is now in the process of analysis. Preliminary results show that at 40° the differential inelastic scattering cross section for $E_{n'} > 2.57$ MeV is approximately 50 mb./st. No multiple scattering correction has yet been made.

The data was taken using a new 3" scintillator of NE-213 coupled to a 7850 photomultiplier. This detector gives high enough counting rates with typical machine conditions to obtain 2% or better statistics for the inelastic cross section of Co^{59} reported above with running times on the order of three hours.

Work remaining on Co^{59} includes obtaining angular distributions for the inelastic neutron scattering cross section for angles in the range 30° to 150° and at energies from 2.0 to 5.2 MeV. Also a study of the need for multiple scattering corrections will be made.

J. L. Lindow and E. F. Shrader

7. Neutron Total Cross Sections

Data has been taken for 1% statistics on neutron total cross sections between 2 and 17 MeV. for eight elements (Magnesium, aluminum, calcium, vanadium, iron, palladium, silver, and lead). In addition transmissions for polyethylene have been measured for the purpose of checking the method.

The neutron source is a "white" spectrum produced by the $Li^7(d,n)\,2\alpha$ reaction. Neutron energies are obtained from neutron velocity which is obtained from measured values of time-of-flight and flight path. Nonlinearities in the time-of-flight system are corrected for by integrating the random time spectrum which in practice is not perfectly flat between channels whose time difference is to be computed. Given a known time separation between two channels of the random time spectrum i.e. centroids of gamma rays separated a known time, the time difference between any pair of channels can be computed.

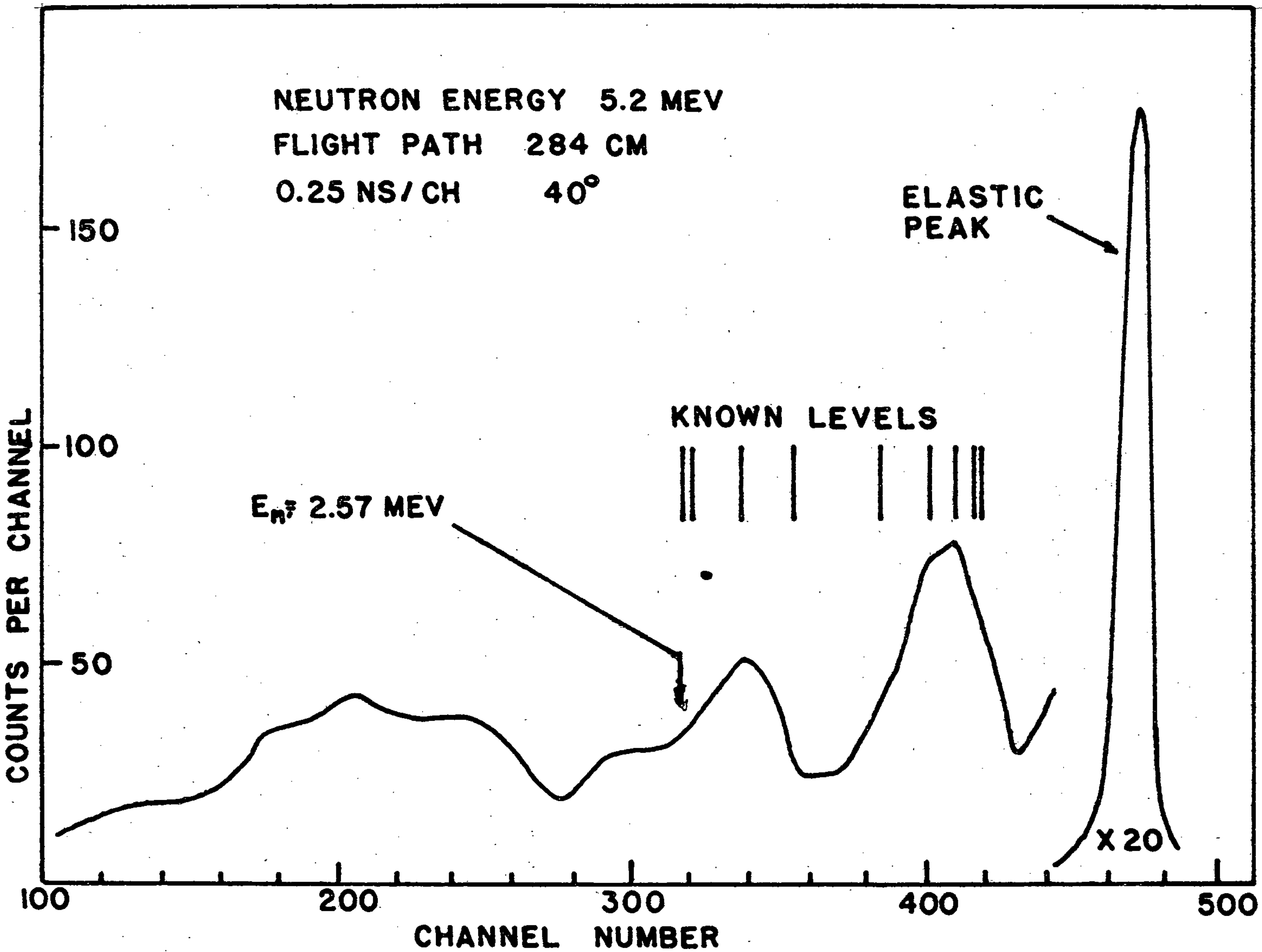


Figure 3. Time-of-flight spectrum of 5.2 MeV neutrons scattered from Cobalt^{59}

As a check on the energy measurement, monoenergetic neutrons were produced by bombarding a thin target (50% enriched with C-13) with deuterons. Neutron energies for the $C^{13}(d,n)\ N^{14}$ reaction are obtained from a relativistic "Q" equation and checked against time-of-flight measurements. Fig. 4 is a plot of the "Q" equation neutron energies against the time-of-flight energies. The point at 17.25 MeV. is obtained from the white spectrum cut off and a "Q" equation calculation of the maximum energy for neutrons from the Li (d,n) reaction. Since all points lie on the 45 degree line (within the resolution of the time-of-flight energies) the measured energies can be taken as correct within the appropriate uncertainties which range from 0.5% of the neutron energy at 2.00 MeV. to 1.5% at 17 MeV.

Problems involving counting rate dependence of the resolution which were observed in earlier measurements were successfully eliminated. Other problems were assumed negligible and this premise is fairly well substantiated by demonstrating that the transmissions vary exponentially with absorber thickness. As seen from figure 5, the points corresponding to like neutron energy lie on straight lines in the semilog plot thus the transmissions over five mean free paths are exponential and the magnitude of other problems is small enough to be ignored. The four plots shown are typical of the 100 points at which the behavior of the transmissions was checked.

One nonnegligible problem uncovered by measuring the transmissions is a varying yield of neutrons above 14 MeV. The variation is a decrease in yield from run to run (predominant among the earlier runs) and the result is that transmissions for a given absorber at a given energy do not agree from run to run. Below 14 MeV. the transmissions agree well from run to run as well as behaving exponentially. It is the variation in yield with run number which seems to account for the lack of agreement. The cause of the variation seems to be due to a nonuniform carbon build up on the lithium target which reduces the mean deuteron energy and introduces additional spread in deuteron energy. The reaction cross section is well behaved between 2 and 3 MeV. so one does not expect the rate of formation of the compound nucleus in the target to change for a slight degradiation in deuteron energy. That the yield below 14 MeV. is relatively unaffected by slight changes in deuteron energy is understood from a phase space argument.

In measuring total cross sections for the eight elements, the cycling frequency for absorber and unattenuated runs was much higher than in the measurement of polyethylene transmissions. In addition the variation in yield seems to disappear (after the carbon reaches some asymptotic thickness) for the later runs. There is a good chance that cross sections above 14 MeV. for the eight elements will be self consistent.

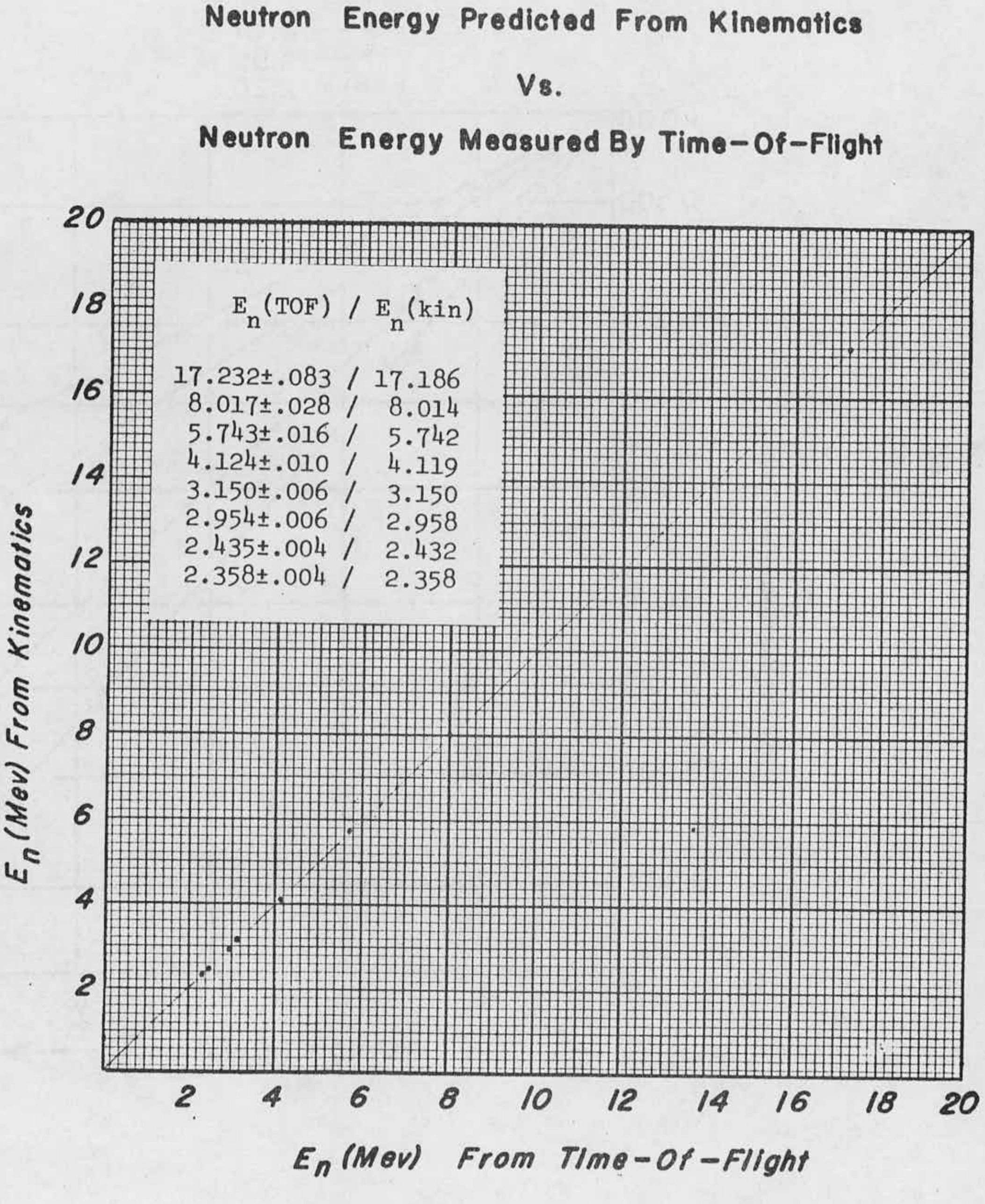
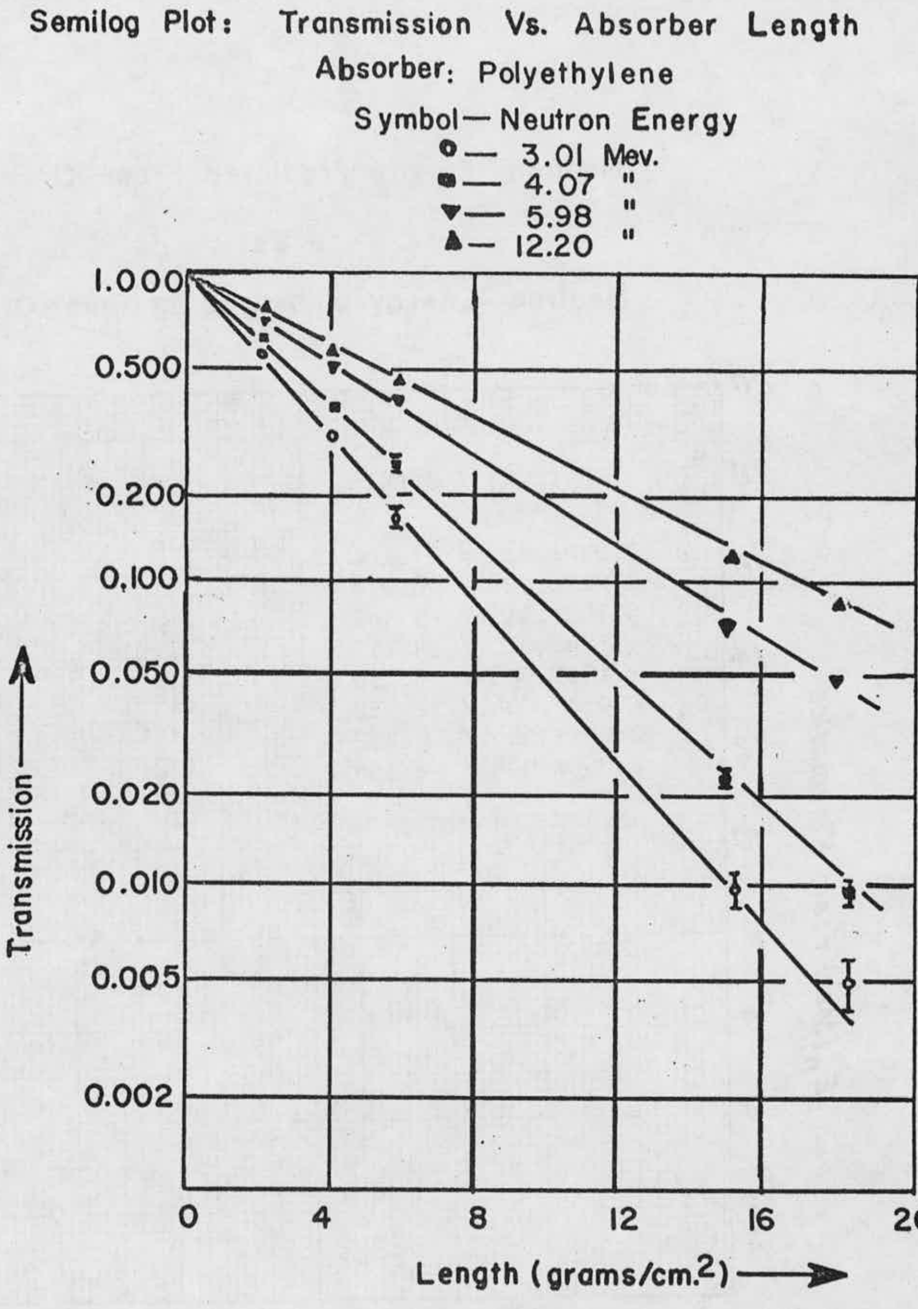

Neutron Energy Predicted From Kinematics
Vs.
Neutron Energy Measured By Time-Of-Flight
En(TOF) / En(kin)
17.232±.083 / 17.186
8.017±.028 / 8.014
5.743±.016 / 5.742
4.124±.010 / 4.119
3.150±.006 / 3.150
2.954±.006 / 2.958
2.435±.004 / 2.432
2.358±.004 / 2.358
En (Mev) From Kinematics
En (Mev) From Time-Of-Flight
2
4
6
8
10
12
14
16
18
20

Figure 4.



Semilog Plot: Transmission Vs. Absorber Length
Absorber: Polyethylene
Symbol — Neutron Energy
○ — 3.01 Mev.
■ — 4.07 "
▼ — 5.98 "
▲ — 12.20 "
1.000
0.500
0.200
0.100
0.050
0.020
0.010
0.005
0.002
Transmission
0
4
8
12
16
20
Length (grams/cm.2)

Figure 5.

Neutron total cross sections for the CH molecule obtained from the polyethlyene transmissions between 2 and 14 MeV. are shown in Figures 6 and 7. These cross sections agree with the sum of two hydrogen and one carbon total cross section as quoted in BNL 325.

L. A. Galloway and E. F. Shrader

8. Charged Particle Spectroscopy

Work is continuing on the $C^{13}(d,p)C^{14}$ studies reported on in the previous progress report. These studies consist of the measurement of the polarization of protons from the reaction $C^{13}(d,p)C^{14}$ (ground state, Q = 5.947 MeV), the measurement of the $C^{13}(d,d)C^{13}$ elastic differential cross sections, and the measurement of the $C^{13}(d,p)C^{14}$ differential cross sections to various excited states of C^{14}. These data will be analyzed by the direct reaction program of Tobocman et al yielding optical model parameters for the deutron C^{13} system.

Work completed by G. Gross[7] showed both the feasibility of the present project and the need for improving the scattering apparatus, particularly with regard to alignment problems.

The scattering chamber has been extensively rebuilt to give better beam alignment. An improved beam collimating and collecting system has been built and installed. The new collimating system is provided with more rugged apertures spaced farther apart. The apertures are better protected from burnup by the beam, both by rough-collimating protective apertures and by better thermal contact with the surrounding metal of the collimating system.

After passing into the beam collector, the alignment of the beam is monitored by a ring, the current on which is minimized, all current incident on the collection system being brought together for beam integration. By monitoring the alignment of the beam after passing through the target and at a distance of 14.5 inches behind it, a gain is made in the collimation accuracy without resorting to smaller apertures and thereby sacrificing intensity. The beam

[7] G. Gross, M.S. Thesis, Case Inst. of Tech., 1965.

NEUTRON TOTAL CROSS SECTIONS FOR CH_2

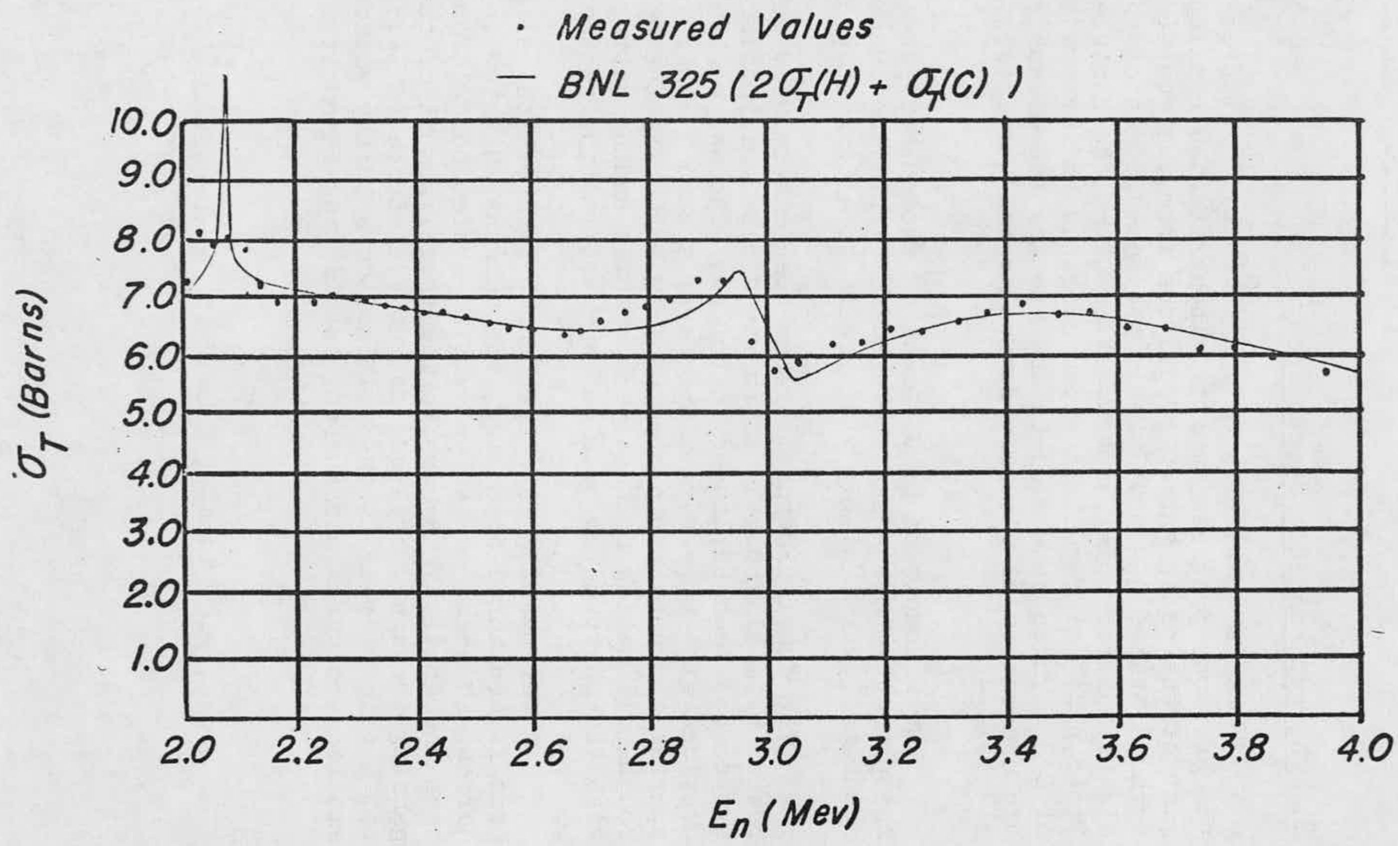
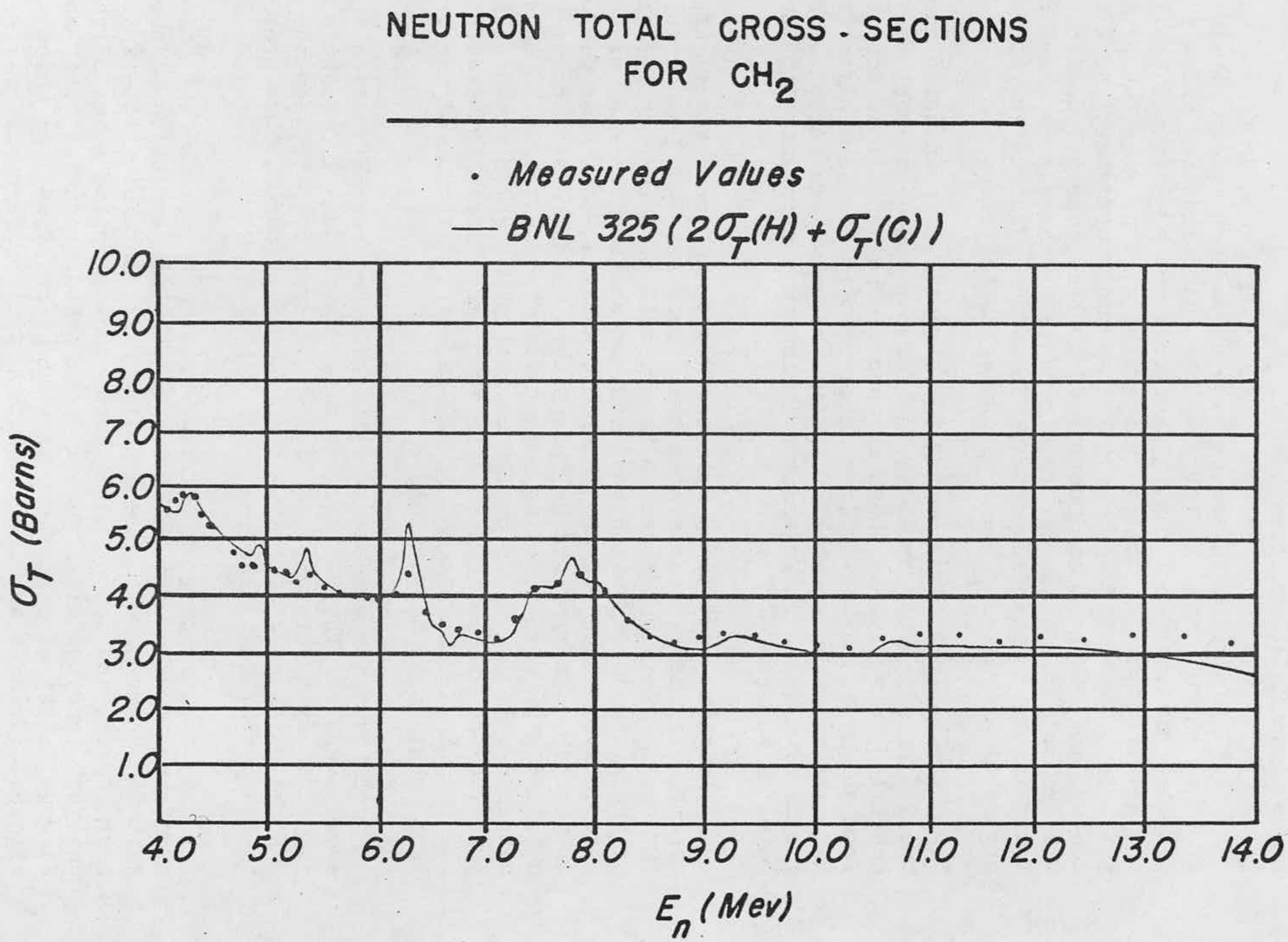


Figure 6.



NEUTRON TOTAL CROSS - SECTIONS
FOR CH2
• Measured Values
— BNL 325 (2σT(H) + σT(C))
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
σT (Barns)
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
En (Mev)

Figure 7.

centering is also monitored before the first collimator by means of another ring. Both monitoring apertures can have their currents read remotely and the beam is kept centered by means of steering magnets. The steering magnet system is only partially completed; more steering magnets are under construction.

Preliminary measurements have shown that we can obtain beams of 80 μA through the chamber and into the collector, using a pair of 1/8 inch diameter collimating apertures spaced 9 inches apart. It now appears that the collimation system will provide beams of sufficient intensity, of sufficiently small diameter, and with the center line of the beam constrained to less than 0.2 degree, which will be sufficient for our requirements. Inadequacies have been found in the counter support system of the polarimeter resulting in errors of alignment. These are being corrected.

The equipment for making C^{13} targets has been built and tested. The 90% enriched C^{13} comes in the form of $BaCo_3$ and must be first converted to acetylene which is then cracked on a thin foil base from which the carbon-foil is later removed for use. After starting out with measured amounts of natural $BaCO_3$ we are satisfied that the yields of carbon cracked on the foils are consistant with the process going as expected.

Problems were found with the vacuum in the chamber; after assembly of the rebuilt system the vacuum was found to be only about 10^{-4} mmHg. This was found to be a result of both poor performance of the system's diffusion pump and excessive outgassing of condensible materials from the chamber interior, gaskets, etc. The performance of the pump was improved by operation at higher input power. The outgassing problem is being solved with the installation of a liquid nitrogen cold finger, a preliminary trial of which immediately improved the vacuum from 10^{-4} to 10^{-5} mmHg. By mild bakeout of the chamber, including bakeout of all gaskets, a vacuum of the order of 10^{-6} mmHg should be possible.

An oven for bakeout of O-rings is under construction for the above purpose. The O-rings would be heated to $\sim 150°C$ while being pumped on by a forepump. A liquid nitrogen trap between the oven and the forepump will remove the bakeout products, thus protecting the pump from contamination.

A computer program is being written to correct the polarization data for the effects of finite angular resolution of the counter system. Starting with the experimentally obtained left-right assymetries, and accepting as known the analyzing power of the analyzer, and the differential cross sections in the first and second targets, a set of polarizations will be obtained from which the effects of finite angular resolution will be removed.

P. Liebenauer and E. A. Silverstein

9. Gyromagnetic Ratios of the 2^+ States in Ytterbium 170, 172, 174 and 176

The work on the even-even ytterbium isotopes has been completed and submitted for publication.

Results

84.1 kev 2^+ State in Yb^{170}

$g = 0.33 \pm 0.02$ $\tau = 2.28 \pm 0.07$ ns

78.7 kev 2^+ State in Yb^{172}

$g = 0.279 \pm 0.014$ $\tau = 2.46 \pm 0.07$ ns

76.5 kev 2^+ State in Yb^{174}

$g = 0.247 \pm 0.013$ $\tau = 2.59 \pm 0.07$ ns

82.1 kev 2^+ State in Yb^{176}

$g = 0.299 \pm 0.015$ $\tau = 2.54 \pm 0.07$ ns

R. P. Scharenberg and J. W. Tippie

10. Nuclear g-factors of the First 2^+ States of Samarium 152 and 154

The measurements are made on isotopically enriched samarium metal targets which are made by reduction of Sm_2O_3 with lanthanum metals. The reduced samarium metal is vapor deposited from the reaction vessel directly onto the target mount.

The g-factor of Sm^{152} is being measured at three temperatures to check the magnetic field corrections which must be made due to the paramagnetism of the ionic shell. This correction was calculated by Kanamori and Sugimoto(8) and more recently refined by Günther and Lindgren.(9) At present we have made several experimental runs near room temperature and a few in the region of 160°K. The low temperature measurements will be continued to reduce the error on the result.

[8] J. Kanamori and K. Sugimoto, J. Phys. Soc. Japan 13, (1958) p. 754

[9] C. Günther and I. Lindgren, Perturbed Angular Correlations, ed. Karlsson, Matthias, and Siegbahn, (North Holland, Amsterdam, 1964) p. 357.

The g-factor will also be measured near 800°K. We are limited to 800°K by the vapor pressure of samarium metal.

Gunther and Lindgren's calculations for the corrections to the magnetic field at the nucleus give:

$$H_{effective} / H_{external} = 1.41 \text{ at } 150°K$$
$$= 1.14 \text{ at } 320°K$$
$$= 1.05 \text{ at } 800°K$$

Applying these corrections to our present results for Sm^{152} we get

$g = + 0.300 \pm 0.020$ near room temperature

$g = + 0.269 \pm 0.039$ in the region of 150°K

$g = + 0.293 \pm 0.018$ combined result

Measurements on isotopically enriched Sm^{154} give, after applying the theoretical field correction at room temperature,

$g = + 0.286 \pm 0.017$.

P. J. Wolfe and R. P. Scharenberg

11. Nuclear g-factors of Gadolinium Isotopes

The nuclear g-factors of the first 2^+ states of several even A gadolinium isotopes are being measured.

A new target approach is being utilized for these isotopes. Isotopically enriched gadolinium metal is alloyed with about 12% copper which makes a eutectic alloy with a melting point near 800°C. The alloy is used as a target in the liquid state. The use of a eutectic alloy permits operating with a liquid metal in a temperature range where the vapor pressure is less than 10^{-6} mmHg. Pure gadolinium metal would vaporize away quickly at its melting point. Copper and gadolinium have similar vapor pressures so that any evaporation which does occur will not significantly alter the composition.

Molten metal targets have several advantages over solid ones. In a liquid there is very rapid averaging of the electric field gradient set up by neighboring atoms. This reduces the effect of electric quadrupole perturbations on the angular correlation. The elevated temperature causes rapid re-orientations, compared to the nuclear lifetime, of the electronic shell of the atom. This averages out the instantaneous magnetic field at the nucleus produced by the 4f electrons so that all nuclei experience the same average magnetic field. The elevated temperature is particularly important for the gadolinium ion since it is an S state and at low temperatures relaxes slowly. Solid gadolinium metal targets have been tried and found too heavily perturbed to be useful for g-factor measurements. Figure 8 compares the magnitude of the angular distribution as a function of time in a solid and in a molten eutectic target.

The gadolinium metal is made by reducing isotopically enriched gadolinium oxide with zirconium at 1900°C. The gadolinium is vaporized at this temperature and collected on a molybdenum ribbon. The gadolinium metal is then put in a crucible with the appropriate amount of copper and the two are distilled together into a depression in another molybdenum ribbon. This second distillation provides good mixing of the alloy and helps to eliminate any zirconium impurity in the gadolinium.

The alloy, lying in the depression in the molybdenum ribbon, is heated by passing current through the ribbon. Since part of the current flows through the molten alloy there is a large force on it when it is heated in a magnetic field. By the proper choice of the current direction the Lorentz force can be made to hold the liquid alloy tightly to the ribbon while it is being heated in a vertical plane.

P. J. Wolfe and R. P. Scharenberg

12. Pulsed Beam Measurements of the g-factors of the 2^+ States of Several Paramagnetic Rare Earth Nuclei

The program to measure the g-factors of the 2^+ states of several even-even rare-earth nuclei continues. The nuclei include neodymium, erbium and dysprosium isotopes. The g-factors will be measured by observing the precession of the deexcitation gamma radiation angular correlation in a magnetic field following coulomb excitation.

The experiment on Nd^{150} can be done in the metal if the metal is above 860°C where it is in the body-centered-cubic phase. Preliminary experiments have been done, and it is found that the angular correlation is essentially free of electric quadrupole perturbations.

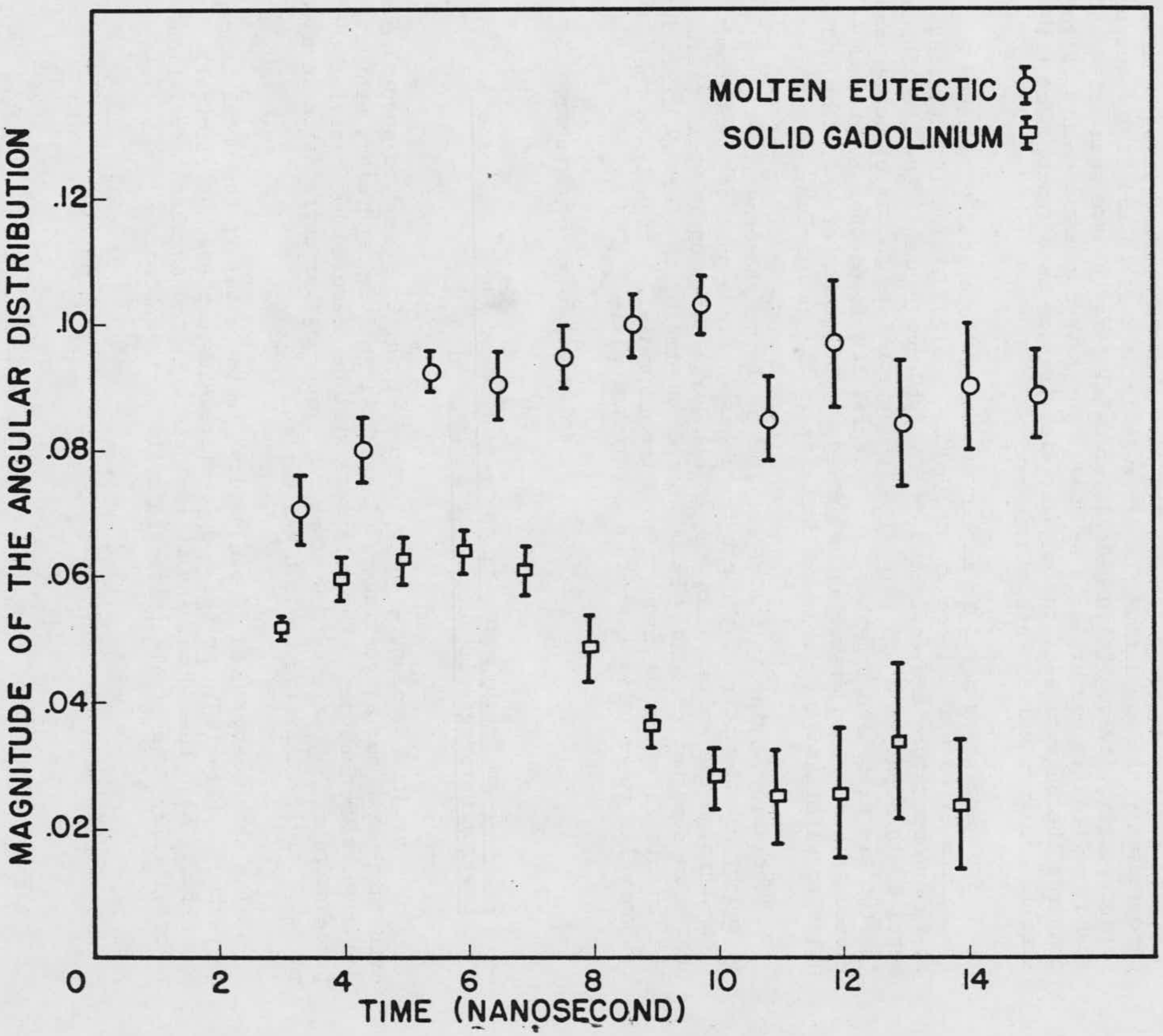


Figure 8. Time Dependence of the Magnitude of the Angular Distribution in Molten Entectic and Solid Gadolinium.

Erbium and dysprosium are hexagonal-close-packed metals, so the g-factor measurements must be done with either cubic alloy targets or in a liquid. A preliminary experiment of Dy^{162} in a dysprosium-copper eutectic which melts at 825°C indicates that this liquid target would be suitable. An experiment using a 50 - 50 erbium-silver alloy is planned to determine the possibility of using alloy targets. The problem of knowing the magnetic field at the nucleus is discussed elsewhere in this report.

The reduction of the rare-earth oxide to the metal is similar to the method used described in a previous report for reducing ytterbium. Stoichiometeric quantities of rare-earth oxide and zirconium are mixed and pressed into a pellet. The pellet is heating in a molybdenum crucible to 1800°C where the reaction

$$2La_2O_3 + 3Z_r \rightarrow 3Zr\,O_2 + 4La \quad \text{(vapor)}$$

occurs. La represents any rare-earth element. The rare-earth metal is deposited onto a molybdenum filament just above the crucible. A eutectic or alloy target can be made by redepositing the rare-earth metal with copper or silver onto another molybdenum filament. The target is then melted in either vacuum or an inert atmosphere to achieve homogeniety.

J. Kurfess and R. P. Scharenberg

13. Measurement of the Paramagnetic Susceptibility of Erbium - Silver and Dysprosium - Silver Alloys

As described in a previous report, we are interested in the paramagnetic susceptibilities of the 50 - 50 silver alloys of erbium and dysprosium. The paramagnetic susceptibility is related to the magnetic field at the nucleus, which must be known for measurements of the gyromagnetic ratio of the 2^+ states of even-even nuclei.

The rare-earth-silver alloys were made by arc melting pellets in an inert atmosphere. The paramagnetic susceptibilities were measured by the Faraday method in a furnace capable of going up to 700°C. The results of some preliminary experiments are shown in Figure 9 and Figure 10.

These results seem to indicate that rare earth ions are free tri-positive ions in the silver alloys. This agrees with the results of Walline and Wallace who measured the magnetic properties of rare-earth silver alloys from 77°K to 300°K(10). They found that the dysprosium acts as a free tripositive ion, but that the erbium ion had a variable magnetic moment. However, their data indicates that the erbium ion becomes more non-interacting closer to room temperature, which agrees with our results.

[10] Walline, R. E. and Wallace, W. E., J. Chem. Physics 41, No. 11 (1964) p. 3285-8).

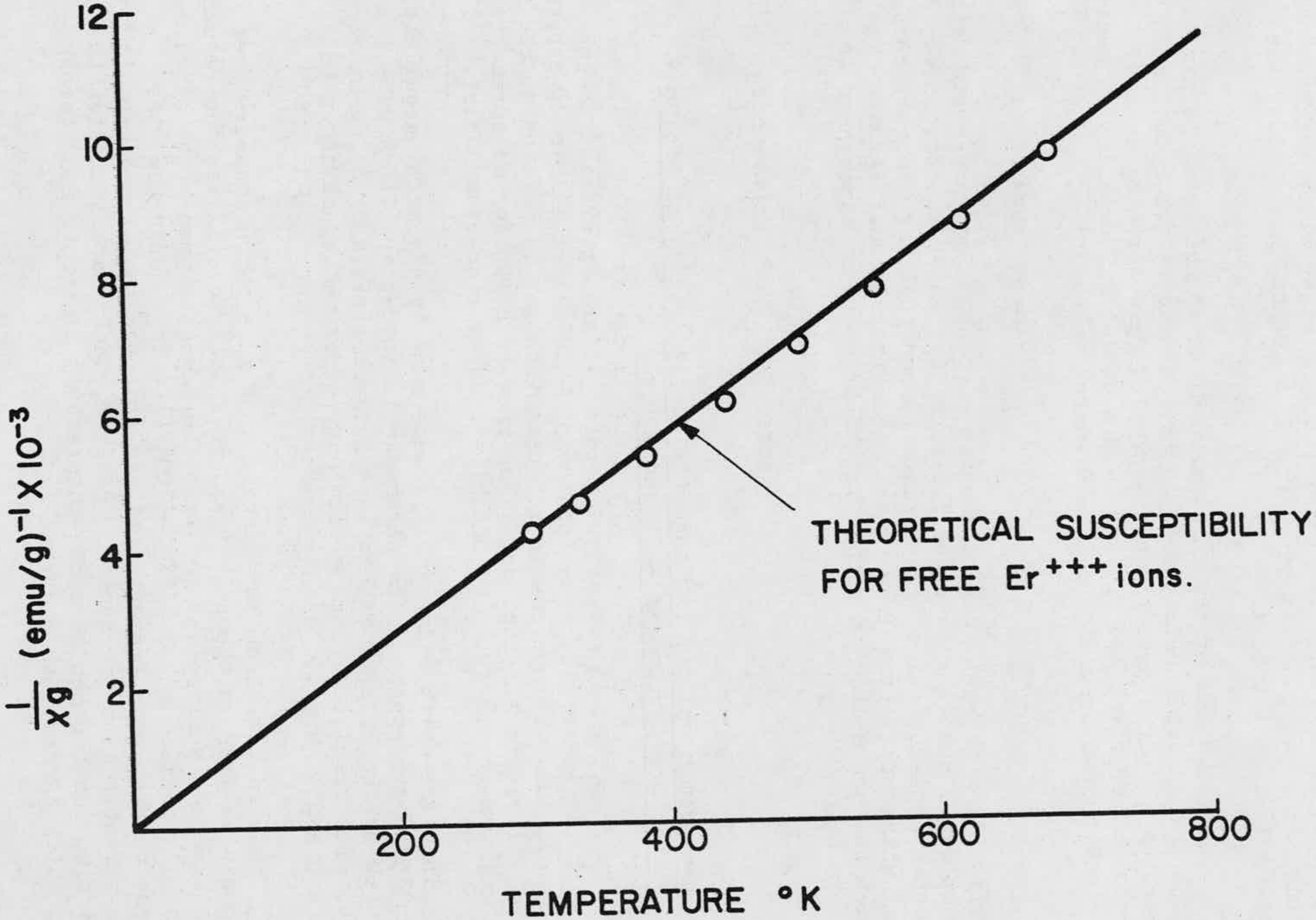


Figure 9. Reciprocal Susceptibility vs. Temperature Curve for Er^{+++} ion in Er Ag.

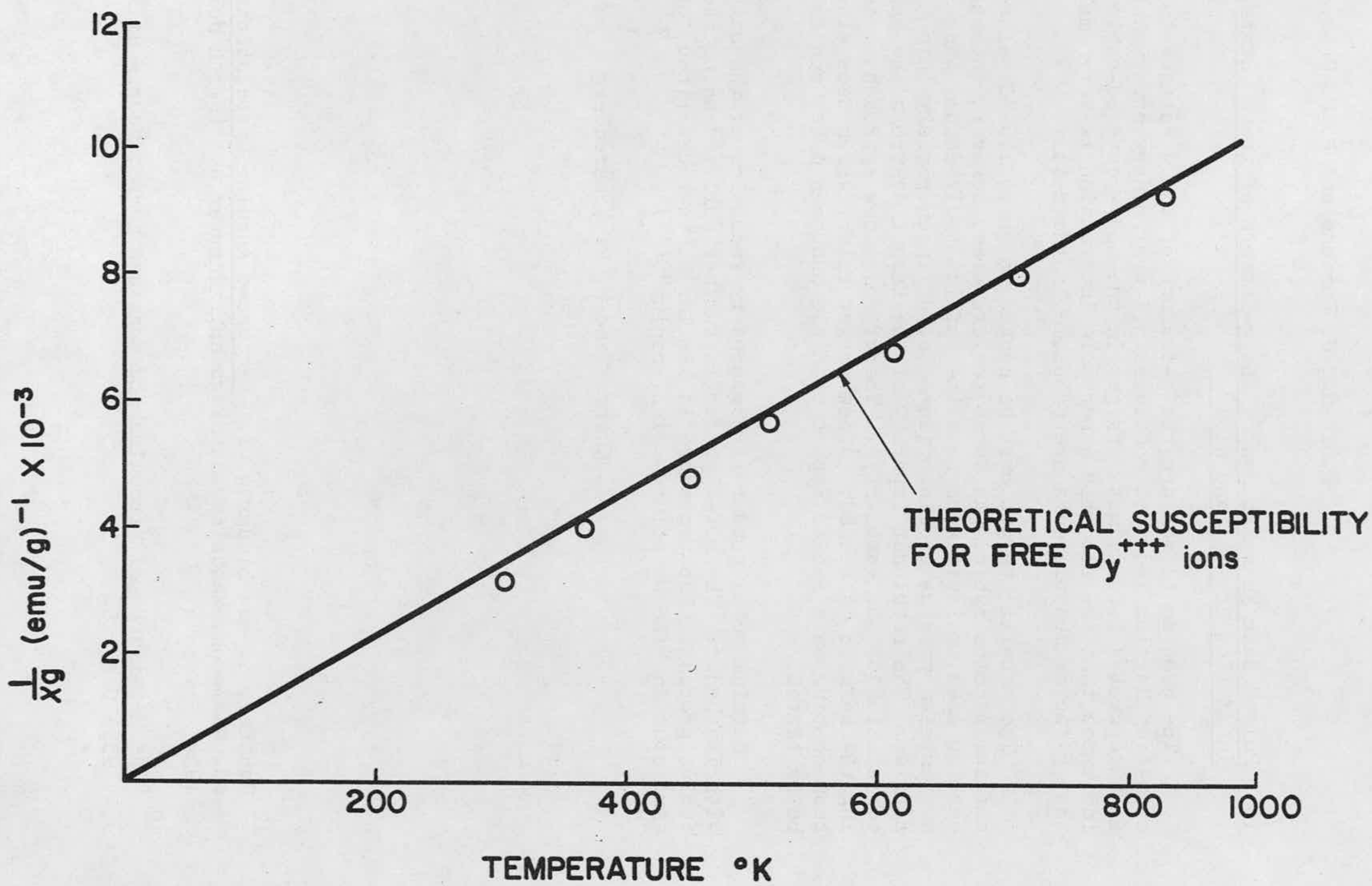


Figure 10. Reciprocal Susceptibility vs. Temperature Curve for Dy^{+++} ion in Dy Ag.

These results indicate that in the erbium and dysprosium-silver alloys, magnetic field at the nucleus can be calculated assuming the free tripositive ion. Such calculations have been done by several authors[11].

E. Tsang, J. Kurfess and R. P. Scharenberg

14. Pulsed Beam Measurements of the g-factors of the 2^+ States in Hf 176, Hf 178, and Hf 180

The program to measure the g-factors of the 2^+ states in the even-even hafnium isotopes continues. A preliminary experiment using an unseparated hafnium metal target in the body-centered-cubic phase indicates that the electric quadrupole interaction is very small, so that g-factor measurements are possible in the metal.

The metallic target must be heated to above 1760°C before hafnium becomes cubic. At these temperatures, however, the target backing used to resistance heat the hafnium (molybdenum, tungsten or tantalum provide backing filaments) diffuses rapidly into the hafnium. The resultant impurity of the target destroys the angular correlation of the gamma rays. Therefore, a new approach to heating the hafnium is needed. A new target holder which uses electron-beam heating on a cooled copper crucible has been made, and is now being tested.

Hafnium metal powder is prepared by reduction of the oxide with lanthanum. The metal powder is further purified using the iodide process. The procedure is similar to that described for zirconium in "The Metallurgy of Zirconium".[12]

J. Kurfess and R. P. Scharenberg

[11] Gunther, G. and Lindgren, I. Perturbed Angular Correlations ed. Karlsson, Matthias and Siegbahn. Chapter 4. (North Holland) 1964.

[12] "The Metallurgy of Zirconium" Lustman and Kerze, McGraw-Hill (1955) Chap. 5.

15. Mean Life Measurement of Some Even-Even Rare Earth Isotopes

The mean lives of the 2^+ rotational state in Yb^{170}, Yb^{172}, Yb^{174}, Yb^{176}, Sm^{152}, W^{182}, W^{184}, and W^{186} have been measured using the nanosecond pulsed proton beam from the Case Van de Graaff. One of the quantities determined in the g-factor measurement of this laboratory is the mean life. The mean life determined in the g-factor experiments is used as a cross check on the timing techniques by comparing it with published values. As the number of g-factors measured by this and other laboratories has increased, some discrepancies in the mean lives between laboratories has become apparent. Also, some mean lives such as Yb^{176} have not been accurately measured. In order to try to clarify this situation, the mean lives of the above mentioned isotopes were measured independently of the g-factor results.

These measurements were made by observing the exponential decay of γ -rays from the Coulomb excited 2+ state to the 0+ ground state of the nuclide under investigation. The equipment and procedure used was similar to that used in the g-factor measurements discussed in this and previous reports of this laboratory. The only major differences were that the external field was zero, and observations were made at only one angle.

The experimental procedure consisted of setting a differential discriminator on the γ-ray peak and recording the time between a beam pulse detected by a beam pickup just ahead of the target and a γ -ray of appropriate energy. Each run consisted of about 140,000 events, and two runs were made on each isotope. In general, the angular distribution of the γ-rays at the instant of excitation can be written(13)

$$W(\theta) = + \alpha_2 P_2 (\cos \theta) + \alpha_4 P_4 (\cos \theta),$$

where α_2 and α_4 are determined by the spin and multipole orders involved in the excitation and de-excitation process and the Coulomb excitation process itself. For proper choice of excitation conditions α_4 can be made to vanish. For this choice of excitation conditions the angular distribution as a function of time becomes

$$W(\theta, t) = \alpha_1 \; e^{-\lambda t} + \alpha_2 \, e^{-\lambda t} \; G_2(t) \, P_2(\cos \theta),$$

where λ is the nuclear decay constant and $G_2(t)$ represents the time dependence of the magnitude of the angular distribution. The time dependence of $G_2(t)$ can arise for example from the interaction of randomly oriented electric field gradients with the excited nuclear quadrupole moment. If θ is chosen so that P_2 (cos θ) = 0 then the counting rate should decay exponentially in time. These measurements were performed at such an angle and energies as to meet the above conditions.

The delay-time-to-pulse-height converter used was calibrated both before and after the mean life measurements using the same technique used in the g-factor measurements. This involves five delay cables inserted between the beam pickup and the converter and the essentially prompt γ-ray from Ta^{181}. The delay cables used had been calibrated in the manner discussed in a previous progress report (COO-720-044). As a result of cable calibration measurements made since the above report the accuracy of the cable calibration is estimated to be ± .11 ns on each cable.

The results of these measurements is summarized in Table IV along with values obtained from g-factor measurements of this laboratory. The mean lives were calculated by making a least squares fit of a decaying exponential to the data over those channels free from prompt background from the beam, and a general background of several counts. A typical time spectrum is shown in Figure 11. All targets used were metal targets prepared for g-factor measurements except for one which was separated isotope Sm^{152} in the form of Sm_2O_3.

The conclusion of these measurements is that the mean life derived from the g-factor measurements is in agreement with those measured here. When the present values are compared to those of other laboratories, it is found that some of the present values tend to be higher and some lower. This indicates that there may be errors in the published mean lives of as much as 5% which are probably due to time calibration errors. The time calibration and associated cable calibration has been the subject of careful investigation in this laboratory (see progress report COO-720-044), and all results to date are consistent with the quoted errors. An additional corroberation of this conclusion is that often the comparison of the quantity $g\tau$ between laboratories agrees more closely than g alone.[14]

SUMMARY OF MEAN LIFE DATA

Isotope	Mean Life (independent meas.)	(g-factor exp.)	
Yb^{170} (metal)	2.253 ± 0.024 ns	2.28 ± 0.07 ns	(2)
Yb^{172} "	2.440 ± 0.024 ns	2.46 ± 0.07 ns	(3)
Yb^{174} "	2.578 ± 0.025 ns	2.59 ± 0.07 ns	(3)
Yb^{176} "	2.492 ± 0.025 ns	2.54 ± 0.07 ns	(3)
Sm^{152} (oxide)	2.113 ± 0.020 ns		
Sm^{152} (metal)	2.137 ± 0.025 ns	2.14 ± 0.04	+
W^{182} "	2.018 ± 0.020 ns	1.98 ± 0.02 ns	(1)
W^{184} "	1.806 ± 0.020 ns	1.85 ± 0.03 ns	(4)
W^{186} "	1.652 ± 0.019 ns	1.67 ± 0.05 ns	+

+ Preliminary results from measurements made in this laboratory (unpublished).

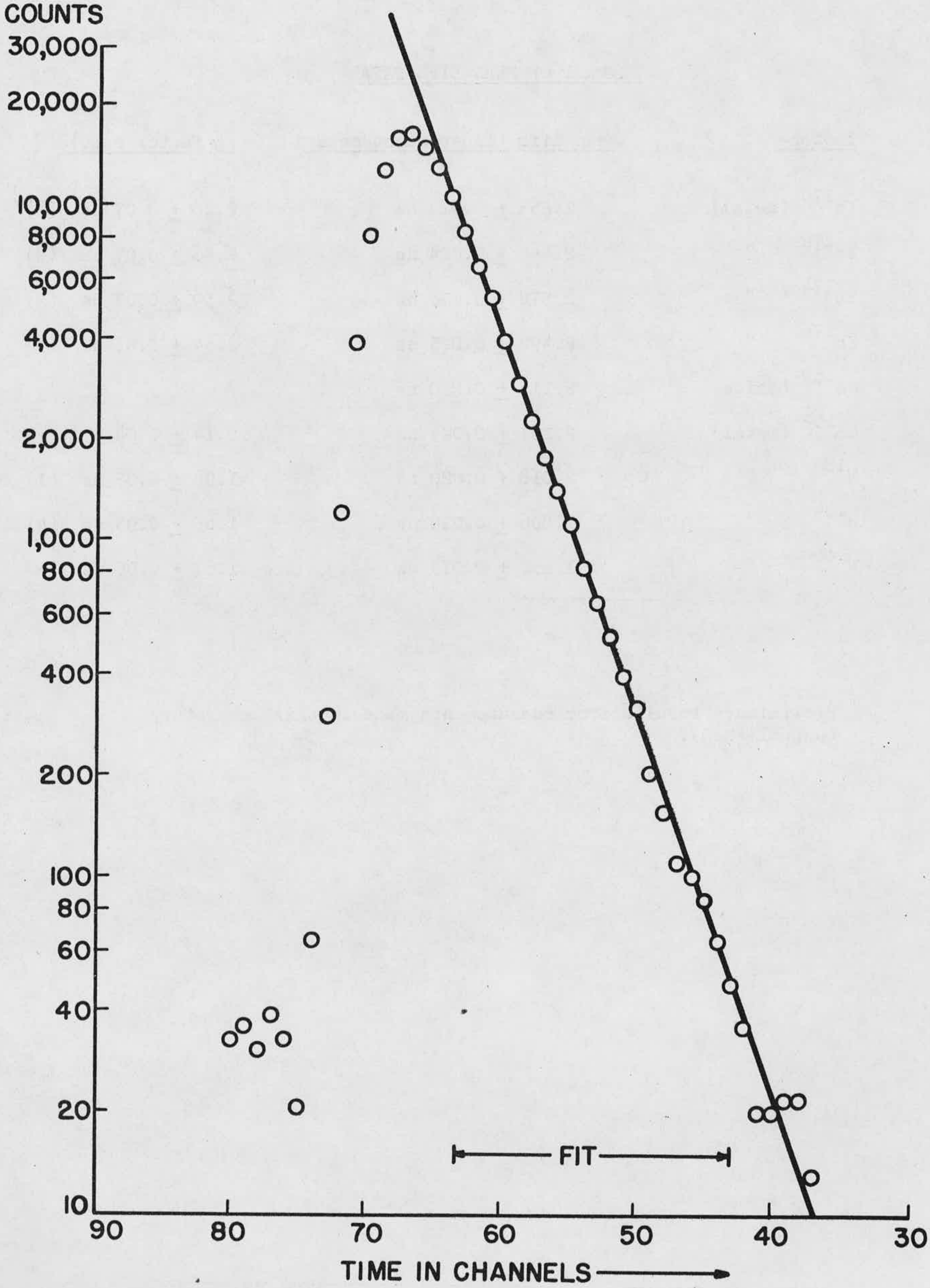


Figure 11. Typical Time Spectrum of Sm^{152} Metal Target

16. Electric Quadrupole Moments of Excited Nuclear States

Interference effects in the Coulomb excitation of nuclei with heavy ions allow the electric quadrupole moments of excited states to be determined by measurement of the angular distribution of the exciting particles. Theoretical and some preliminary experimental work has been discussed in previous progress reports of this laboratory.

In the past year progress in this study has been largely in the design and development of the necessary techniques and equipment for this study. Also some preliminary experimental work has been done with both the 3 Mev proton beam from the Case Van de Graaff, and the 30 Mev oxygen beam from the tandem at Argonne National Laboratory.

The development and construction of a suitable scattering chamber and associated experimental equipment has been completed, and at present is located at Argonne National Laboratory. Prior to moving this equipment to Argonne some experiments were performed using the 3 Mev proton beam from the Case Van de Graaff. It was found to be necessary to incorporate a thick lead shield around the scattering chamber and scintillation counter to reduce background gamma radiation. It was also found necessary to construct a flexible beam collimating system to properly fix the position and direction of the beam in the chamber. Details such as particle detector placement, target positioning, and collimator alignment were worked out in these runs.

An energy spectrum of 3 Mev incident protons scattered from a thin Sm^{152} target evaporated onto a thin carbon backing foil is shown in Figure 12. These protons were gated by the de-excitation gamma ray and are, in order of increasing energy, protons elastically scattered from the carbon backing, protons which have excited the Sm^{152} nucleus and have thus lost the excited state energy, and protons which have elastically scattered from the Sm^{152} nucleus.

Since the equipment has been moved to Argonne several preliminary experimental secessions have taken place with the 30 Mev oxygen beam from the Tandem. These have included aligning of the chamber and collimator, some development of the oxygen beam, testing of equipment and procedures, and obtaining of both ion and gamma-ray spectra from various targets of interest. Originally thin targets using 60 $\mu g/cm^2$ carbon film backings were used. These, however, proved inadequate due to large gamma backgrounds resulting from nuclear reactions of oxygen ions on carbon. Thin self-supporting films of 120 $\mu g/cm^2$ or less of aluminum, copper, and silver have also been tried. Aluminum, although better than carbon, also exhibited considerable background. Gamma rays from Coulomb excitation of silver prevents its use as a backing. Copper also gave gamma background, but less than silver, aluminum, and carbon. The copper gamma-ray spectrum was relatively flat so that it might be possible to pick out

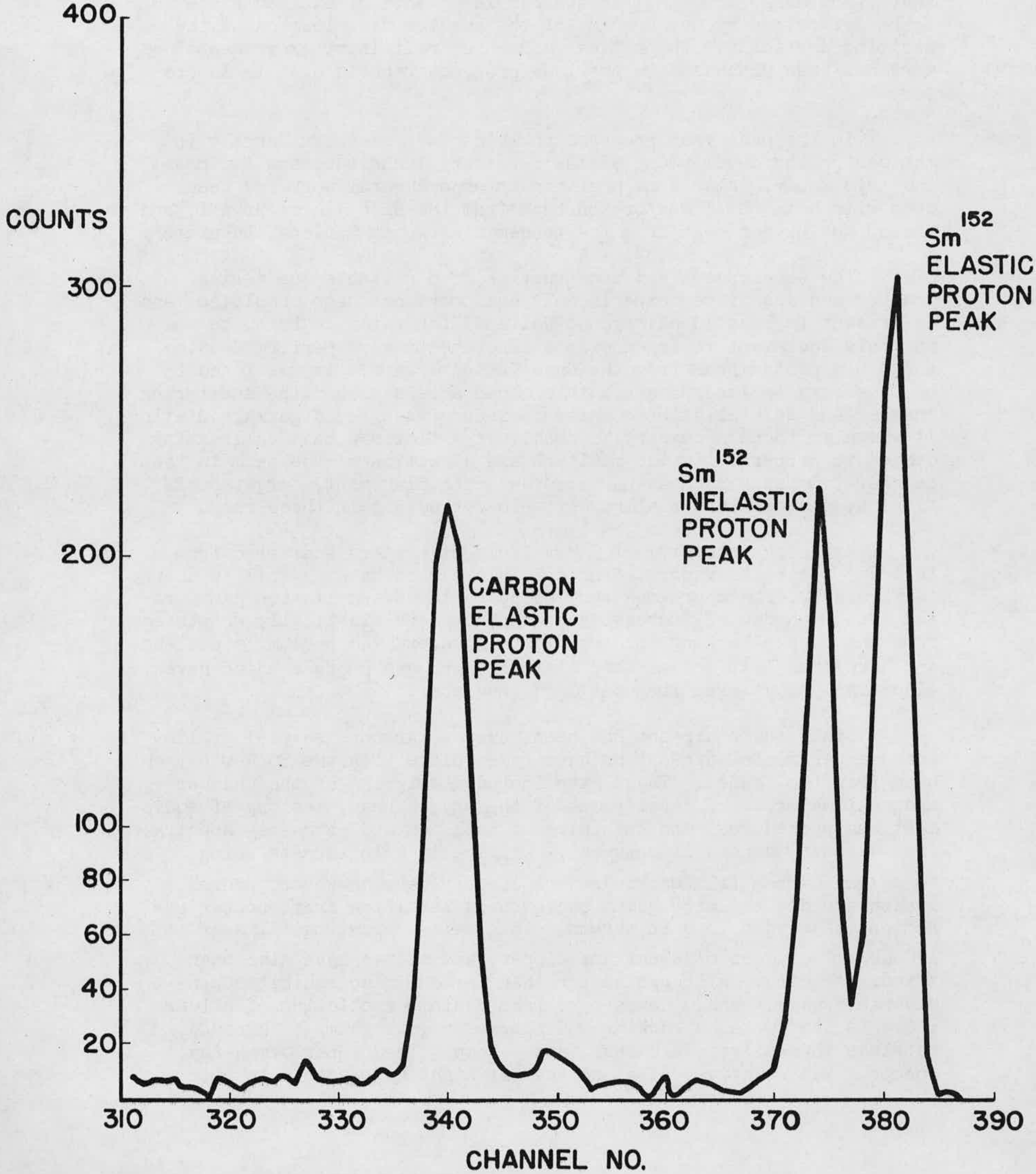


Figure 12. Proton Energy Spectrum Scattered from Sm^{152}

the gamma rays from the target material deposited on the copper backing.

A number of problems have been encountered and overcome in the preparation and mounting of self-supporting backings of 50 - 60 μg/cm^2 (560 - 670 Å) copper. Foils of 100 μg/cm^2 and thicker have been prepared by vacuum depositing copper onto glass slides coated by dilute solution of detergent, and then floated off on water and mounted. Efforts to use this procedure on thinner foils resulted in cracking of the films before they could be mounted. It was suggested that this cracking was due to stress setup in the film during evaporation and that this could be avoided by annealing.+ By heating the glass substrate to about 140°C it was possible to offset the cracking some, however, above this temperature the film would no longer float. This was overcome by using an evaporated layer of KCl of about 10 μg/cm^2 instead of detergent. KCl was used instead of NaCl due to background which Na might produce if any NaCl should remain on the foil. KCl has worked very well up to substrate temperatures as high as 250°C and should work to even higher temperatures. Thin films of copper of 50 μg/cm^2 have been reliably produced and mounted using this technique with substrate temperatures between 180°C and 250°C. It was found that some care in preparation of the mount must be exercised on the thinner foils (50 - 60 μg/cm^2) as microscopic burrs can cause the film to crack after mounting. Also, in the case of the thinner foils (50 - 60 μg/cm^2) cracking of the foil has occurred several hours after the foil was mounted. This cracking may be due to corrosion. Water present from the mounting procedure tends to evaporate slowly where the copper foil is backed by the target holder. Also, excess water accumulates around the edges of the 3/8 inch hole in the target holder which is covered by the foil. At these edges the surface tension of the water probably sets up considerable stress in the copper foil. The combination of water, stress, and probably some Cl^- ions in this region can cause corrosion of the foil, and thus weaken the foil. It has been found that this cracking can be prevented if the target is placed in a dry nitrogen atmosphere immediately after the foil has been mounted and the excess water drained away. It appears from experience gained so far that self-supporting foils of copper cannot be made and mounted much thinner than 40 or 50 μg/cm^2 with the present size target which is 3/8 inch diameter of unbacked foil.

Al foils of 30 μg/cm^2 deposited at room temperature on detergent coated slides are easily produced and handled. Judging from copper data it might be possible to produce self-supporting foils of

+ The development of these thin film techniques has been greatly aided by many very worthwhile discussions with R.W. Hoffman of the Case Thin Film Group.

Al as thin as 10 or 15 μg/cm^2. Ag foils of 70 μg/cm^2 are also easily produced at room temperature on detergent coated slides, however, thinner foils may present problems similar to copper.

Once the backing has been made, mounted, and measured as to thickness the target material is vacuum evaporated onto the backing. The present targets of interest are Sm and Cd. The reduction of Sm_2O_3 to the metal has been discussed in previous progress reports. Once the metal has been produced it is a relatively simple matter to deposit a thin layer onto the backing at room temperature. Cd, however, presents problems as it will not nucleate on almost anything including the backing at room temperature. It has been found that in order to vacuum deposit Cd it is necessary to cool the backing to near liquid nitrogen temperature. The necessary vacuum feed throughs have been developed to cool a block of copper to liquid nitrogen temperature. The target holder with copper backing is then clamped to the cooled copper block. Thin coatings of Cd of about 30 μg/cm^2 have been deposited on the Cu backings with excellent results.

The thickness of foils in the range of 100 μg/cm^2 or less are difficult to measure. The present scheme of measurement consists of measuring the energy loss of alpha's from Am^{241} when they pass through the foil. This energy loss is typically in the 20 to 50 kev range. An accuracy of approximately $\pm$ 3 μg/cm^2 has been achieved by calculating the shift in the centroid of the α spectrum from Am^{241} when it is observed directly by a solid state detector and when the foil is inserted between the α source and the detector. Drifts are a major source of trouble in this measurement and a mercury pulser peak taken at the same time as the α spectrum can correct this difficulty to some extent. This technique has not been without its difficulties and it may not be possible to increase its accuracy much over the present value without fundamental changes.

(R.P. Scharenberg, G. Schilling and J.W. Tippie)

THEORETICAL RESEARCH PROGRAM

THEORETICAL RESEARCH PROGRAM

1. Crossing Matrices and Dominance Theorems for Exchanged Systems

Further work on the structure of crossing matrices associated with internal symmetry groups has been principally directed toward the investigation of the crossing matrix between the s-channel (physical channel) and the u-channel which, in the case of elastic scattering, is closely related to "bootstrap" calculations. Some general properties of such crossing matrices have been found together with some indications as to the conditions under which a successful "bootstrap" can be achieved. A publication of a paper of a "review" character covering the general theory of crossing matrices is still envisaged.

It appears that a long-sought solution to the problem of a dominance theorem for the u-channel has finally been achieved valid for any semi-simple internal symmetry group. It has been demonstrated that dominance in this channel by exchanged systems belonging to the highest weight representation of the internal symmetry group, as had been previously conjectured, is the only dominance consistent with unitarity. While there is no experimental evidence that such dominance is ever achieved in actual physical situations, so that the result would appear academic, it is nevertheless useful in that it suggests that bootstrap calculations require the existence of the highest-weight representation amplitude in the crossed channel in order to achieve consistency with unitarity.

The extension of these crossing matrix ideas to external symmetry groups (the inhomogeneous Lorentz group) has not been further pursued as a result of indications from G.C. Wick that no results of interest seem to appear.

(H. Kottler and L.L. Foldy)

2. Muon Capture in Complex Nuclei

Work on the problem of muon capture in selected light nuclei and the role of giant resonances in this process (initiated at CERN) has now appeared in print: L.L. Foldy and J.D. Walecka, Nuovo Cim. 34, 1026 (1964). Some of the theoretical speculations concerning the existence of a "giant resonance supermultiplet" has since received experimental confirmation at Stanford through the identification of the "giant resonance" 2^- state in C^{12} and O^{16} via inelastic electron scattering experiments. A considerable amount of theoretical work has been carried out to the end of understanding why the supermultiplet structure of the giant resonances survives the strong symmetry-breaking effects of the nuclear spin-orbit force and the weaker symmetry-breaking effects of Bartlett and Heisenberg forces taking O^{16} as an example. The picture that emerges from this work is that the

Wigner and Majorana forces so strongly separate the Wigner supermultiplets which arise out of the original degenerate harmonic oscillator states without particle interaction, as to make the strong spin-orbit force relatively ineffectual in admixing states belonging to other supermultiplets with the "giant resonance" supermultiplet. There is further a tendency for the effects of Bartlett and Heisenberg forces to cancel the effects of the spin-orbit force in producing mixing. The effects of tensor forces has also been explored and it appears that these are even less effective than spin-orbit forces in producing admixture in the "giant resonance" supermultiplet. These investigations are nearly complete; a technical report covering these investigations will be issued and selected material from this submitted for publication.

(G. Walker and L.L. Foldy)

Theoretical investigation on the nuclear correlation function which plays an important role in the calculation of muon capture in heavy nuclei in the closure approximation also continues. Work in this area initiated at CERN has now been published: L.L. Foldy and J.D. Walecka, Nuovo Cim. 36, 1257 (1965). More recent investigations have centered around the problem of finding a suitable representation of this correlation function for finite nuclei in the approximation of non-interacting particles. A model which one has good reasons to believe may be a suitable approximation for heavy nuclei. Toward this end, detailed calculations have been made for a one-dimensional finite Fermi gas where exact calculations as well as asymptotic forms can be analytically carried through. These are to be used to test an approximate expression which has been derived for the required correlation function, this expression having the virtue that it overcomes the major objections to the infinite Fermi gas result which were raised by Foldy and Walecka in the publication referred to above. Provided that the exact results are not very sensitive to boundary conditions for the system at the momenta transfer appropriate to the muon capture problem, it is hoped that the proposed approximate expression can give a good accounting of the effects of finite size in this momentum transfer range. Should this be the case, we are optimistic that it can be applied to the three-dimensional spherical nucleus case, where exact calculations would involve a prohibitive amount of labor even with the use of a computer. The degree to which one might expect corrections from interparticle forces will also be investigated in the random phase approximation to determine whether in fact it is reasonable to ignore these forces for the purposes at hand.

(A. Bogan and L.L. Foldy)

Work on muon capture in C^{12} leading to the ground state of B^{12} as a means of determining the coupling constants in muon capture with relatively high precision has now been completed. A preprint covering the results has been issued as Report ITP-176 by the Institute of Theoretical Physics at Stanford University, and an essentially identical manuscript has been accepted for publication by the Physical Review. The abstract of this paper follows:

The measured capture rate of muons in C^{12} leading to the ground state of B^{12}, in combination with other data, is employed as a basis for a determination of the weak interaction coupling constants associated with muon capture. The study of this transition has the advantages (1) the rate depends only weakly on the vector, induced pseudoscalar, and (possible) tensor coupling constants, not at all on a possible scalar coupling constant; (2) empirical information from inelastic electron scattering on C^{12} leading to the excitation of the 15.1 MeV level, the M1 lifetime of this level, and the $f\tau_{\frac{1}{2}}$ value for the beta decay of B^{12} allows one to determine the required nuclear matrix elements of major importance (as well as some of minor importance) in practically a model-independent way. The capture rate can thus be expressed in terms of the axial vector coupling constant and the weak magnetism coupling constants. Assuming the validity of the Conserved Vector Current hypothesis, and $5 < C_p < 28$ one then finds that $F_A^{\mu} / F_A^{\beta} = 1.04 {+0.07 \atop -0.10}$. On the other hand, if one assumes $F_A^{\mu} = F_A^{\beta}$, one obtains for the isotopic vector magnetic moment of the nucleon (at the appropriate momentum transfer) $\mu(v^2)=5.7 {+1.1 \atop -1.6}$ nuclear magnetons which is consistent with CVC which predicts 4.60 nuclear magnetons and can be considered as evidence for weak magnetism in muon capture.

The exploration of the role of the "giant resonance" supermultiplet in inelastic electron scattering, mentioned in the last progress report as a possible area for futher work has been actively pursued by Walecka and his associates at Stanford and by H. Uberall at the Catholic University of America with very favorable results. No further work in this area is presently planned at Case. The problem of whether such a supermultiplet exists as a general feature of most nuclei appears to be quite formidable from the point of view of direct shell-model calculations, and it appears desirable to first determine if a 2^- giant resonance state is found experimentally by electron scattering in other nuclei then C^{12} and O^{16}.

[J.D. Walecka (Stanford) and
L.L. Foldy]

3. Cartesian Tensors in Spaces with an Indefinite Metric with Applications to Relativity

A new formalism for dealing with Cartesian tensor analysis in flat spaces with an indefinite metric with the same ease as in Euclidean spaces is introduced. It avoids the necessity of distinguishing covariant and contravariant indices and the consequent use of the metric tensor in raising and lowering indices; neither does it require the introduction of imaginary coordinates and components of tensors. It is based on the use of a modified Einstein summation convention combined with a modified differentiation with respect to tensor components in such a way that all formal manipulations are essentially identical with those employed in Cartesian tensor analysis in Euclidean spaces. The further introduction of a modified matrix multiplication and a modified definition of a determinant serves to round out the formal analogy with the Euclidean space. The convenience, simplicity, and typographical economy of the new formalism is illustrated by examples drawn from special relativity. The formalism can be trivially generalized to complex linear vector spaces with an indefinite metric.

(L.L. Foldy)

4. Pair Correlation Functions in Classical Statistical Mechanics

This work covers certain investigations relevant to the problem of determining information about an n-particle statistical mechanical system from knowledge of the two-particle correlation function. Problems of a similar character arise as well in determining the ground state energy of boson gases (charged boson gas, liquid helium) by certain types of variational approaches.

It has been found that the k-particle distribution function for an n-particle system can be reconstructed explicitly from the two-particle correlation function in a form involving power series in the density with coefficients which are explicit functionals of the two-particle correlation function expressed in terms of sums of "weights" associated with specific classes of graphs. In addition the inter-particle potential can likewise be explicitly given in similar form. Unfortunately, little can at present be said concerning the convergence of the associated series so that no direct answer can be given to the question as to whether a particular two-particle correlation function can be explicitly realized by some potential. This last problem is the one of specific interest in connection with the variational approaches to the quantum problem mentioned above.

Attempts have been made to obtain information concerning this last problem by other methods. These consist in approximating certain "exact" integral equations which connect the two-particle correlation function with the potential. These equations are "exact" only in a formal sense since they contain infinite series whose convergence properties are unknown. The approximations involve truncation or partial summations of these series so as to yield equations which are free of such series and hence give rise to a mathematically "well-defined" equation. The problem of finding sufficient conditions on the pair-correlation function in order that a solution of the integral equation for the potential exists. Included are some previously proposed equations such as the Percus-Yevick equation and the Born-Green equation. By the use of mathematical techniques from functional analysis and the theory of Banach spaces, one indeed can find classes of pair correlation functions for which a potential exists which will give rise to them, in every case. The results suggest, but unfortunately do not rigorously establish, that in the exact case a pair-correlation function $g(r)$ such that the absolute value of $g(r) - 1$ and the integral over its absolute value are suitably bounded, can in fact be realized by some inter-particle potential. Could this be established rigorously, it would yield support to the method used by Feenberg and his students for bounding the second term in the high-density limit for a charged boson gas and for their treatment of superfluid helium which already exhibits some remarkable successes in comparison with experimental results.

These results constitute the doctoral dissertation of Mr. F.A. Blood and have been issued as Technical Report No. 53 under this contract. Publication of selected portions of this report is anticipated.

(F.A. Blood and L.L. Foldy)

5. Bottles for Neutrons

A short paper discussing the theoretical feasibility for making a "bottle" to hold neutrons has been submitted as the author's contribution to a volume to be published in honor of Prof. V.F. Weiskopf entitled "Preludes in Theoretical Physics". In brief summary it shows that a cavity in liquid helium with a helium wall thickness greater than 6×10^{-5} cm and maintained at a temperature below 10^{-5} degrees Kelvin would be capable of holding a neutron gas with a density of the order of 10^{14} neutrons/cm^3 with a loss rate which is comparable with that arising from spontaneous neutron decay.

(L.L. Foldy)

6. The Structure of Nucleons

At the request of the editors of the journal, "Physics Today" a popular review article on the subject of nucleon structure has been prepared and was published: Physics Today, Vol. 18, No. 9, p. 26 (1965).

(L.L. Foldy)

7. Are the Low Energy Nucleon-Nucleon Scattering Data Consistent with Charge Independence?

This work has now been published under the title "Effect of Electromagnetic Corrections to Low-Energy Nucleon-Nucleon Scattering on Charge Independence": Phys. Rev. 137 B 874 (1965).

(R.E. Schneider and R.M. Thaler)

8. Proton-Alpha Elastic Scattering and Polarization

This work described in the last Progress Report continues. A paper discussing some results has been presented at the 1965 Summer Meeting at New York: B. A. P. S. 10, 601 (1965). A full discussion of this work is now being written.

(R.M. Thaler, C. Giamati, and H.C. Volkin)

9. Scattering Theory

The manuscript of this book has finally been forwarded to the publisher.

(R.M. Thaler and L. Rodberg)

10. Effect of Pauli Principle in Nucleon-Nucleus Scattering

The work described in the last Progress Report is now completed. A paper reporting some of the results of this research is now in preparation.

(J. Holdeman, R. Schenter, and R.M. Thaler)

11. Scattering of Electrons by Atoms

This work described in the last Progress Report is now completed. Some of this work has been reported by C.D. Le in the Master's thesis. A paper entitled "The Scattering of Slow Electrons from Helium Atoms", by R.E. Schenter and R.M. Thaler has been submitted for publication.

(C.D. Le, R.E. Schenter and R.M. Thaler)

12. Optical Theorem for Charged Particle Scattering

This work described in the last Progress Report has now been completed. A preliminary report of the results of this investigation has been given in Phys. Rev. Letters 14, 81 (1965). A more detailed account of this investigation has now been given: Phys. Rev. 139, B 1186 (1965)

(J. Holdeman and R.M. Thaler)

13. Antiproton-Nucleus Scattering

Another student has taken up this problem.

(C. Lennon and R.M. Thaler)

14. Exchange Character of the Optical Model Spin-Orbit Potential

The numerical calculations referred to in the last Progress Report did not support the conjecture under investigation, no further work in this direction is contemplated.

(R.E. Schenter, H.C. Volkin and R.M. Thaler)

15. The Wave Matrix for Bound States

The work described under this title in the last Progress Report has been temporarily put aside.

(M.Nagarajan and R.M. Thaler)

16. On the Theory of Rutherford Scattering

A careful study of the limiting processes involved in the treatment of Coulomb scattering has been made. This work has been reported at the 1965 Summer Theoretical Physics Institute at the University of Colorado, and will appear shortly as a chapter in the book published by the Institute.

(R.M. Thaler)

17. Relativistic Small Angle Scattering of Two Charged Particles

An attempt was made to understand the phase of the forward Coulomb scattering amplitude at high energies, by means of a Coulombic potential in the Bakamjian-Thomas formalism. Some aspects of this work have been reported in Phys. Rev. Letters: Phys. Rev. Letters 14, 572 (1965) and Phys. Rev. Letters 15, 117 (1965). Unfortunately, the novel result obtained was due to an error. When this error is corrected this approach also gives the conventional answer. An erratum has been submitted. Work on this problem continues.

(W.B. Rolnick and R.M. Thaler)

18. Schwinger Polarization of Protons

Interest in the practical possibilities of polarizing protons by scattering them from heavy nuclei at low energies has lead to calculations of the magnetic polarization of particles of charge z and magnetic moment μ by a static Coulomb field. The technical difficulties in such a calculation have been overcome and practical numerical results are now available.

(J.T. Holdeman and R.M. Thaler)

19. D-State and Pickup Effects in Nucleon-Deuteron Scattering

This work has now been published: Phys. Rev. 137, B 1350 (1965).

(H. Kottler and K.L. Kowalski)

20. Lower Bounds on the Shrinking of Diffraction Peaks

Lower bounds on the width of a diffraction peak are found using unitarity and analyticity in cos θ in Lehmann-type ellipses. When the forward elastic scattering amplitude is predominantly imaginary, the lower bound obtained is proportional to $(\ell n\ s)^{-2}$. In deriving this result no restrictions, except those imposed by unitarity and analyticity, were made concerning the asymptotic behavior of the total cross section. This work has now been published: Phys. Rev. 137, B1350 (1965)

(K.L. Kowalski)

21. General Properties of the Overlap Function

One method which has been employed to study the elastic scattering of two elementary particles in the high-energy limit involves the introduction of a model for the dominant (production) amplitudes at high energies. Then if the elastic scattering amplitude is supposed to be purely imaginary it may be calculated from the unitarity equation in which any dynamical consequences of a model for the production amplitudes are conatined in the so-called overlap function. In view of the critical role of the overlap function in determining the elastic scattering at high energies those properties of this function which are independent of any particular model and which in turn must be any model were studied. This work has now been published: Nuovo Dim. 38, 1073 (1965).

(K.L. Kowalski)

22. Truncation of the Unitary Sum

An ambiguity in the truncation of the unitary sum has been pointed out and resolved, at least when the scattering is invariant under time reversal. As a consequence of this work some limitations involved in the calculation of unitary (absorptive) corrections in the so-called one-meson-exchange model of certain elementary particle reactions as well as in the dispersion theoretic approach to direct nuclear reactions have been removed. Similar ambiguities have been shown to exist and have been resolved in the K-matrix formalism as well. A manuscript covering this work has been accepted for publication by Nuovo Cimento.

(K.L. Kowalski)

23. <u>Phenomenological Investigation of Very High-Energy Collisions</u>

Extensions and possible implications of the phenomenological treatment of very high-energy two-body collisions of elementary particles initiated by Van Hove continue to be studied. The implications of the hypotheses of Van Hove concerning the form of the final state wave functions on the actual structure of the high multiplicity production amplitudes are being investigated.

(K.L. Kowalski)

24. <u>Shape of the Forward Peak in High-Energy Elastic Scattering</u>

All cross sections for elastic elementary particle scattering at very high energies (> 10 BeV) can be fit by a function of the form $\exp(a + bt + ct^2)$ where t is the negative of the invariant momentum transfer squared. It is interesting to study the constraints imposed on the shape parameters a, b, and c by unitarity when the scattering is primarily absorptive. This investigation is concerned with the previously unexamined parameter c. A rigorous lower bound on c has been found. Unfortunately, this bound does not indicate a definite range of values of the total and total-elastic cross sections and the slope of the forward peak where c is necessarily positive which is the most prevalent situation experimentally. More refined bounds are being sought presently using several methods.

(K.L. Kowalski and J. Krauss)

25. <u>The Equivalence of Elementary and Composite Particles</u>

Given the Hamiltonian density of a system of interacting fields, it is possible to specify a second system which differs from the first by having one more or one less field in the Hamiltonian density and which has the interaction terms of the Hamiltonian density so modified that the physical properties of the two systems are the same. It follows that certain single-particle states of one system that are regarded as elementary-particle states must be present in the other system as composite-particle states. The connection between such physically equivalent systems is derived. The formalism is applied to the Lee model and the extended Lee model.

This has been published in the Physical Review <u>137B</u> 1236 (1965).

(M.A. Nagarajan and W. Tobocman)

26. Boundary-Condition Constraints for the Shell Model: A Method for Nuclear Structure and Nuclear Reactions.

It is proposed that the asymptotic boundary conditions be used as constraints for shell-model calculations. Two formalisms which permit this to be done are presented. In one formalism the boundary conditions are introduced as constraints in a variational principle. In the other formalism Green's theorem is used to make the dependence on the boundary conditions explicit. The use of boundary-condition constraints permits the use of the shell-model method for scattering and reactions as well as for nuclear-structure calculations. It is suggested that the constrained-shell-model method will improve the representation of the nuclear surface and will provide the basis for a truly unified treatment of nuclear reactions. In such a unified treatment compound-nucleus resonances, direct-reaction transitions, and optical-model scattering will be generated from a single, fairly fundamental model.

This work has been published in the Physical Review 138B, 1351 (1965).

M. A. Nagarajan and W. Tobocman

27. Test of the Boundary-Condition Constraint Method for Nuclear Reactions

The boundary-condition constraint method (BCCM) is a generalization of R-matrix theory that permits the shell model to be used as a basis for nuclear-reaction calculations and which permits the correct far-asymptotic behavior of the wave function to be imposed as a constraint on shell model bound-state calculations. For practical application it is necessary to truncate sums over an infinite number of levels. The purpose of this paper is to investigate how effective the few-level approximation might be. The BCCM is used to calculate an s-wave bound state for a square well in the two and three level approximations. The BCCM is used to calculate the s- and p-wave scattering from a square well in the two and three level approximations. The results are found to compare favorably with the exact and Wigner R-matrix-theory results. We note that within the n-level there is some ambiguity in the form of the Green's function to be used with the BCCM.

This work was done in collaboration with Dr. S. K. Shah and Professor W. Tobocman. This will be published in the October 1965 issue of the Physical Review.

M. A. Nagarajan, S. K. Shah and W. Tobocman

28. Theory of (p, n) Reactions

The theories of (p, n) reactions proposed so far have implicitly assumed that the reactions proceed through a direct interaction mechanism. Tjey have therefore been inadequate to analyse reactions where resonances are observed in the cross-sections. We have extended this theory along the lines of Feshbach's[17] unified theory to allow a calculation when isolated resonances contribute to the cross-section. We have been able to obtain general expressions for the cross-section which includes the direct reaction as well as the resonance amplitudes. Calculations are being done for the analysis of the reaction N^{15}(p, n) O^{15}.

[17] H. Feshbach, Annals of Physics (N.Y.) 19, 287 (1962).

(M.A. Nagarajan)

29. Analysis of the Reactions N^{15}(p,n) O^{15} and N (p,δ) O^{16}

We have used the formalism of Tobocman and Nagarajan[18] to calculate the contribution from the compound nucleus to the reactions N^{15}(p,n) O^{15} and N^{15}(p,δ) O^{16}. This formalism also allows one to calculate the elastic scattering in the initial and exit channels. These wave functions are then used to calculate the distorted wave amplitudes which measure the contribution from the region external to the compound nucleus. Calculations are being done on this project now.

[18] W. Tobocman and M.A. Nagarajan, Phys. Rev. 138B 1351 (1965).

(S.K. Shah)

30. Condensation Phenomena

In the past several years, considerable progress has been made (by various authors) in understanding the microscopic basis of the van der Waals theory of the liquid-gas phase transition. The man result is that this theory can be derived rigorously for a certain class of interparticle potentials with range parameter R, in the limit as $R \to \infty$. The investigations have necessarily been highly mathematical and, in particular, the work of Lebowitz and Penrose employs an involved triple limiting process. We propose a simple geometrical picture which allows one to "see" why such multiple limiting processes are essential to van der Waals behavior and why, for example, a one-dimensional gas with a long but finite range potential does not condense. This picture, while qualitative, helps to bridge an apparent gap between the approximate theory of van Kampen and the rigorous work of Lebowitz and Penrose. Furthermore, it suggests that the limit $R \to \infty$ is necessary for van der Waals condensation for systems of any number of dimensions. One cannot draw any conclusions about the effects of short range forces. This work will be published under the title "Remarks on Condensation Theory".

(H.S. Leff)

31. Inhomogeneities in Finite Systems

The study of classical fluids in equilibrium statistical mechanics is by now very familiar. It is based, however, on the assumption of homogeneity, a property which is seldom investigated rigorously. We have begun an investigation of this property for the simplest non-trivial model in classical statistical mechanics: a gas of hard rods in a one-dimensional "box". This model allows an exact calculation of the single particle distribution function for a finite number of particles and a finite "volume". Preliminary results show that for densities less than one-half closest packing density ($1/2\ P_0$) a "central region" exists for which this function is exactly constant. In the limit of an infinite system this constant approaches the number density. Outside the central region the function is continuous but non-analytic, due to the presence of the hard cores. For densities higher than ($1/2\ P_0$) no such central region exists and the function is not constant for a finite system. Near closest packing, one can show that the function approaches a sum of Dirac delta functions, as expected. The problem of investigating this single particle distribution function in the limit of an infinite system is presently in progress.

(H.S. Leff)

32. Equilibrium Statistical Mechanics with External Fields

The usual methods of obtaining equations of state via a canonical or grand canonical partition function must be modified if, for example, an external gravitational field is present. For such cases, the pressure is a function of position and even the simple "barometer formula" is not readily obtainable from a partition function without further definitions and/or assumptions. Several authors have proposed definitions of pressure for such non-uniform systems, but few concrete applications have been made. We plan to initiate an investigation, the objectives of which are:

(a) to analyze and compare the existing definitions of pressure and to seek non-trivial models to which these may be applied;

(b) to extend certain theories of condensation to include an external field in order to examine its effect(s) on the phase separation and on the critical point.

(H.S. Leff)

33. Incompletely Specified Systems

A formalism has been introduced for treating thermodynamic systems whose Hamiltonians are not completely known. This work has been published, J. Chem. Phys. 41, 596 (1964). Subsequently, a simple model was proposed which lends support to the formal theory and which utilizes the common technique of dividing a large system into many smaller sub-systems rather than the idea of a dual ensemble, as such. A preliminary report of this work has appeared in Bull. Am. Phys. Soc. 9, 662 (1964). We propose an extension of this work which will emplou specific physical examples in order to gain a deeper understanding of the theory's significance. The simplest example is provided by the Debye solid, which may be viewed as a system of uncoupled harmonic oscillators with incompletely specified spring constant. Other possible examples include simple spin systems. An analysis of such examples is planned and the possibility of incorporating information-theoretic techniques into the dual-ensemble formalism will be investigated. The recent calculations of Morita for quenched solid solutions and especially his introduction of a "fictitious system" appear relevant and will also be studied.

(H.S. Leff)

34. Time Delay for Wave Packets

Time delay is considered in nonrelativistic scattering theory with two-particle inelastic channels present. A comparison method is discussed, which in turn leads to a more natural definition based on the classical definition of time delay for inelastic scattering. This work is scheduled to be published in the November 8, 1965 issue of the Physical Review.

(R. Fong)

PERSONNEL

Faculty

Professor E. F. Shrader
Professor L. L. Foldy
Professor R. M. Thaler
Professor R. P. Scharenberg[*]
Professor K. Kowalski
Professor H. Leff
Professor M. A. Nagarajan
Professor E. A. Silverstein
Dr. D. I. Garber
Dr. J. W. Tippie

Research Associates

Dr. R. Fong
Dr. R. E. Schenter[**]
Dr. S. K. Shah
Dr. J. Rix

Graduate Students

[illegible]
M. A. Berger[†]
F. A. Blood[†]
A. Bogan
H. J. Braathen
R. Braley
G. Chow
L. A. Galloway
J. S. Hanna
R. V. Heckman
J. T. Holdeman
H. Kottler
J. Krauss
C. D. Le[†]
C. J. Lennon
P. H. Liebenauer
J. T. Lindow
W. W. Lindstrom
W. L. Rogers
G. Schilling
G. Walker
P. A. Wolfe

Non-Academic

B. M. Shoffner	Senior Staff Physicist
A. A. Hruschka	Research Engineering Associate
L. Hinkley	Van de Graaff Engineer

* On leave of absence 1965 - 1966

** Terminated July 1965

† No longer in residence

PUBLICATIONS

Published Papers

L.L. Foldy and J.D. Walecka, "Muon Capture in Nuclei", Nuovo Cim. 34, 1026 (1964).

L.L. Foldy and J.D. Walecka, "Nuclear Correlation Functions and Muon Capture", Nuovo Cim. 36, 1257 (1965).

L.L. Foldy and J.D. Walecka, "Muon Capture in Nuclei", Comptes Rendus du Congres International de Physique Nucleare, Vol. II, pp. 1168 (1964).

L.L. Foldy, "Neutron Scattering, Electrostatic" in Encyclopaedic Dictionary of Physics, Pergamon Press (Oxford).

L.L. Foldy, "The Structure of Nucleons", Physics Today, Vol. 18, No. 9, pp. 26 (Sept. 1965).

K.L. Kowalski, "Lower Bounds on the Shrinking of Diffraction Peaks", Phys. Rev. 137, B1350 (1965).

H. Kottler and K.L. Kowalski, "D-State and Pickup Effects in Nucleon-Deuteron Scattering in the Impulse Approximation", Phys. Rev. 138, B619 (1965).

K.L. Kowalski, "Some Properties of the Overlap Function", Nuovo Cim. 38, 1073 (1965)

H.S. Leff, "Asymptotic Densities in Statistical Ensembles", Phys. Rev. 136, A355 (1964).

V.A. Madsen and W. Tobocman, "Calculation of Inelastic Alpha-Particle Scattering by Ni^{58}", Phys. Rev. 139, B864 (1965).

M.A. Nagarajan and W. Tobocman, "The Equivalence of Elementary and Composite Particles", Phys. Rev. 137, B1236 (1965).

W. Tobocman and M.A. Nagarajan, "Boundary-Condition Constraints for the Shell Model: A Method for Nuclear Structure and Nuclear Reactions", Phys. Rev. 138, B1351 (1965).

R.E. Schneider and R.M. Thaler, "The Effect of Electromagnetic Corrections to Low Energy Nucleon-Nucleon Scattering on Charge Independence", Phys. Rev. 137, B874 (1965).

J.T. Holdeman and R.M. Thaler, "Optical Theorem as Applied to Charge Particle Scattering to Yield Reaction Cross Sections from Elastic Scattering Data", Phys. Rev. Letters, 14, 81 (1965).

W. B. Rolnick and R. M. Thaler, "Relativistic Scattering of Two Equal Mass Charged Particles", Phys. Rev. Letters, 14, 572 (1965).

W. B. Rolnick and R. M. Thaler, "Relativistic Small Angle Scattering of Two Charged Particles", Phys. Rev. Letters, 15, 117 (1965).

C. C. Giamati and R. M. Thaler, "Possible Proton-Alpha Scattering Experiment at 40 MeV", Nuc. Phys. 59, 159 (1964).

R. P. Scharenberg, J. Kurfess, G. Schilling, J. W. Tippie, P. Wolfe, "Pulsed Beam Measurement of the Gyromagnetic Ratio of the 111-heV 2+ State in Tungston 184", Phys. Rev. 137, 1B, (1965).

J. W. Tippie and R. P. Scharenberg, "Measurement of the Gyromagnetic Ratio of the 84 HeV 2+ State in Ytterbium 170", Phys. Letters 16, 154 (1965).

In press.

B. M. Shoffner and E. F. Shrader, "True Zero-crossing Fast Discriminator" Transactions of the IEEE.

J. W. Tippie and R. P. Scharenberg, "Pulsed-Beam Measurement of the Gyromagnetic Ratio of the first Excited Rotational States in Ytterbium 172, 174 and 176", Phys. Rev. (1965) in publication.

L. L. Foldy and J. D. Walecka, "Coupling Constants in Muon Capture", (Physical Review).

L. L. Foldy, "Bottles for Neutrons", (Preludes in Theoretical Physics).

L. L. Foldy, "Tensor Analysis in Spaces with an Indefinite Metric with Applications to Relativity", (Jour. Math. Phys.)

K. L. Kowalski, "Truncation of the Unitary Sum", (Nuovo Cim.)

R. Fong, "Time Delay for Wave Packets in Non-Relativistic Scattering Theory with Inelastic Channels Present", (Phys. Rev.).

S. K. Shah, M. A. Nagarajan, and W. Tobocman, "Test of the Boundary-Condition Constraint Method for Nuclear Reactions", (Phys. Rev.).

R. M. Thaler, "On the Theory of Rutherford Scattering", 1965 Lectures in Theoretical Physics at the University of Colorado, Boulder, Colorado.

Papers Presented at Scientific Meetings

L.L. Foldy, "Muon Capture in Light Nuclei", Midwest Conference on Theoretical Physics, Ohio State University, Columbus, Ohio May 14-15, 1965.

H.S. Leff, "Incompletely Specified Systems", Bull. Am. Phys. Soc., 9, 622 (1964).

C.C. Giamati, H.C. Volkin, and R.M. Thaler, "Analysis of the Energy Variation of Proton-Alpha Phase Shifts", Bull. Am. Phys. Soc. 10, 601 (1965).

D.I. Garber and E.F. Shrader, "Polarization of Neutrons from (d,n) Reactions on Carbon", Bull. Am. Phys. Soc. 10, 510, (1965)

Technical Reports

H. Kottler, "D-State and Pickup Effects in Nucleon-Deuteron Scattering", Technical Report COO-720-045, Case Institute of Technology, Nuclear Physics Program.

J. W. Tippie, "The Gyromagnetic Ratio of the First Excited Notational States in Ytterbium 170, 171, 174 and 176", Technical Report COO-720-046, Case Institute of Technology, Nuclear Physics Program.

Le Dinh Chinh, "Exchange Effects in Scattering of Slow Electrons by Atoms", Technical Report COO-720-047, Case Institute of Technology, Nuclear Physics Program.

M. A. Nagarajan, "Boundary Condition Constraints for the Shell Model: A Method for Nuclear Structure and Nuclear Reactions", Technical Report COO-720-048, Case Institute of Technology, Nuclear Physics Program.

R. M. Thaler and R. E. Schneider, "Effect of Electromagnetic Corrections to Low-Energy Nucleon-Nucleon Scattering on Charge Independence", Technical Report COO-720-049, Case Institute of Technology, Nuclear Physics Program.

R. M. Thaler and J. T. Holdeman, "Optical Theorem as Applied to Charged-Particle Scattering to Yield Total Reaction Cross Sections from Elastic-Scattering Data", Technical Report COO-720-050, Case Institute of Technology, Nuclear Physics Program.

R. M. Thaler and J. T. Holdeman, "Some Remarks on Charged Particle Scattering", Technical Report COO-720-051, Case Institute of Technology, Nuclear Physics Program.

R. M. Thaler and William B. Rolnick, "Relativistic Scattering of Two Equal Mass Charged Particles", Technical Report C00-720-052, Case Institute of Technology, Nuclear Physics Program.

F. A. Blood, Jr., "Pair Correlation Functions in Classical Statistical Mechanics", Technical Report C00-720-053, Case Institute of Technology, Nuclear Physics Program.

R. Scharenberg and W. Tippie, "Measurement of the Gyromagnetic Ratio of the 84 KeV 2^+ State in Ytterbium 170", Technical Report C00-720-054, Case Institute of Technology, Nuclear Physics Program.

R. Fong, "Time Delay for Wave Packets in Non-Relativistic Scattering Theory with Inelastic Channels Present," Technical Report C00-720-055, Case Institute of Technology, Nuclear Physics Program.

R. M. Thaler and C. C. Giamati, "Possible Proton-Alpha Scattering Experiments at 40 MeV", Technical Report C00-720-056, Case Institute of Technology, Nuclear Physics Program.

W. B. Rolnick and R. M. Thaler, "Relativistic Small-Angle Scattering of Two Charged Particles", Technical Report C00-720-057, Case Institute of Technology, Nuclear Physics Program.