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NUCLEAR DATA UNIT

REPORTS TO THE AEC NUCLEAR CROSS SECTIONS ADVISORY GROUP

LAWRENCE RADIATION LABORATORY

October 15-16, 1962



Submitted by JOHN R. STEHN, Secretary NCSAG

BROOKHAVEN NATIONAL LABORATORY

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BROOKHAVEN NATIONAL LABORATORY UPTON, NEW YORK

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INTRODUCTION

The reports which follow were presented to the AEC Nuclear Cross Sections Advisory Group for consideration at the meeting on 15-16 October 1962, at the Lawrence Radiation Laboratory, Livermore, Calif. These reports contain an informal statement of recent developments, changes of emphasis, and preliminary data which are of importance to the cross section measurement program of the AEC. They are not intended to be complete and formal reports, nor do they cover all of the work of the laboratories relating to nuclear cross section measurements.

The data which appear in this report must not be quoted in publications without the express permission of the experimenter. Persons who might make use of these data for serious computations should contact the experimenter directly to verify the numbers.

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1. ARGONNE NATIONAL LABORATORY

A. ACCELERATOR PROGRAM (Physics Division)

Polarization of Neutrons From the Li⁷ (p,n)Be⁷ Reaction A.J. ELWYN, R.O. LANE, A. LANGSDORF, JR.

The polarization of the neutrons emitted at an angle of 99° from the $Li^{7}(p,n)Be^{7}$ reaction has been measured using Mg, Li, and O scatterers as analyzers, at proton energies from 2 to 4 Mev. Preliminary results indicate that the polarization is 0 at 2.0 Mev, rises to a peak of about +35% near 2.2 Mev, drops to 0% near 2.4 Mev, rises slowly to a value of about +32% at 3.0 Mev, and stays approximately constant near this value up to 4.0 Mev. (One may note that these results indicate a source of polarized neutrons of about 80 to 100kev energy.) These results can be compared to the results previously measured at Argonne and elsewhere¹ at a neutron emission angle of 50 and 51°. In this previous work the polarization in the reaction reached a peak of about +57% at 2.2 Mev, dropped to +20% near 2.35 Mev, and rose slowly to a constant value of about +35% from 3.0 to 4.0 Mev. A more careful analysis of the present data is in process.

Polarization of Neutrons Scattered From Zr, Nb, Mo, and Cd A. LANGSDORF, JR., A.J. ELWYN, R.O. LANE

The following is an abstract of a paper to be presented at the Thanksgiving meeting of the American Physical Society, November 1962.

The polarization and differential cross section for neutrons scattered from samples of Zr, Nb, Mo, and Cd were measured at five angles and at about twelve energies in the range 0.275 to 0.85 Mev. The source of polarized neutrons was the Li⁷ (p,n)Be⁷ reaction with the neutrons emitted at 51° with respect to the proton beam. Polarization was measured by determining the differences between the scattered intensity without a magnetic field and the intensity when the neutrons incident on the scatterer were passed through the transverse field of an electromagnet set to precess the spins by 180°. The angular dependence of the polarization at any given energy is usually similar both in sign and magnitude for neutrons scattered from Nb, Mo, and Cd; and this shape changes gradually with energy throughout the region of interest. The results on Zr, however, show that both the sign and the magnitude of the polarization change rapidly as a function of energy. The unpolarized differential cross sections measured simultaneously with the polarization vary smoothly with energy, are similar in shape and magnitude for all four of the nuclei, and are in agreement with our previous measurements.

B. ACCELERATOR PROGRAM (Reactor Division)

1. The Elastic and Inelastic Scattering of Fast Neutrons

A. SMITH, D. REITMANN

As a portion of the continuing program of studies of the differential scattering of fast neutrons from intermediate and heavy nuclei measurements of elastic scattering from U²³⁵, U²³⁸, natural W, and W¹⁸⁴ were completed. Measurements were made at \lesssim 50-kev intervals throughout the incident neutron range 0.3 to 1.5 Mev. The neutron resolution was \lesssim 25 kev. Each angular distribution was measured at ten or more angles. All measured distributions were corrected for multiple scattering and the experimental results expressed in the form

$$(d\sigma/d\Omega) = \frac{\sigma_{\rm el}}{4\pi} \left[1 + \sum_{i=1}^5 W_i P_i \right],$$

where W_i are experimentally determined parameters, P_i are Legendre polynomials, and σ_{el} is the total elastic cross section. The absolute normalization of the measurements was made relative to the elastic scattering cross section of C at each incident neutron energy. The detailed results follow.

a. Natural Tungsten (see Figure 1). The total elastic cross section and the five coefficients of the Legendre expansion of the differential cross section are given. The open data points above 1.3 Mev denote measurements including the first inelastic component (Q = -110 kev). These have been corrected to the elastic contribution only as denoted by triangles. The correction was made assuming isotropy of the inelastic distribution and

¹A. J. Elwyn and R.O. Lane, Nuclear Phys. 31, 78 (1962).

employing inelastic cross section values measured at one angle. All solid data points refer to measurements carried out with sufficient spectrometric resolution to clearly resolve elastically scattered components from inelastic contributions.

b. W^{184} (see Figure 2). The total elastic cross section and the Legendre coefficients for the differential scattering distributions from W^{184} are given. The notation is identical to that utilized in the case of natural W in the above paragraph.

c. U^{238} (see Figure 3). The total elastic cross section and the Legendre coefficients of the angular distributions are shown. As above, solid points refer to measurements clearly resolving elastic from inelastic components. The open circles refer to measurements including the first inelastic component (Q = -45 kev, 2+) while the squares denote the inclusion of the first two inelastic groups (Q = -150 kev, Q = -45 kev). As before, the triangles signify the experimental measurements corrected to represent the elastic contribution only. The correction is based upon the measured respective inelastic cross sections and the assumption of inelastic isotropy.

d. U^{235} (see Figure 4). The total elastic cross section and the Legendre coefficients for the angular distributions are given. Since the first nuclear level in U^{235} is very low (in the order of a few ev) and subsequent structure complex, it is impractical to completely resolve the elastic component from all inelastic contributions. Thus the results shown include inelastic contributions with the elastic scattering in those cases where the Q value of the inelastic process is within the instrumental resolution function. This resolution is velocity dependent and indicated in the figure by the usual triangles.

2. Fast Neutron Activation Cross Section of Th²³² D. STUPEGIA, A. SMI1H, K. HAMM

The fast neutron activation of Th²³² was measured at ~100 kev intervals between 200 and 1.1 Mev. The resulting Th²³³ activity was determined by beta counting a suitably chemically prepared sample. The flux incident on the sample was determined using the U²³⁵ fission cross section. The absolute disintegration rate of the sample was determined with liquid scintillation techniques. The results, tabulated in Table 1, tend to resolve current large discrepancies in the measurement of this cross section (see BNL 325).







NEUTRON ENERGY, MEV

Figure 2. Neutron elastic scattering by W¹⁸¹.



Figure 3. Neutron elastic scattering by U^{238} .



Figure 4. Neutron elastic scattering by U^{235} .

3. Delayed Fission Neutron Emission From Th²³², U²³⁵, and U²³⁸ S.A. Cox

The total delayed neutron yield and its time dependence were studied for Th²³², U²³⁵, and U²³⁸ fission. The fissions were induced by essentially monoenergetic neutrons in the energy ranges 250 to 1500 kev (U^{235}), 1100 to 2400 kev (U^{238}), and 1350 to 1650 kev (Th²³²). For all isotopes no dependence of delayed neutron periods (0.5 to 54-sec groups) on bombarding energy was noted. However, both U²³⁸ and Th²³² exhibited an increase of \approx 20% in total delayed neutron yield at and near the fission threshold. The total delayed neutron yield of U²³⁵ was constant throughout the experimental range. In both U²³⁸ and Th²³² fission, no change in total delayed neutron yield was noted as the incident neutron energy increased once the fission threshold was passed. This consistency was maintained across the sharp resonance structure in the Th²³² fission cross section near 1.6 Mev.

4. Instrumentation

During this period extensive modification to the ion system of the accelerator were completed. The new pulsed source is expected to appreciably increase the nanosecond pulse intensity available.

C. CHOPPER PROGRAM (Physics Division)

1. Fission Cross Section of Th²²⁹ L.M. BOLLINGER

The relative fission cross section of Th²²⁰ has been measured over the energy range 1 to 10⁴ ev. The foil used in the measurement contained about 0.6 mg Th²²⁹. A 15% impurity of Th²²⁸ in the sample caused it to be extremely radioactive, the most bothersome activity being an alpha particle disintegration rate of about 2×10^9 per sec. A gaseous scintillation chamber, with $He + N_2$ as the scintillator, was chosen as the most suitable detector of fission pulses in the presence of the intense alpha activity. With this system, the optimum conditions were those for which the ratio of the pulse height for fission and alpha particles was 45; and the scintillation pulses were shaped to a width of 10 nsec. Under these conditions, fission was detected with about 85% efficiency when the counting rate from the pile-up of alpha particles was adjusted to be about 1/10 count/min.

The counting system described above has been used with the Harwell electron linac to study the

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Neutron Capture Cross Section of Th²³²

Neutron energy, kev	Spread, kev	Capture cross section, mb
191	38	217±15
290	36	183±13
394	36	164 ± 11
482	35	167 ± 11
491	37	193 ± 13
493	36	178±12
493	36	182 ± 12
523	50	180±17
590	36	188±13
684	38	220 ±15
689	39	197 ±14
705	50	210 ± 20
785	32	213 ± 14
791	37	196±13
809	50	180 ± 17
885	38	176 ± 12
887	43	195±13
978	38	165 ± 12
988	38	152 ± 11
1086	39	152 ± 11
1091	39	156±10
1170	43	152 ± 11

energy dependence of the fission cross section of Th²²⁰. Although the counting rate available with the small sample was only about 1/5 count/sec, the much lower rate of background counts made it possible to make a measurement of good quality. Resonances were observed at all of the energies at which Coté et al.² have reported resonances in the total cross section of the same sample of Th²²⁹. In addition, many new resonances were observed at energies >9.5 ev. In contrast to the good agreement with the transmission measurements, the resonances reported by Konakhovich and Pevzner³ in the fission cross section of Th²²⁹ could not be detected. No explanation for this discrepancy has been found. A quantitative treatmert of the data is in progress.

The detection system used for the above measurements at Harwell is now being reassembled at

²R.E. Coté, H. Diamond, and J.E. Gindler, Bull. Am. Phys. Soc. II 5, 417 (1961).

³Y.Y. Konakhovich and M.I. Pevzner, Atomnaya Energ. 8, 47 (1960).

Argonne for use with the fast chopper. The objective is to extend the measurement of the fission cross section into the thermal range of energy.

2. Direct Measurements of Resonant *p*-Wave Capture H.E. JACKSON

Capture gamma-ray spectra have been examined for resonances below 1200 ev in Mo⁹⁵ in order to make unambiguous identification of resonances resulting from the capture of p-wave neutrons. Initial results have already been reported [Phys. Rev. 127, 1687 (1962)]; recently, however, measurements have been made with improved time-of-flight resolution by use of the new Argonne fast chopper 60-meter station. Table 2 shows the absolute intensities of the 8.38 and the 9.16-Mev lines in resonances detected in Mo⁹⁵ below 1600 ev. The 9.16-Mev line corresponds to a transition from the capture state to the ground state of Mo⁹⁶. Spin and parity considerations prevent measurable values for this intensity unless the capture state is 1⁻. The intensities of the 8.38-Mev line have been used to calculate the reduced width under the assumption that the transition is magnetic dipole. The values obtained are then compared with the recent compilation of Bartholomew [Ann. Rev. Nuclear Sci. 11, 259 (1961)]. Because of fluctuations in partial widths, the strengths of E1and M1 transitions show a considerable overlap in the region of atomic masses of interest here. Consequently, the presence of a primary transition to the first excited state is not conclusive evidence of p-wave capture. Only transitions with reduced

widths much too large to be consistent with M1radiation give an unam. 'guous indication of pwave capture. The presence of ground-state transitions in the spectra of resonances at 107 and 1010 ev indicate p-wave capture forming a 1⁻ state. In addition, very large reduced widths for resonances at 215 and 330 ev indicate that they result from p-wave capture. Transmission measurements, contingent upon the availability of the separated isotope Mo⁹⁵, are planned in the near future in an effort to determine the radiation widths of these resonances.

The Total Cross Section of Cm²⁴⁴ R.E. Coté, H. DIAMOND, R.A. BARNES, J.R. PATTERSON

In a continuing effort to extend nuclear systematics through the study of heavy nuclides, the total cross section of a sample of Cm has been measured with the fast chopper. The sample contained \approx 41.4 mg Cm, the isotopic composition of which was 96.50% Cm²⁴¹, 1.60% Cm²⁴⁵, 1.87% Cm²⁴⁶, 0.022% Cm²⁴⁷, and $\leq 0.0044\%$ Cm²⁴⁸. The experimental work performed with flight paths of 25 and 60 m has been completed as has a large part of the analysis. However, at this time it is convenient to report only the energies at which resonances have been observed. The remaining parameters shall be reported when the analysis has been completed. There are resonances at 4.33, 7.73, 16.8, 22.7, 35, 52.8, 66.5, 69.9, 85.9, 96.3, 133, 172, 181, 197, 209.5, 221, 231, 263, 272.6, 360, 419, 443, 514, 645, and 770 ev.

Parameters for Resonances in Mo ²⁵						
D	Absolute intensity	(photons per capture)	k ₁₁ , Mev ⁻³			
energy, ev	$E_{\gamma} = 8.38 \text{ Mev}$	$E_{\gamma} = 9.15 \text{ Mev}$	$E_{\gamma} = 8.38 \text{ Mev}$	$g\Gamma_n^{i}$, 10 ⁻³ ev		
45	0.006±0.001	0.0000±0.0005	0.09×10-1	13.1 ±0.8°		
107	0.019 ± 0.004	0.041 ±0.008		0.010±0.006 ^b		
160	0.014 ± 0.003	0.000 ± 0.001	0.19×10-1	$0.55 \pm 0.10^{\circ}$		
215	0.052 ± 0.010	0.000 ± 0.002	0.74×10-1	0.08 ± 0.04^{h}		
330	0.086 ± 0.016	0.000 ± 0.002	1.19×10-1	_		
345	0.018 ± 0.003	0.000 ± 0.001	0.25×10^{-1}			
570	0.004 ± 0.001	0.000 ± 0.001	0.05×10^{-1}			
1010	0.002 ± 0.002	$>0.012 \pm 0.002$				

Table 2

^aBrookhaven National Laboratory Report BNL 325, U.S. Government Printing Office, Washington, D.C. (1955). ^bJ.P. Marion (private communication, 1962). These values were calculated by assuming *s*-wave capture.



Figure 5, Total cross section of selenium.

4. Angular Correlation of Gamma Rays Following the Capture of Thermal Neutrons by Ni⁵⁸ and Ni⁶⁰ R.E. COTÉ, H.E. JACKSON, JR., L.L. LEE, JR., J.P. SCHIFFER

The following is an abstract of a paper to be presented at the Thanksgiving meeting of the American Physical Society, November 1962.

Recent disagreements in the interpretation of (d, p)reaction spectra^a have indicated the need for accurate determinations of the spins of the states in question. In an effort to determine the spins of several low-lying states in Ni⁵⁹ and Ni⁴¹, we have measured the angular correlation of cascade gamma rays following thermal neutron capture in Ni⁵⁸ and Ni⁶⁰. From the (d, p) reaction work, these states are known to have odd parity and spins of either 1 or 3. Data obtained with three NaI(Tl) crystals were studied with the Argonne three-parameter analyzer.^b The correlations are believed to be accurate to about 2%. The isotropy of the correlations measured for the cascades through the 466-kev state in Ni59 and the 284-kev state in Ni^{α 1} indicates spin $\frac{1}{2}$ for these states. For the 880-kev state in Ni⁵⁹, a 30% anisotropy was obtained. This state must therefore have spin 3. All of these states were assigned spin $\frac{1}{2}$ by Cohen et al.

5. A Boron-Loaded Liquid Scintillation Neutron Detector Mounted on a Single Photomultiplier

G.E. THOMAS

Boron-loaded liquid scintillation neutron detectors have been successfully used for almost ten years with the Argonne fast chopper. Recent advances in photomultiplier tube design have now made possible great simplifications in the use of these scintillators. Because of these advances, the need for a fast coincidence between two phototubes viewing the same volume of scintillator is no longer required. No change has been made in the liquid scintillator itself, but cells containing the scintillator are mounted directly to the front faces of single 5-in. E.M.I. type 9579A tubes. A bank of three to six of these detectors is now the standard detector for transmission measurements with the fast chopper. A paper that describes these detectors will appear in the October issue of Nuclear Instr. & Methods.

6. The Neutron Resonances of Selenium R.E. Coté, J.P. Marion, L.M. Bollinger

The analysis of our data on Se is just about finished. The results are summarized in Table 3 and Figure 5.

^aB.L. Cohen, R.H. Fulmer, and A.L. McCarthy, *Phys. Rev.* **126**, 698 (1962); J.P. Schiffer, L.L. Lee, Jr., and B. Zeidman, *Phys. Rev.* **115**, 427 (1959).

^bC.C. Rockwood and M.G. Strauss, *Rev. Sci. Instr.* 32, 1211 (1961).

Table 3

Resonance Parameters of Scientum

E _a , ev	Isotope	J	σ _{at} b	l', ev	1'n, ev	l' ₉₁ ev	Γ _n ×10 ¹ , ev
27	74		Nots	tudied in this seri	es of measurements		
113*	77×	14	65 ± -20	0.4 ±0.1	$(1.5 \pm 0.2) \times 10^{-6}$	0.4 土0.1	0.14± 0.02
127 ^{n.b}	78 or 80*						
150 ^{a.b}	77×						
175***	77×					0.4*	105 土15
209	77	()"	2450 ± 950	1.92 ± 0.5	1.52 ± 0.2	0.4°	256 ± 50
270	74		8800±3800	4.6 ±1.1	4.2 ±0.8	0.4°	0.86± 0.12
290	77	14	250 ± 50	0.4 ±0.1	(1.47 土0.2)×10 **	0.41 ± 0.15	7.0 土 1.1
340	77	1#	1350± 540	0.54 土0.13	0.13 ± 0.02	0.4"	16.5 ± 8
376	76×		3000 ± 600	0.72 ±0.15	0.32 ± 0.15	0.4°	16.5 ± 8
381	78		3050 ± 600	0.72 ±0.15	0.32 ± 0.15	0.4"	0.3 ± 0.15
442"	77*	li -	43 土 20	0.406±0.1	0.006±0.003	0.4"	0.46± 0.05
485"	77 *	14	97士 10	0.41 ± 0.1	0.01 ±0.001	0.54 ± 0.5	90 ± 10
685	77	01	770土 230	2.9 ± 0.6	2.36 土0.24		
858	76 and 77*		Nots	tudied in this ser	ies of measurements	0.4"	172 ±20
987	77	l q	1840出 50	5.8 ± 0.6	5.4 ±:0.6		
1014	1					0.27 ± 0.4	32 ± 3
1256	77	ta	1260 ± 390	1.40 ±0.24	1.13 ± 0.16		
1462	+						24 ± 6
1480)	77	į a	870± 500	1.38 ± 0.48	0.91 ± 0.23		
1677	1						
1726	(77) ^{#.1}						
1963	80		Not a	tudied in this ser	ies of measurements		

"Resonance not reported before.

^bThese resonances were not observed in the total cross section measurements. However, their existence, based on the capture γ -ray measurements, is certain.

 $\Gamma_{y} = 0.4$ ev assumed.

^dSpin assignment made on the basis of the observation of *E*1 transitions to the ground or first excited state of the compound nuclide,

"Spin assigned on the basis of total cross section analysis.

¹Spin taken from Saclay data [Julien, Corge, Huynh, Morgenstern, and Netter, *Bull. Am. Phys. Soc.* 7, 288 (1962)]. *Isotopic assignment based on relative values of the binding energy as shown in capture γ -ray coincidence spectra. ^b $g=\frac{1}{2}$ assumed.

¹The isotopic assignment of these resonances cannot be made with certainty. Values of $ag\Gamma_n$, where a is the isotopic fraction, are 0.6×10^{-2} , 1.42×10^{-2} , and 5.1×10^{-2} for the resonances at 1014, 1677, and 1726, respectively.

¹The analysis of this resonance includes the effects of that resonance at 1462 ev.

^kThere is an indication of resonances at 354, 915, and 1360 ev. These appear in the total cross section measurements; but, because of the poorer resolution in the γ -ray measurements, it is not possible to verify their existence.

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2. BROOKHAVEN NATIONAL LABORATORY

A. BNL HIGH FLUX BEAM RESEARCH REACTOR T.V. SHEEHAN

The containment building, consisting of a 176ft-diam-steel cylinder, 23 ft high, surmounted by a 88-ft radius hemisphere, is complete. Inside the building, the main concrete foundations, together with all buried piping, most of the equipment floor, the columns for the experimental floor, and the shielded equipment rooms, are complete. The canal, except for surface chipping, is complete. The framework and reinforcing, as well as all buried piping on the experimental floor, are about ready for start of concrete placement. All major subcontracts are placed. Major equipment is either at the site, ready for shipment, or under manufacture.

B. NUCLEAR ORIENTATION V.L. SAILOR, G. BRUNHART, H. MARSHAK,* H. POSTMA,** C.A. REYNOLDS,† R.I. Schermer, F.J. Shore††

Transmission effects for polarized monochromatic neutron beams and polarized nuclei were measured for Li^a, B^{1o}, Se^{1b}, V^{b1} (H. Marshak), and Co^{ao} (R.I. Schermer) in the energy region of ~ 0.1 ev and at higher energies. Large effects were observed which will yield the fraction of the low energy cross section for each spin state. The analysis is incomplete.

Several resonances in Tb^{159} were studied and the g value for each was determined. Data were completed for obtaining the hyperfine splitting in metallic Tb, but final results have not been completed. Data were also obtained on a single crystal of Ho which will permit comparison of the magnetic structure of Ho with various models.⁴

The second order contamination of the monochromatic beam obtained from Bragg reflection from a 92% Co-8% Fe crystal has been measured.

C. DOPPLER BROADENING OF THE 4.14-EV RESONANCE IN W¹⁸⁴ BROTHER AUSTIN BERNABEI

Detailed studies on the Doppler broadening of the 4.14-ev resonance ($W^{(*)}$) in metallic W have been made at room temperature, 77°, and 4.23°K. Additional measurements at higher temperatures are planned. The measurements are expected to provide information about the effects of lattice binding on the Doppler broadening of resonances.

D. SLOW CHOPPER K. Otnes, K. Ogawa, H. Muether, H. Palevsky, B. Mozer

The modified slow chopper time-of-flight spectrometer is now operating in a routine fashion. Experiments are being carried out on mixed crystals of NH₄I-KI in order to determine the effect of nearest-neighbor NH₄ ions on the rotational characteristics of the NH₄ ion in the body-centered configuration. These measurements are being carried out as a function of temperature from liquid nitrogen up to $\approx 500^{\circ}$ K.

A series of measurements on the effect of small quantities of Ni in Pd are being carried out with the purpose of trying to identify high frequency localized modes which are expected from general theoretical considerations. These localized modes have been the subject of a great many theoretical papers in the last few years with very little experimental justification. The cold neutron experiments have shown that these modes do exist and further work with this system and other alloys is being carried out.

A good bit of the effort in the group is going towards the design and construction of the new cold neutron facility for the Brookhaven High Flux Beam Reactor. The general design features were established about one year ago and a good bit of construction is now under way in the shops. The system that is being built is a three-rotor monochromating time-of-flight apparatus consisting of one rotor spinning around a vertical axis and two rotors on horizontal axes. The rotors are driven synchronously and are operated with a constant

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^oThe Ho single crystal was kindly loaned to us by Drs. S. Legvold and F.H. Spedding of the Institute for Atomic Research, Iowa State University.

phase difference between the slits. At the present time the vertical rotor, which is the most complex element of the system, is nearing completion in the shop. Models of the horizontal rotors have been spun to verify engineering calculations and have proved that the original design concept was conservative. It is hoped that the entire equipment will be completed by January 1, 1964, in time for installation when the new reactor will be finished.

E. FAST CHOPPER J.A. Moore, A.P. Jain, W. Lee, R.E. Chrien, H. Palevsky

During the second quarter of this year the fast chopper has been used to study capture γ -rays from Fe and Zr, with emphasis on the possibility of establishing the parity of the capturing state by studying the capture γ -ray spectrum.

Unfortunately, the protracted shutdown of the NRU reactor at Chalk River (lasting from late July to the present) has delayed completion of the capture γ -ray studies.

Data thus far taken on Zr suggest that the following resonances are due to *p*-wave neutron capture in Zr^{p_1} : $E_o = 238$ ev and $E_o = 420$ ev. Several resonances at higher energies also show strong high-energy transitions. Since the parities of the low-lying states of Zr^{p_2} are even, and *s*-wave capture in Zr^{p_1} leads to even-parity states, *s*-wave neutron resonances are not expected to show strong high-energy transitions.

Self-indication measurements yield a preliminary value for Γ_{μ}^{0} of $1.2\pm0.6\times10^{-3}$ ev for the 1167-ev resonance in Fe⁵⁶. The radiation from this level has been compared to thermal capture γ -rays from Fe. Both show strong ground-state transitions; however, there is some difference in strengths for the other high energy y-rays. The isotopic identification of the 1167-ev resonance was established with the aid of self-indication experiments with a sample enriched in Fe⁵⁷, and from the examination of the γ -ray spectrum of this resonance. The fast chopper at Brookhaven has been used to examine the total cross section of Fe from 1 ev to 10 kev. An effort will be made to fit these data assuming that a negative energy resonance is responsible for the shape of the cross section in this energy region.

A preliminary run on Y with the capture γ -ray spectrometer has revealed the apparent presence

of a neutron resonance near 19.5 ev not previously reported.

For further resonance capture γ -ray work a large 6×8 -in. NaI crystal has been purchased and is being tested. The feasibility of coincidence work with this crystal in conjunction with the 3×3 -in. crystals already in use is being studied.

F. SIGMA CENTER

1. Reactor Cross Section Evaluation Group C.E. Porter, T.J. Krieger, S.O. Moore, E.H. Auerbach, N. Ullah

Newsletter No. 6 was issued in June, 1962 (BNL 732).

A digital computing machine program is now operating to diagonalize randomly chosen matrices of various orders. The eigenvalues of these matrices can be thought of as the energy levels of particular families of quantum systems The nearest-neighbor spacings of the eigenvalues are found to have distributions remarkably similar to those observed for nuclear levels. The distributions of next-nearest-neighbor spacings, of next-nextnearest-neighbor spacings, etc., are computed by the program.

The ABACUS program for optical model computations of cross sections has been used in a novel application to compute the scattering of slow electrons by Ar atoms. The theory seems capable of yielding qualitative agreement with the experimental Ramsauer resonance, which is analogous to the "Barschall" size resonances of neutronnucleus scattering. An imaginary part to the potential has been introduced, and its effects are being explored.

2. Neutron Cross Section Compilation Group J.R. STEHN, M.D. GOLDBERG, B.A. MAGURNO

The graphs for the revised version of BNL 400, "Neutron Cross Sections – Angular Distributions," are completed. Textual and reference material is well along toward completion, and publication is hoped for in February.

Serious consideration is being given to preparing duplicate storage on magnetic tape of all the separate items of cross section data in the Sigma Center files. Advantages foreseen are flexibility, ease of access, and automatic presentation of desired data. A program is being prepared to use the IBM 7090 computer as a searching device.

3. CASE INSTITUTE OF TECHNOLOGY

A. ANGULAR CORRELATION IN THE B¹¹(d,nγ 15.11 Mev)C¹²* REACTION H.J. KIM, E.F. SHRADER

It has been indicated by W. Tobocman and others that the distorted wave treatment of stripping reactions may show its effects more sensitively in the analysis of nucleon γ -ray angular correlation than in the angular distribution of the stripped nucleon. The reaction $B^{11}(d,n\gamma \ 15.11$ Mev)O¹² is a particularly well suited reaction to study the distortion effect since the angular distribution of neutrons feeding 15.11 Mev 1 (+) state shows remarkably good agreement with the Butler stripping pattern while the other neutron groups of the reaction $B^{11}(d,n)C^{12*}$ show rather poor fits.⁵

The neutrons feeding the 1 (+) 15.11-Mev state of C¹² are detected in coincidence with the 15.11-Mev de-excitation γ -ray directions of 11° and 90° relative to the incident deuterons of 2.59 and 2.29 Mev. A pulsed beam of incident deuterons was used with pulses which were <2ns in duration. The neutrons were observed by the time-of-flight method in coincidence with the associated 15.11-Mev pulse height selected γ -ray. The accidental coincidence rate from nonassociated events was determined concurrently by observing delayed coincidences arising from events occurring in consecutive beam pulses.

The result of the $n-\gamma$ correlation shows marked departure from the plane wave, Butler theory.

B. THE C¹³(d,n)N¹⁴* REACTION E.F. Shrader, R.L. ZIMMERMAN

By using the neutron time-of-flight technique and a nanosecond-pulsed Van de Graaff the angular distribution of neutrons from the $C^{13}(d,n)N^{14}$ reaction have been measured at deuteron energies of 1.685, 2.198, and 2.70 Mev. Neutron energy groups leading to the ground state and the first eight excited states of N¹⁴ have been resolved. The low Q reactions can be fitted reasonably well by the Butler plane wave approximation permitting an l value assignment to be made. Previously observed⁶ l=1 and 0 stripping patterns for the 3.945 and 4.91 Mev states respectively were confirmed. For the reactions leading to the 5.10, 5.69, 5.83, and 6.23-Mev states of N¹⁴ the *l* assignments are 1, 2, 2, and 1 respectively. The assignment of the 5.69-Mev state is in agreement with that of Warburton and Pinkston.⁷ The reactions involving the ground state and the 2.31 and 3.94-Mev states show appreciable backward peaking in the neutron angular distributions. The cross sections for all exit channels including the 6.23-Mev state are comparable except that for the 2.31-Mev state which is only 25% of the ground state reaction.

C. NEUTRON TOTAL CROSS SECTIONS L.A. GALLOWAY

Neutrons from a (d,n) reaction have been used to measure neutron total cross sections. Time-offlight techniques were used to identify neutron energy groups.

For the $C^{13}(d,n)$ reaction, C^{13} was purchased in the form of methyl iodide at 55% enrichment. Targets of C¹³ were prepared by cracking the CH₃I vapor on a Ta backing heated under vacuum. These targets were bombarded by 1.7-Mev deuterons giving neutron groups of 1.85, 2.02, 3.02, 4.64, and 6.88 Mev at 30° to the incident beam. The cross sections of Mg, Al, Ca, and V were measured at these neutron energies. The 4.64-Mev group was of lower yield than the other groups and the presence of a d,d neutron of about 4.4 Mev at 30° made the determination of neutrons under its peak somewhat complicated. Except for the 4.4 and 4.64-Mev groups the time-of-flight system successfully separated all groups of neutrons and made possible the observation of systematic background fluctuations which were important.

The measured cross sections were (in barns):

	1.85 Mev	2.02 Mev	3.02 Mev	4.64 Mev	6.88 Mev
Mg	2.92 ± 0.02	2.18 ± 0.02	2.01 ± 0.01	$2.11{\pm}0.03$	2.12 ± 0.03
Al	2.38 ± 0.02	3.44 ± 0.03	$2.46{\pm}0.02$	2.10 ± 0.04	1.80 ± 0.05
Ca	2.84 ± 0.03	2.58 ± 0.04	3.98 ± 0.04	3.45 ± 0.06	2.80 ± 0.06
V	3.62 ± 0.02	3.64 ± 0.02	3.83 ± 0.02	3.61 ± 0.04	3.19 ± 0.04

^aR.E. Benenson, Phys. Rev. 90, 420 (1953).

⁵H.J. Kim, D.A. Brand, and E.F. Shrader, Bull. Am. Phys. Soc., Sec. 11, 7, 60 (1962).

⁷E.K. Warburton and W.T. Pinkston, Phys. Rev. 118,733 (1960).

The $\text{Li}^7(d,n)$ reaction has been studied for possible use as a neutron source in these measurements. At the writing of this report the systematic variation of background has not been determined for this "white" spectrum of neutrons. It has been shown that this systematic behavior of background is important and must either be eliminated with a γ -ray insensitive detector or its magnitude must be determined. If neither of these procedures can be employed the $\text{Li}^7(d,n)$ reaction will not prove useful for these measurements.

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D. INELASTIC SCATTERING CALCULATIONS V. Madsen, W. Tobocman, H. Volkin

The distorted wave Born approximation treatment for direct interactions is being used to study inelastic scattering interactions. A calculation has been programmed for the NASA IBM 7090 computer. Our object is to try to use the direct interaction analysis as a probe to determine the structure of the various excited states that occur in inelastic scattering reactions.



4. COLUMBIA UNIVERSITY

A. NEUTRON PHYSICS

Nevis Synchrocyclotron Neutron Velocity Spectrometer J. RAINWATER, J.B. GARG, J. SCHIELLERUP-PETERSEN, A. BLAKE, W.W. HAVENS, JR.

All the data taken on the six-week run during January and February 1962 have been reduced and plotted as cross section *vs* energy. Two reports presenting the data arc being prepared. The first report will include the data on elements with widely spaced levels (Fe, Co, Zn, V, Ti, Cu, Ni, F, Al, and Bi) in the energy interval up to 200 kev. The second report will contain results of the neutron total cross section measurements for elements having closely spaced levels (Th, Ag, Ta, I, Br, Cs, Pr, and Tm) up to 4 kev.

An IBM 1620 program has been written to analyze the level-spacing distributions, and some interesting effects have been observed. However, more complete analysis and checks on the analysis must be made before results will be reported.

A computer program has been written for the determination of the resonance parameters, and analysis of the Th resonances is proceeding smoothly.

A series of measurements has been made to determine the source of the detector background in the neutron velocity spectrometer. The background was found to come from the concrete of the tunnel surrounding the detector. Shielding the detector with Pb decreases the background by at least an order of magnitude. A detector housing with ample shielding is being designed to take advantage of this possible decrease in background.

2. Ternary Fission of U²³⁵ in the Resonance Energy Region G.K. MEHTA, E. MELKONIAN

The measurements in the resonance region of the variation with neutron energy of the ratio of yield of fission fragments to that of ternary α particles have been analyzed. The results in the energy region 8 to 60 ev cluster into two groups indicating a possible correlation with the *J*-values of the resonance levels, but there was only a small correlation with the ratios of asymmetric to symmetric fission measured in the "bomb" experiment by Cowan et al. There have been no new runs at Nevis. During the next run we expect to repeat the measurements to obtain more accurate results and also to investigate whether the observed variations could arise from other causes, such as variations in the average α energy and/or the fission fragment energy.

Mass Distribution of Fission Fragments by Simultaneous Energy and Time-of-Flight Measurements M. DERENGOWSKI, E. MELKONIAN

An experiment is being set up to measure simultaneously the energy and velocity of fission fragments in thermal neutron fission so as to obtain directly the mass distribution after neutron emission. A simultaneous measurement of the energy of the other fragment will also be made. It may then be possible to get a complete picture of the masses before and after neutron emission as a function of fragment energies.

The above measurements as well as the determination of mass distributions in fission in the resonance region require the recording of two or three coincident parameters. Since the count rates rarely exceed a few per second, punching the information on paper tape is sufficiently rapid. A three parameter data acquisition system is on order with RIDL. Three pulse heights (1000 channels each), or two pulse heights and one time-offlight (100,000 channels), may be recorded. Triple coincidence logic, internal amplifiers, and other features are included. Totalizing of the results will be performed on one or more of the available computers.

4. Thermal Neutron Fission of U²³⁵ With Emission of Long Range α Particles I. SCHRODER, J.A. MOORE, A.J. DERUYTTER

The ratio of binary to ternary fission in U^{235} for neutrons in the thermal region has been studied using solid state detectors. This ratio has been measured not only for pile neutrons with radically different Cd ratios, but also measured at 0.003, 0.0253, 0.08, and 0.3 ev respectively, using the Columbia Crystal Spectrometer at Brookhaven National Laboratory. No difference in this ratio has been observed in these measurements. At present an absolute measurement is being performed to normalize the data.

Single fragment kinetic energy and total kinetic energy distributions of the fission fragment associated with the emission of long-range α particles in the thermal neutron fission of U²³⁰ are continuing.

A study of the energy distribution of the longrange α particles in the thermal neutron fission of U^{230} which are emitted at small angles with respect to the light fission fragments is under study.

5. Emission of Prompt γ Roys in the Thermal Fission of U²³⁵

A.J. DERUYTTER, J.A. MOORE, I. SCHRODER

The prompt γ rays emitted in the thermal fission of U²³⁵ are being studied with a coincidence crystal spectrometer. This study measures the energy distribution of the prompt γ rays below 1 Mev. The dependence of the energy distribution of the γ rays on the total energy of the related fission fragments and the relation between the structure observed in the γ -ray distribution and the masses of the coincident fission fragments will be determined.

6. Measurement of the Half-Life of U²³⁵ A. DERUYTTER, I. SCHRODER, J.A. MOORE

Solid state detectors have been used to perform an accurate measurement of the alpha spectrum of natural U. The half-life of U^{235} will be determined from a comparison of the activity of U^{235} to that of U^{238} and U^{234} respectively.

7. Studies of Liquids and Solids by Inelastic Neutron Scattering G. J. SAFFORD

In cooperation with the members of the Physics Dept. of the Brookhaven National Laboratory, experiments are in progress to study atomic motion in liquids and solids. Three abstracts on this work have been submitted to the Seattle Meeting of the American Physical Society: "A study of the liquid and solid phases of HF, HCl, and HBr by neutron inelastic scattering," H. Boutin, G. J. Safford, and V. Brajovic; "An investigation of the energy levels in alkaline hydroxide by inelastic scattering of slow neutrons," G. J. Safford, V. Brajovic, and H. Boutin; "A study of rotational freedom in several ammonium salts by slow neutron inelastic scattering," V. Brajovic, H. Boutin, G. J. Safford, and H. Palevsky.

8. n-p Total Cross Section J. LEBOWITZ, C. ENGELKE

Because of unexplained fluctuations in earlier data on the n-p total cross section at 3.2 MeV, the measurements have been repeated and the data are now being analyzed.

Study of Neutron Polarization in the B¹¹(d,nγ)C¹² Reaction

M. COPPOLA, A. SAYRES

An apparatus to study the polarization of neutrons leading to the first excited state of C^{12} is under development. Results on the neutron angular distributions [J.B. Garg, et al., *Nuclear Phys.* 23, 630 (1961)] show that the reaction mechanism cannot be explained satisfactorily by simple direct interaction theory. The experimental apparatus consists of a liquid He neutron scatterer and a fast neutron time-of-flight spectrometer, using neutron-gamma pulse-shape discrimination. Tests of coincidence systems using these components are being made.

10. Elastic Scattering of Neutrons by Oxygen A. SAYRES

Further analysis of data reported elsewhere [Bull. Am. Phys. Soc., Ser. II, 6, 237 (1961)] indicate that the accuracy of the $O^{16}(n,n)$ cross section deduced from the recoil spectra is limited by the necessity of combining data from CO_2 , CH_4 , and C_3H_8 runs.

A gridded ion chamber has been arranged with an alpha source to test the performance of the chamber with various gas fillings at various pressures. At a low pressure filling of oxygen it is expected that a sufficient number of electrons will be collected on the collector plate to give satisfactory energy resolution. Using pure oxygen as a filling will enable data to be accumulated more rapidly and with better accuracy than that previously obtained.

11. He³ Neutron Spectrometer

D. LIGHTBODY, D. LISTER, M. AMORUSO, A. SAYRES

The liquid He scintillator was tested for light collection stability, using a Po^{210} alpha source and quaterphenyl wavelength shifter. The full width at half maximum resolution was 26%. The pulse height gradually decreased slightly, probably as a result of a gradual lowering of temperature of the photomultiplier tube. After 2 hr the pulse height was stable with time. A 3-in.-diam proportional counter (used for n-O¹⁰ elastic scattering studies) was filled (1 atmos He⁴+4 atmos Kr) giving 5% resolution for thermal neutrons for He³(n, p)T reaction and 6% at $E_n = 3$ Mev where part of width is due to target thickness. This counter and a similar counter (4-in.-diam) will be used for elastic scattering studies.

B. CHARGED PARTICLE RESEARCH

1. Van de Graaff Operation A. SAYRES, P. OSMON, L.J. LIDOFSKY

The Van de Graaff has operated satisfactorily for about 2000 hr during this period using the original rf terminal. A new pulse terminal was received from High Voltage Engineering Corp. but has not as yet been installed.

2. New 90° Reflecting Magnet L.J. LIDOFSKY, H. DOWDS, L. ROTHMAN

The new mass product 28 deflecting magnet was tested at Harvey Wells and passed specification tests satisfactorily. The magnet was disassembled and has been received at Columbia. A new base has been installed on the basement level of the Pegram Laboratory and the magnet will be set up there.

3. Deuteron Stripping

R. WEINBERG, R. HOROSHKO, P. OSMON, L.J. LIDOFSKY

The angular distributions of protons from the $Mg^{25}(d,p)$ reaction have been measured at ≈ 18 angles and deuteron energies from 2.5 to 5.2 Mev. The thin NaI(Tl) detector used was able to resolve the ground state proton group as well as groups corresponding to transitions to the 1st four excited states. $O^{16}(d, p)$ and $C^{12}(d, p)$ groups from contaminants were also resolved. The characteristic resonances of $C^{12}(d, p)$ were observed. These data are now being transferred from punched tape to cards prior to analysis into cross sections using a Los Alamos least squares program.

4. Deuteron Elastic Scattering

R. WEINBERG, R. HOROSHKO, P. OSMON, L.J. LIDOFSKY

The angular distribution of deuterons from $Mg^{25}(d,d)$ as well as from contaminant $O^{16}(d,d)$ and $C^{12}(d,d)$ has been measured at ≈ 18 angles and energies from 3 to 5.2 Mev. A surface barrier detector was used and could clearly resolve the Mg^{25} elastic deuteron group into angles greater than $\sim 60^{\circ}$. These data are also being transferred

to punched cards for further analysis. It is planned to use these data together with data from Mg²⁶ (p, p) and Mg²⁵(d, p) in a distorted wave analysis of the Mg²⁵(d, p) reactions.

5. Beta Spectrum of N¹² and B¹² C.S. Wu, Y.K. LEE, LUKE MO

The large electron spectrometer has been modified and used to measure the β^- spectrum of B¹² and the β^+ spectrum of N¹². A chopped beam with synchronous detection was used to minimize background. A thin detector was used to reduce possible uncertainties in the counter efficiency as a function of background. Anti-scattering baffles and low-Z coatings of baffles were used to minimize scattering effects. After data reduction, the shapes of the spectra will be compared with those predicted by the conserved vector current theory of beta decay.

6. Internal Conversion Electrons From O¹⁶ (6.06) State

C.S. WU, Y.K. LEE, LUKE MO

Improvement in the detector resolution of the large electron spectrometer has enabled the observation of internal conversion of electrons from the EO transition between the O^+ 1st excited state and the ground state of O^{16} . The observed intensity agrees closely with theory.

7. Inelastic Scattering of Protons From N¹⁴ C. NISSIM-SABAT, E. BOGART, M. TATCHER, S. DEVONS

A search was made for a possible state in N¹¹ near the well known 2.3-Mev, T=1, 1st excited state which might bear on certain anomalies privately reported in the C¹³(d,n) and B¹¹(α,n) reactions to this region of excitation. The double focusing magnet spectrometer was used at 9-kev resolution to study N¹⁴(p, p'). No inelastic scattering group corresponding to any other state within 100 kev of the 1st excited state was seen.

8. Angular Correlations in S³²(d,p) J. SILVERSTEIN, T. KRUSE

Tests of counting rates and targets are being made prior to the study of this reaction.

9. Proton Elastic Scattering R. WEINBERG, G. MITCHELL, L.J. LIDOFSKY

The elastic scattering of 13-Mev protons from Mg²⁶ has been observed at large angles using the

external cyclotron beam. This run was interrupted by failure of the surface barrier detector. It is being repeated at several energies between 11 and 15 Mev and at angles from 10° to 150°. An optical model program for analysis of the data has been tested using 18-Mev data reported at Princeton. The final results will be used in the distorted wave

analysis of $Mg^{25}(d,p)$. $Mg^{26}(p,p')$ was also observed in three preliminary runs. An analysis of data on the inelastic scattering is planned using a collective model description of Mg^{26} .

(p,γ) Studies in Light and Medium Weight Elements L. FELDMAN, M. NESSIN, B. BALIGA

The yield of gamma rays from transitions to the ground state and to the first excited state following

proton capture has now been determined for proton bombarding energies 10 to 11 Mev and 12 to 14.5 Mev for a number of elements. Observations have been made in steps of ≈ 100 kev throughout these energy regions. Measurements in the 11 to 12-Mev region are now beginning.

Hyperfine Structure of O¹⁵ H. FELDMAN (Columbia Radiation Lab.), F. MORRISON

Transitions observed between states of O¹⁵ using atomic beam techniques have now been observed at a number of magnetic fields. The indicated magnetic moment of O¹⁵ from these measurements support the (tentative) value of $\mu = 0.718$ Bohr magnetons reported in the last report to the NCSAG.

5. DUKE UNIVERSITY

A. NEUTRON PHYSICS

Resonance Cross Section Measurements With Continuous Beam FARRELL, BEARD, PARKS, BILPUCH, NEWSON

We are in the process of obtaining Ca¹², Ca¹⁴, Cr⁵⁰, Ni⁵⁸, Ni⁶⁰, Ni⁶², Ni⁶⁴, and Zn⁶⁵ from the Cross Section Pool. The neutron total cross sections of these isotopes will be measured in the energy range 50 kev $\langle E_n \langle 700 \text{ kev} \rangle$. The results will be used in further studies of level densities and isotopic spin.

2. Average Total Neutron Cross Sections TABONY, SETH, BILPUCH, NEWSON

Since the last report several more thin samples have been analyzed by the parameter fitting program (Nd, Gd, Er, La, Ir). The analysis of thicker samples is now in progress and takes into account both interference and Doppler broadening effects.

A calculation of the Doppler integrals

$$4(x,t) = 1\sqrt{4\pi t} \int_{-\infty}^{\infty} 1/(1+y^2) \exp[((x-y)^2/4t]] dy$$

and

$$\phi(x,t) = 1/\sqrt{4\pi t} \int_{-\infty}^{\infty} y/(1+y^2) \exp[(x-y)^2/4t] dy$$

has been performed for values of t ranging from 0.25 to 10,000. For each value of t the integrals were calculated for 400 values of x.

3. Capture Cross Sections FURR, ROHRER, NEWSON

Part III of our series (Neutron Capture Cross Sections in the kev Region) is nearly ready for publication.

4. Thin Targets for Production of Neutrons BEARD, PARKS, FARRELL, BILPUCH, NEWSON

In the last report we showed the results of our threshold measurements on the B¹¹(p,n)C¹¹ reaction using BF₃ gas in the cryostat. We are now repeating these measurements on the 3-Mev Van de Graaff where our beam resolution can be made ~ 1 part in 20,000. We hope to be able to use this reaction to produce neutrons for high resolution total cross section measurements.

Neutron Total Cross Sections With Pulsed Beam Inactive.

6. Neutron Polarization Measurements R.L. WALTER, J.R. SAWERS, F.O. PURSER

An apparatus is being prepared to measure the polarization of neutrons produced in several reactions. Scattering from He will be used as the polarization analyzer. Present plans are to construct a He gas scintillator similar to the one which was used successfully at Wisconsin.8 In order to reduce background, a fast coincidence will be required between the He-recoil pulses and pulses in the neutron detectors. The first reactions to be studied will be T(p, n)He³ and $C^{12}(d, n)$ N¹³. Information concerning the first reaction will be of value for the current study regarding a virtual state of the α particle.⁹ Knowledge of the polarization produced in this reaction for proton energies below 3 Mev will aid in the determination of the T(p,n) reaction mechanism and the interaction parameters. As the earlier experiments of Haeberli and Rolland¹⁰ indicate, the $C^{12}(d,n)N^{13}$ reaction might prove to be the best source of partiallypolarized low-energy neutrons. In addition, very little experimental data has been obtained on the polarization of neutrons produced in stripping reactions. Results for the $C^{12}(d,n)$ reactions are of interest from this viewpoint also. Therefore, a thorough polarization study of this reaction should be carried out.

7. Elastic and Inelastic Neutron Scattering by Time-of-Flight BUCCINO, HOLLANDSWORTH, BEVINGTON, KAPADIA, PETITT, LEWIS

Data of inelastic scattering from 23 elements described in the last report have been reduced and analysis is nearly completed. The data indicate a general agreement with the predictions of the

^{*}R.L. Walter, W. Benenson, P.S. Dubbeldam, and T.H. May, Nuclear Phys. 30, 299 (1962); P.S. Dubbeldam and R.L. Walter, Nuclear Phys. 28, 414 (1961).

[&]quot;C. Werntz (private communication). See also C. Werntz (submitted to *Phys. Rev.*).

¹⁶W. Haeberli and W.W. Rolland, Bull. Am. Phys. Soc. 2, 234 (1957).



Figure 6. Differential elastic scattering cross section of praseodymium.

Fermi gas calculations of Ericson for an energy distribution of the form

$$\mathcal{N}(E) = CE\sigma_i U^{-5/4} \exp(2\sqrt{aU}),$$

where a and C are constant, σ_i is the inverse cross section, E is the exit neutron energy, and U is the effective excitation energy taking pairing energy into account.

The relative angular distributions of neutrons elastically scattered from C, Zr, Nb, Ag, Sb, Ce, Pr, Ta, Au, Tl, radiogenic Pb, Th, and U have been measured for an incident neutron energy of 5.00 Mev. These data were taken with a time resolution of about 7 nsec and a flight path of 1.44 m.

Relative differential cross sections have been calculated for these samples. Optical model fits to the data have been made using a local potential code developed at Duke* based on a UCLA code. The parameters agree well with local fits of Perey and Buck, and Bjorklund and Fernbach at other energies. The data agree fairly well with nonlocal potential calculations of Perey and Buck. A typical comparison is given in Figure 6 for Pr¹⁴¹. We are now in the process of constructing a larger and more versatile detector shield for use in our scattering experiments. Renovation of the experimental area is also in progress. An improved neutron-gamma discriminator is being investigated for use with the detector, and solid-state triggering and coincidence circuits are being incorporated into the timing system to improve time resolution. It is expected that an over-all time spread of 3 to 4 nsec with a greatly enhanced signal-to-noise ratio will result from these modifications.

8. Windowless Gas Target Chamber PARKS, BEARD, BILPUCH, NEWSON

The Ar⁴⁰ (p,n) reaction has been studied from threshold to 120 kev above threshold in an effort to determine the resolution capabilities of our windowless target chamber. To obtain maximum possible yields from this reaction an unshielded, nearly 4π counter matrix has been constructed of polyethylene and BF₃ counters. The relative total yield has been measured in the region from 2.323 to 2.464 Mev.

Threshold appeared to occur at 2.338 ± 0.001 Mev and the first resonance was observed at 2.3466 Mev. In the region studied, 69 resonances were observed with an average spacing of ≈ 1.7 kev. Figure 7 shows a portion of the data over an energy range of 32 kev. The data were obtained by taking proton energy steps of 100 ev between the resonances and 50-ev steps over the resonances. The inset in Figure 7 shows an energy range of 2 kev with two resonances separated by 360 kev. By setting up the same gas flow, the reproducibility of the data from day to day was excellent and yields could be changed by simply changing the gas flow.

In an independent check on the resolution of the Duke 3-Mev Van de Graaff accelerator, it was found that if the "homogenizer"¹¹ was employed, a beam spread half width of 100 to 150 ev was consistent with the measured $C^{13}(p,\gamma)$ thick target yield at 1.76 Mev. In the case of Ar we assume that the energy spread from the accelerator is comparable to the C^{13} measurement even though the machine energy is greater. The remaining sources of energy spread are Doppler effect and target thickness. Our target was maintained at

^{*}The computations were carried out in the Duke University Computing Laboratory which is supported in part by the National Science Foundation.

¹¹P.B. Parks, H.W. Newson, and R.M. Williamson, *Rev. Sci. Instr.* 29, 834-9 (1958).

 $\approx 60^{\circ}$ K to insure that no solid could build up on the walls of the target chamber. This leads to a Doppler 1/e width of ≈ 70 ev. The observed resonances in Ar showed half-widths as small as 140 ev and as large as 440 ev with the majority having between 180 and 220 ev half-widths. Since these numbers include the natural width, Doppler spread, machine energy spread, and the target thickness, it can easily be seen that the target thickness is ≤ 100 ev. At present a study is under way to determine if the observed asymmetry of the resonances might in some way give a better estimate of the target thickness.

An attempt was also made to observe the $Ar^{10}(p, p'\gamma)$ reaction but in no case was the inelastic γ observed with sufficient intensity to permit any analysis. Also, a Li⁶ loaded glass crystal was employed in an unsuccessful attempt to take the angular distribution of the (p,n) reaction. However, we were able to make some 0°, 90° anisotropy studies by utilizing the two halves of the 4π BF₃ matrix counter.

At present an analysis of all the Ar data is under way. Another experiment involving improved anisotropy studies is being considered since this type of data can indicate the angular momentum of the existing neutron and spins and parities of states in the compound nucleus.

B. CHARGED PARTICLE REACTIONS

1. C¹²(d,p)C¹³ Reaction KATMAN, TILLEY, GERKE, WILLIAMSON

The $C^{12}(d, p)C^{13}$ reaction is being investigated in the range of incident deuteron energies from 2 to 3 Mev. The purposes of the investigation are (1) to ascertain the relative contributions of the direct interaction and compound nuclear reaction mechanism, (2) to test the validity of the distorted wave-Born-approximation theory of the (d, p) reaction in light nuclei at low energies, and (3) to test the prediction of Wilkinson to the effect that stripping reactions should follow the Butler plane wave de-



Figure 7.



Figure 8. Angular correlations between second group protons and de-excitation gamma rays.

scription most nearly when the Q values are negative and the bombarding energies are low.

For these purposes the yields of the second and third excited state proton groups were measured as a function of deuteron energy at several angles selected with a view toward analysis of the resonances.

Angular distributions of the protons were measured at several energies both on and off resonance.

Angular correlations between the protons and the de-excitation gamma rays of C^{13} were measured at energies on and off resonance. In each case, angular correlation measurements were made in the reaction plane and in one or more planes perpendicular to it.

Analysis of the data is not complete. However, the analysis of the p_2 - γ correlations at 2.35 and 2.50 Mev (shown in Figure 8) supports the predictions of Wilkinson in that the reaction plane anisotropies do not appear attenuated; the axes of symmetry coincide with the C¹³ recoil axes, and the azimuthal plane correlations are isotropic within the experimental error.

A: Resonance Inelastic Proton Scattering Measurements Kourse Russian Neurope

KYKER, BILPUCH, NEWSON

Considerable study has been given the feasibility of measuring compound nucleus resonances in the inelastic scattering of protons by intermediate even nuclei. The angular distribution of the deexcitation γ ray is easily measured and yields considerable information about the spin and parity of the compound state. Any residual ambiguity in the level assignments could be resolved by proton penetrability calculations and by the presence or absence of anisotropy in the (p, p') scattering. It is hoped that such measurements on a series of nuclei in the range $20 \leqslant Z \leqslant 30$ will yield useful information on level spacings, and possibly proton strength functions, in these nuclei.

A preliminary investigation of the Fe⁵⁶ $(p, p'\gamma)$ reaction has been carried out recently using a thin natural-Fe target. About 40 resonances in the region $2.68 \le E_p \le 3.00$ Mev were observed, and preliminary angular distributions have been obtained for a few of the stronger resonances. Although considerable refinement in technique is still necessary, our results thus far support the feasibility of resonance studies by this method.

3. Neon Drive-In Targets SAWERS, WILLIAMSON

At the time of the last report we had made natural neon drive-in targets. With proton energies between 2 and 3 Mev the γ rays from the reactions Ne²⁰($p, p'\gamma$) and Ne²²($p, p'\gamma$) were visible after backgrounds were reduced. However, with the present equipment it has proved fairly difficult to obtain high quality Ne targets using drive-in technique. Therefore the inelastic y's are being studied with a gas cell target using both natural Ne and the isotope Ne²² (60% enriched). Resonances in the γ yield as well as the angular distributions of the γ 's are being studied in the same energy region. Also, using solid state detectors we have observed the reactions $Ne^{26}(d, p\gamma)$, $Ne^{22}(d, p\gamma)$, and $Ar^{36}(d,p\gamma)$ with thick drive-in targets (proton energy loss \sim 50 kev).

4. Charged Particle Scattering Chamber GERKE, LOVETTE, TILLEY, WILLIAMSON

A versatile scattering chamber using semiconductor counters has been designed and construction is nearly complete. The rotating assembly consists of an 11%-in.-diam plate attached to 4½- in.-diam hub which passes through an O-ring vacuum seal and is attached to a handle outside the chamber. In this manner the advantages of having a large rotating assembly are achieved without the disadvantage of having to rotate a large area against a vacuum seal. The rotating assembly rides against and is held in position by Teflon thrust bearings. One set of bearings is mounted inside the chamber and the other outside. The bearing pressure is controlled by set screws attached to the outside handle. An angular scale is stamped on the side of the rotating plate and readings are made through a glass window in the side of the chamber. The angular position may be read to 1/10 of a degree using a vernier scale mounted inside the chamber. A rotating assembly is installed in both the top and bottom plates of the chamber.

Six equally spaced 60° grooves are cut in each of the rotating plates in which counter mounts may be placed. Metric scales are placed along each groove so that the counters may be set at a given distance from the center of the chamber. To allow electrical feed through to the counters, six ORTEC C-13 O-ring sealed connectors are placed through the base of both of the rotating hubs. This allows the lead wires to be rotated along with the counters and prevents mechanical interference from the wires.

Various types of target mounts can be used; they are held in one or both of the sliding O-ring seals at the top and bottom of the chamber. These seals are carried in Delrin liners so that the target holder is insulated from the rest of the chamber. The present holder is of the ladder type and carries four targets.

Before entering the chamber proper, the incident beam passes through a pair of defining slits 14 in. apart in the entrance tube. These slits and the larger antiscattering slits behind them are all mounted in a Ta-lined SS tube and may be removed as a unit through the chamber. A quartz plate with a hole in its center slightly larger than the first slit is mounted just ahead of this slit. The hole in the quartz is at the center of radius of a ball joint, one side of which is attached to the chamber and the other to the beam pipe. In order to align the chamber, the beam is first centered on the quartz, which may be viewed through a glass window in the beam pipe, and then the chamber is moved about the ball joint until its centerline lies along the beam axis. This position is determined either by using a quartz plate in the Faraday cup position or by maximizing the beam current on the Faraday cup. The alignment is carried out by using a horizontal plate and screw jacks mounted on a special table.

The Faraday cup, which is 1⁴/₄ in. in diam and 6 in. long, is lined with Ta. It is insulated from the rest of the chamber by a Teflon insulator. Secondary electron emission from the Faraday cup is suppressed by a ring which may be biased negatively with respect to the cup. The entire Faraday cup may be replaced by a quartz plate for beam alignment purposes as mentioned above.

In order to reduce hydrocarbon build-up on the thin self-supporting targets to be used, a 15 l/scc high-throughput Vac Ion pump has been mounted on the chamber. The only connection between the chamber and the Van de Graaff vacuum system is through the small beam defining apertures in the collimator. A large liquid nitrogen trap has been built to go in the beam tube and should effectively isolate the two vacuum systems.

The first project to be undertaken using this chamber will be a study of the yield curves and angular distributions of charged particles from the reactions $C^{13}(d,d)C^{13}$ and $C^{13}(d,p)C^{13}$.

C. GENERAL

1. 3-Mev Van de Graaff Energy Resolution KYKER, BEARD, FARRELL, PARKS, BILPUCH, NEWSON

The last NCSAG report included resolution measurements on the controlled proton beam direct from the 3-Mev Van de Graaff. We have extended these measurements since installing the cylindrical analyzer and homogenizer on this machine. An upper limit on the residual beam energy spread at the 25° port (with control and energy analysis on the HH + beam at the 18° port) is 220 ev using the homogenizer. This is to be compared to ~400 ev in the earlier measurements on the direct beam.

An attempt to repeat the measurements in the absence of Doppler broadening (using the lowtemperature windowless gas target chamber currently being developed here) was inconclusive due to our inability to produce a "thick" target.

2. 4-Mev Van de Graaff

BEVINGTON, BUCCINO, BILPUCH

At the present time we are in the process of trying to improve the energy resolution from our 4Mev machine. We have added a screen in the terminal to remove charge from the belt and some improvement in machine stability was observed. We are now adding a screen at the base of the Van de Graaff, and through a constant current supply we will be assured of a constant charge density on the belt. In the past, corona discharge

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from the needles to the belt has been observed to fluctuate in intensity, producing an unstable condition in the energy control system. The generating voltmeter is also being modified to improve long term stability. The substitution of an ac digital voltmeter for the signal rectifier has removed the nonlinearity previously observed.

6. HANFORD LABORATORIES

A. PULSE-SHAPE DISCRIMINATION D.G. FOSTER, JR., J.T. RUSSELL

The following abstract was presented at the American Physical Society meeting in Seattle, Washington, August 27-29, 1962:

Simple Pulse-Shape Discriminator for Fast Time-of-Flight Service. J.T. Russell and D.G. Foster, Jr. We are using a simple ionization-density discriminator which is particularly convenient for fast-neutron time-of-flight service. The input signal, with a decay time of 15 µsec, feeds 2 parallel channels composed only of passive elements. In one channel, it is clipped to 0.2 μ sec and stretched back to 15 μ sec. In the other channel, it is fed through a diode identical to the stretching diode in order to cancel out nonlinearities. The 2 channels then feed the inputs of a difference amplifier, which is the first interstage coupling amplifier in a commercial nonoverloading amplifier of the Chase-Higinbotham type. The input signal is derived from the last reasonably linear stage of the protomultiplier, and fed to the discriminator unit by a cathode follower and 70 ft of cable. When adjusted to reject 99% of all recoil electron pulses, the circuit has a threshold for recoil protons of about 0.8 Mev for stilbene, or 0.9 Mev for NE-213, on a photomultiplier 2 in. in diam.

B. FAST NEUTRON TOTAL CROSS SECTIONS D.G. FOSTER, JR., D.W. GLASGOW

Measurements were continued on the program of neutron total cross sections using the pulsedbeam time-of-flight technique with the 2-Mev Van de Graaff. These measurements utilize the continuous spectrum of neutrons from the thicktarget $\text{Li}^7(d,n)$ reaction and a flight path of 6 m. The neutron energy interval of 3 to 15 Mev is covered with a resolution of 0.45 nsec/m and a statistical precision of 2.5% or better. Measurements have now been completed on the following 23 elements: Li, Na, K, Al, Fe, Cu, Bi, In, Ta, Ca, Ba, Pb, Sr, Co, Mg, Y, Nb, V, Zr, Ag, Sn, Mo, and W. The data for these measurements have not been completely processed. Some of the earlier measurements in this series will be rerun with the present techniques before the data are released. The results of a remeasurement of the total cross section of Na with present techniques have eliminated a discrepancy in the energy scale compared with the data of Meier et al. near 3 Mev.

C. SCATTERING OF SLOW NEUTRONS FROM WATER D.A. Kottwitz, R.B. Smith, O.K. Harling

Measurements of the inelastic scattering of neutrons from room temperature water were completed for incident neutron energies up to 0.4 ev and energy changes up to 0.25 ev. These results were presented at the IAEA Symposium on Inelastic Scattering of Neutrons at Chalk River, September 1962, in a paper entitled "The Scattering Law for Room Temperature Light Water" by D.A. Kottwitz and B.R. Leonard, Jr.

Further measurements with higher energy resolution were completed on the quasi-elastic component of the scattering of neutrons from room temperature water. The results of these high resolution measurements showed a broadening of the observed peak with scattering angle which was consistent with the earlier low resolution measurements.

Instrumentation is being tested for equipment to measure slow-neutron scattering by the rotatingcrystal time-of-flight technique.

7. LAWRENCE RADIATION LABORATORY

A. PROTON ELASTIC SCATTERING BENVENISTE, MITCHELL, FULMER

. The differential cross sections for elastic scattering of protons from Ni⁶⁴ and Zn⁶⁴ were measured and compared in a search for evidence that a symmetry energy term is needed in the real potential of the nuclear optical model. The analysis of the data is complete. The observed shift in the curves representing the ratio $\sigma(\theta)/\sigma_R(\theta)$ [where $\sigma_R(\theta)$ is the Rutherford cross section] is shown to be con-

	-	Table 4	
	Ni" Lo	evel Structure	
Level	9.60-Mev data	11.7-Mev data	Previously known data
1	1.33 ± 0.02	1.34±0.02	1.34
2	1.79 ± 0.03	1.88 ± 0.10	
3	2.24 ± 0.03	2.30 ± 0.06	
4	$2.56 {\pm} 0.02$	2.60 ± 0.04	
5	2.94 ± 0.02	2.93 ± 0.06	
6	3.13 ± 0.02	3.15 ± 0.04	
7	3.53 ± 0.02	3.55 ± 0.02	
8	3.79 ± 0.03		3.83
9	4.17 ± 0.05		
10	4.38±0.05		
4 <u></u>		Table 5	
	Zn ⁶⁴ L	evel Structure	
•			Previously
Level	9.60-Mev data	11.7-Mev data	known data
1	0.98±0.02	0.99±0.02	0.99
2	1.78±0.02	1.77 ± 0.03	1.78
3	1.92 ± 0.04	1.91 ± 0.04	
4	2.28 ± 0.02	2.31 ± 0.03	2.29

 2.62 ± 0.05

 2.74 ± 0.05

 3.03 ± 0.05

3.0 3.2

3.3

5

6

7

8

9

10

11

12

13

14

 2.59 ± 0.03

 2.73 ± 0.02

 2.98 ± 0.02

 3.53 ± 0.02

 4.12 ± 0.02

 4.27 ± 0.03

 4.49 ± 0.03

 3.27 ± 0.03 (double level)

3.84±0.02 (double?)

4.66±0.05(multiple)

sistent with the presence of a symmetry energy term, C(N-Z/A), where $C \approx 40$ Mev. This is in reasonable agreement with the results of other observations.

Comparison of the back angle data yields an estimate of ≈ 16 mb for the compound elastic scattering cross section of Zn^{64} at 9.60 Mev. At 11.7 Mev the data show no contribution from compound elastic scattering.

B. INELASTIC PROTON SCATTERING BENVENISTE, FULMER, MITCHELL

The level structure of Ni⁶⁴ and Zn⁶⁴ has been studied by inelastic proton scattering for bombarding energies of 9.60 and 11.7 Mev. The protons were observed in a "particle namer" detector composed of a gas proportional counter and a p-n junction solid state detector. Spectra were measured at several angles. At each of these, independent excitation energy measurements were made by comparison with well-known states in carbon and oxygen. The results of these observations are presented, together with previously known levels, in Tables 4 and 5.

Angular distributions for the first excited state of each nucleus have been measured and interpreted in terms of the Butler theory. This work shows that there is reasonable agreement with the spherical Bessel function $j_2^2(ka)$ where $a = r_o A^{1/3}$ fermis, if r_o is taken to be about 2.0. The $j_2^2(ka)$ dependence is expected in view of the known spin and parity (2+) of these states. The rather large value of r_o required seems to be customary in the simple Butler theory treatment.

C. PHOTONUCLEAR CROSS SECTIONS OF Ho¹⁶⁵ AND Tb¹⁵⁹ R.L. BRAMBLETT, J.T. CALDWELL, S.C. FULTZ

Measurements on (γ, n) and $(\gamma, 2n)$ cross sections for Ho¹⁶⁵ and Tb¹⁵⁹ have been completed for the photon energy range from 8 to 28 Mev. The formation cross section for the compound nuclei have been examined for structure, and nuclear deformation parameters have been obtained. Figure 9 shows the nuclear formation cross section data for Ho¹⁶⁵. The solid curve represents the sum of two Lorentz curves with parameters given in Table 6. Other data derived from the measurements are also given in Table 6 (for which *a* represents the nuclear level density parameter, Q_{ρ} is the intrinsic quadrupole moment, and *W* denotes the wing correction to the Lorentz curves) which effectively extend the experimental integrated cross section to infinite energy.

D. PHOTOFISSION CROSS SECTION FOR U²³⁵ C.D. Bowman, G.F. Auchampaugh, S.C. Fultz

A preliminary measurement of the (γ, f) cross section for U²³⁵ was undertaken by use of the Livermore gamma-ray monochromator and a multiplate U²³⁵ fission chamber. The efficiency of the chamber for the detection of fission fragments was determined by using the counting rate observed when the chamber was placed in a neutron beam whose intensity had been calibrated and by using the known (n, f) cross section. The profile

	Table 6	
	Ho ¹⁶⁵	Tb ¹⁵⁹
$\int_{0}^{28} \sigma dE$	2.37 Mev-b	2.45 Mev-b
$\int_{a}^{28} \sigma dE + W$	2.68 Mev-b	2.73 Mev-b
σ _a	200 mb	184 mb
σ	249 mb	208 mb
Γ _a	2.65 Mev	2.9 Mev
Γ_{b}	4.4 Mev	5.8 Mev
E_a	12.10 Mev	12.2 Mev
E_{b}	15.75 Mev	15.5 Mev
a -	22.0 Mcv ⁻¹	32 Mev ⁻¹
Q.	7.40±0.09 b	6.30±0.83 b



Figure 9. Photonuclear cross section of holmium.



Figure 10.



Figure 11. Fission cross section of U²³⁵.



Figure 12. Low-energy fission cross section of U²³⁵.

and intensity of the gamma rays irradiating the chamber was measured and thus an absolute cross section scale was determined. Preliminary data obtained from the U^{235} measurements are given in Figure 10. The error bars represent only the statistical errors in the points.

E. NORMALIZATION OF THE EPITHERMAL U²³⁵ FISSION CROSS SECTION C.D. BOWMAN, G.F. AUCHAMPAUGH, S.C. FULTZ

The earlier fission cross section measurements which have been reported in UCRL 6926 were normalized by extending relative cross section measurements down to 0.03 ev where they were matched to those near thermal value. This method of normalization indicated that the fission cross sections generally accepted in the 5 to 60-ev region are about 20% too large. An additional experiment has been carried out to verify these new values for the fission cross section. Scattering material in the beam was significantly reduced and the open beam neutron spectrum was measured by use of both BF_a tubes and a thick Li⁶I crystal. The open beam neutron spectra obtained with the two detectors are in excellent agreement with the earlier experiment. Although the observed cross section curve was slightly modified near the strong resonances by the change in scattering geometry, the resulting normalization of the 5 to 60-ev data were the same as reported in UCRL 6926. The effect of the improved scattering geometry can be seen in Figure 11 where the solid line represents the data reported in UCRL 6926, and the data points were obtained with the improved geometry. It is clear that where the curve matching was carried out above and below the region of strong resonances, the two curves are in good agreement. More detail on the data in the lower energy region is given in Figure 12. As in Figure 11 the points were obtained with the improved geometry while the solid line through them was obtained with the earlier geometry. These measurements therefore confirm the results reported in UCRL 6926.

A. NEUTRON INDUCED REACTIONS

1. Capture Gamma Rays MOTZ, JURNEY, CARTER

A new irradiation and measurement system of very high sensitivity for the observation of (n, γ) spectra has been installed and tested. A solid source can be placed in an evacuated Bi-shielded channel through the Omega West Reactor thermal column so that only the target material is viewed, or the channel can be filled with a gas target, the central region of which is viewed. The background from this arrangement is extremely low and sources less than one millibarn mole are clearly seen above background. In addition to obtaining a high signalto-background ratio for the irradiation, it is also essential for the observation of low cross-section nuclei to have both high sensitivity and adequate resolution for the detection system. An excellent combination of these conflicting sensitivity-resolution characteristics has been obtained in an anticoincidence NaI scintillation counter assembly commercially purchased. Initial data have yielded excellent results from Ar and Ne gaseous targets and indicate that sources of only a few milligrams to 100 milligrams of one-barn material are sufficient. The system is well-suited to enriched isotope targets of light nuclei or to cases where the spectra are not expected to be too complex, such as from Pb.

2. Neutron Polarization Experiments PERKINS, SIMMONS

The polarization in n-p scattering at 23 Mev has been re-measured using an improved experimental setup. The angular distribution of the polarization is in substantial agreement with data taken earlier. Data were taken using two different scattering samples, one being a factor of four larger than the other, to check on the possibilities of errors arising from multiple scattering of neutrons or detection of gamma rays from $C^{12}(n,n'\gamma)$ reactions.

A mockup of a triple scattering experiment using 23-Mev neutrons was tried to discover the magnitude of the background. Neutrons were scattered twice from plastic scintillators at 45° and detected in a final neutron detector. Triple coincidences were seen at the rate of several hundred per hour and the resolving time was measured to be ≈ 5 nsec. Chance coincidence background was determined to be a small fraction of the true rate. The measured rates agree favorably with our expectations. Preparations are therefore being made to measure one of the triple scattering parameters of the *n-p* system at 23 Mev.

3. Inelastic Neutron Scattering CRANBERG, LEVIN

Systematic data on Pb²⁰⁶, Pb²⁰⁷, and Bi²⁰⁹ have been taken as a function of neutron energy and scattering angle. Incident energies of 2.5 and 4.1 Mev have been investigated and the angular range covered is from 30° to 150°. The detector sensitivity has been calibrated from 0.8 to 4.1 Mev by observing the angular distribution of scattered neutrons from the hydrogen in polyethylene. A splitting has been observed into two components 60 kev apart of the 2.7-Mev state in Pb207 and more than five hereto unreported states have been observed in Pb207 and Bi209 at excitations between 2.7 and 3.5 Mev. Anisotropy of two to one has been observed in the neutron group corresponding to the 0 + state in Pb²⁰⁶ at 1.13 Mev. This is in accord with preliminary Hauser-Feshbach calculations. Development work is continuing to improve resolution and reduce background.

4. Capture Cross Sections DIVEN, HOPKINS, SILBERT

A large sodium iodide crystal $(11\frac{1}{2} \times 11 \text{ in.})$ has been purchased and is being set up to measure neutron capture cross sections in the kev region. The first capture cross sections measured will be those of fissionable materials. The quality of the crystal is excellent.

B. REACTIONS INDUCED BY CHARGED PARTICLES

1. Excited State of He⁴ SILBERT, SMITH, JARMIE

5 Low energy scattering of tritons by protons should have a direct bearing on the properties of the first excited state of the He⁴ nucleus believed to be a 0+ state at about 20-Mev excitation. Final data have been taken and analyzed on H(t,p)T. The H(t,p)T cross section has been measured from 163 to 525 kev c.m. energy and exhibits a broad maximum of 240 mb/sr near 275 kev (c.m.) for a c.m. scattering angle of 120°. How this structure affects the question of a resonance in He⁺ must await theoretical analysis.

2. Experimental Study of the (He³,t) Reaction BLAIR, WEGNER

Recent reports from Lawrence Radiation Laboratory have shown that the (p,n) reaction on medium-weight nuclei (50 < A < 100) excites the ground isobaric state of the residual nucleus, i.e., the state which is the analog of the ground state of the target nucleus. They have also shown that excited isobaric states may be reached through the (p,n) reaction. The (He³,t) reaction, which leads to the same final nuclei, has the advantages of a charged final particle and a lower background from compound-nucleus evaporation. Results at LASL indicate that the (He^3, t) reaction excites principally the isobaric states in medium-weight nuclei, e.g., Ti¹⁵, Fe⁵¹, Fe⁵⁶, Fe⁵⁷, Fe⁵⁸, and natural Ni, but that the cross section is lower by an order of magnitude than the cross section for the (p,n)reaction to these states. The low cross section to some extent offsets the advantages mentioned. For light-weight non-mirror nuclei, (p,n) reaction studies similar to those above have not been reported. It has been found that the (He³,t) reaction on the light-weight non-mirror nucleus Mg29 excites some other states as strongly as isobaric states, and the cross sections are in general several times larger than the cross sections observed in the medium-weight nuclei.

3. (He³,n) Reactions

MANLEY, WELLS

(He³,n) angular distributions for He³ energies between 18 and 25 Mev have been examined for several targets between C and Cu. Neutron detectors with thresholds of $\approx 1, 5$, and 12 Mev have been used. All angular distributions are strongly peaked forward with half-angles of the order of 20° for the highest energy neutrons detected. This angle appears to increase monotonically as the neutron threshold is lowered.

4. (He³,2p) Reactions

MANLEY, STOKES

Preliminary data on the $(He^3, 2p)$ reactions have been taken with Be⁹ and C¹² targets. In order to have a complete description of the preference for energy division between the two protons, the Nuclear Data two-dimensional analyzer was used to correlate the pulse heights of the two proton detectors. The data points fell into two or three distinct lines on the 32×32 matrix of the analyzer display. These lines corresponded to the Q-values of known single levels or groups of levels in the residual nuclei. In general, there was a somewhat uniform distribution on either side of a point representing equal proton energy division, with no strong preference for a particular energy ratio. By moving the counters in a common plane which contained the beam axis, evidence was obtained for a diffraction structure in which the yield for various reaction groups behaved differently as the counter angles were varied. It will be of interest to compare these kinds of data with the angular behavior of (d,p) reactions for the same final states.

C. FISSION

1. Charged Particle-Induced Fission BRITT, WEGNER, GURSKY

Measurements with a semiconductor detector system and a two-dimensional analyzer have yielded information on the mass distributions and the details of the kinetic energy release from a series of charged particle-induced fission reactions. The fissioning compound nuclei range from Tm for which the mass distributions are symmetric, to Pu for which the fission is predominantly asymmetric. In an intermediate region, the charged particle-induced fission of Ra226 yields comparable contributions of symmetric and asymmetric fission. All of the results are quantitatively consistent with a two-mode hypothesis for the fission process and indicate that within each mode the distance between the charge centers of the two fragments at the scission point is approximately the same for all mass divisions. The results show a lower total kinetic energy release from symmetric fission than from asymmetric fission, indicating that the distance between the charge centers at the scission point is about 10% greater for the symmetric mode than for the asymmetric mode.

2. Lifetimes of Fissioning Nuclei STEIN

Mean lifetimes of the compound nuclei U²³⁹ and Np²³⁸ have been measured for formation by fission spectrum neutrons. These lifetimes are zero within the sensitivity of the method but upper limits of lower value than previously known may be determined from the data. The total and partial lifetimes for these fissioning compound nuclei

Table 7*

Nuclide	Neutron energy and energy spread	ī	Error (standard deviation)
U ²³³	Thermal	2.460	0.026
	$280 \pm 90 \text{ kev}$	2.476	0.033
	440 ± 80 kev	2.489	0.033
	$980 \pm 50 \text{ kev}$	2.539	0.035
	1.08± 0.05 Mev	2.497	0.030
	$3.93\pm$ 0.29 Mev	2.967	0.040
U^{235}	Thermal	2.412	0.020
	280 ± 90 kev	2.425	0.022
	$470 \pm 80 \text{ kev}$	2.443	0.022
	815 ± 60 kev	2.458	0.026
	1.08± 0.05 Mev	2.517	0.026
	3.93 ± 0.29 Mev	2.921	0.030
	$11.5 \pm 1.0 \text{ Mev}$	4.601	0.075
Pu ²⁴⁰	Spontaneous fission	2.177	0.026
Pu ²³⁹	Thermal	2.816	0.028
	250 ± 50 kev	2.915	0.039
	420 ±110 kev	2.941	0.046
	610 ± 70 kev	2.889	0.041
	$900 \pm 80 \text{ kev}$	2.988	0.041
	3.90± 0.29 Mev	3.404	0.039
	14.5 ± 1.0 Mev	4.916	0.119

*These results are based on $\bar{\nu}$ for spontaneous fission of Cf²⁵² of 3.751 ±0.000. Absolute measurement of spontaneous fission $\bar{\nu}$ of Cf²⁵² yields $\bar{\nu}$ =3.751 ±0.030.

are related through the widths since $\Gamma = \Gamma_{I} + \Gamma_{n}$. The limits determined in units of 10⁻¹⁴ sec are: a) for U²³⁹, $\tau < 6$, $\tau_{I} < 40$, $\tau_{n} < 7$; b) for Np²³⁸, $\tau < 4$, $\tau_{I} < 9$, $\tau_{n} < 7$.

3. v

HOPKINS, DIVEN

Results of the most recent measurements of the numbers of prompt neutrons emitted per fission are shown in Table 7. An absolute measurement of $\bar{\nu}$ for the spontaneous fission of Cf²⁵² has been made. All other measurements are relative to this $\bar{\nu}$. The absolute errors are complicated by the fact that the Cf²⁵² $\bar{\nu}$ uncertainty produces a systematic uncertainty in all other values of $\bar{\nu}$. Also, the errors in the relative measurements are not entirely independent. If the Cf²⁵² $\bar{\nu}$ uncertainty and the errors associated with the relative measurement are treated as independent, and are combined in the usual manner, then the standard deviations for the absolute values will be slightly too large. The neutron energy spreads are mainly due to target thickness.

D. INSTRUMENTATION

1. Mobley Compression System MCKIBBEN, CRANBERG, LEVIN

Beam alignment has been achieved and testing with a bunched beam concluded. The half-width of the gamma burst from the target is 0.7 nsec as measured by a time converter. Average currents up to 3.2 μ A have been brought upon the target with 4.0 μ A measured into a beam cup at the beginning of the tube to the buncher. The buncher will work with 0.7 nsec over-all resolution up to 6-Mev protons and even higher with loss of resolution.

2. King-Size Tandem Van de Graaff

HENKEL, MCKIBBEN

The building is scheduled to be completed and the tandem installed by late fall of 1963. The present 8-Mev electrostatic accelerator can be used as an injector for the tandem and both machines can be used separately.

9. OAK RIDGE NATIONAL LABORATORY

A. NEUTRON REACTIONS

1. Parameters of Neutron Resonances in the Tin Isotopes

T. FUKETA,* J.A. HARVEY

The following is an abstract of a paper to be presented at the Cleveland Meeting of the American Physical Society, November 23-24, 1962:

Measurements were done in the energy range from 30 to 10,000 ev with a time resolution of 10 nsec/m using the ORNL fast chopper and the 180-m flight path (measurements on the other five Sn isotopes were reported by F.A. Khan and J.A. Harvey Bull. Am. Phys. Soc. 7, 289 (1962)]). The metallic sample thicknesses were 0.20 and 0.15 in. for Sn¹¹² and Sn¹¹⁴, respectively, and 1.0 in. for Sn¹²² and Sn¹²⁴. The sample of Sn¹¹⁵ was an oxide powder, and had a thickness equivalent to 0.057 in. metal. We observed 12, 7, 4, 6, and 5 resonances in Sn^{112,111,115,122}. and 124, respectively, in this energy range. Measurements were also made with a 45-m flight path upon 4-in, thick natural Sn and all ten enriched isotopes from 50 to 0.2 cv with an energy resolution of 1.5%. Even below 30 ev several new resonances, which had not been previously observed, were found. Detailed corrections for "missed" resonances must be made to obtain average level spacings and strength functions. The resonance parameters, average level spacings, the s-wave strength functions, and the nuclear radii are reported.

Parameters of the Neutron Resonances of the Stable Isotopes of Tin F.A. KHAN,** T. FUKETA,* J.A. HARVEY

A paper by the above title was presented at the Low-Energy Nuclear Physics Conference, Harwell, England, September 12-14, 1962.

3. Neutron Total Cross Section and Capture Measurements on Separated Zr Isotopes R.C. BLOCK

The following is an abstract of a paper presented at the Low-Energy Nuclear Physics Conference, Harwell, England, September 12-14, 1962:

The ORNL fast chopper time-of-flight neutron spectrometer was utilized to make transmission measurements on isotopically enriched samples of Zr^{**} (97.8% enrichment), Zr^{**} (90.9%), Zr^{**} (95.7%), Zr^{**} (96.5%), and Zr³⁶ (57.3%). In the energy range from ~0.5 cv to 40 key, there were approximately 3 resonances observed in Zr⁹⁰, 5 resonances observed in Zr⁹², 5 resonances observed in Zr⁹¹, and ~7 resonances observed in Zr⁹⁶. Eleven resonances were resolved in Zr⁹¹ up to 3000 ev, and an s-wave strength function of $(1.0\pm0.3)\times10^{-1}$ is assigned to Zr⁹¹. A new weak resonance was observed in Zr^{s1} at ~ 450 ev in these transmission measurements; this level was also observed in capture measurements with the Rensselaer Polytechnic Institute's linear accelerator. It is interesting to note that of the 7 resonances observed in Zr⁹¹ below 1600 ev, 4 of these resonances had a Γ_n^{0} of <3% of the average Γ_n^{0} for all 7 levels. This indicates that some of the small resonances in Zr^{91} may be due to p-wave neutrons.

Neutron Radiative Capture Measurements With the RPI Electron Linear Accelerator J.E. Russell (RPI), R.W. HOCKENBURY (RPI), R.C. BLOCK

The W capture data have been combined with transmission data in order to analyze the resonance parameters. The following spin assignments have been made in resonances observed in the target nucleus W¹⁸³:

$$E = 144.8 \text{ ev}, g = \frac{1}{4};$$

 $E = 154.8 \text{ ev}, g = \frac{1}{4};$
 $E = 157.6 \text{ ev}, g = \frac{3}{4};$
 $E = 174.6 \text{ ev}, g = \frac{3}{4}.$

5. Gamma Ray Spectra From Low Energy Neutron Capture G.G. SLAUGHTER, J.R. BIRD,* G.T. CHAPMAN, J.A. HARVEY

The following is an abstract of a paper to be presented at the Cleveland Meeting of the American Physical Society, November 22-24, 1962:

Equipment for the study of gamma-ray spectra from low energy neutron capture has been installed at the Oak Ridge Research Reactor. The fast chopper, with the high intensity rotor, is used to provide a neutron beam, and the gamma-ray detector is a heavily shielded 9×12 -in. NaI crystal. A flight path of 5 m allows the determination of neutron energies with an energy resolution of $\approx 15\%$. Two types of measurement have been made in initial experiments: (a) the study of thermal neutron capture in small quantities of separated isotopes, and (b) the study of

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capture in the resonance region. For example, thermal capture spectra have been observed for nine of the Sn isotopes. Each spectrum shows a number of prominent gamma rays as well as many that are poorly resolved. Capture in Cu has been compared for the first two resonances at 227 ev (Cu⁴⁵) and 580 ev (Cu⁴³) and for the nonresonant capture at various energies below the resonances. The nonresonant spectra are very similar and differ from the spectrum for the 580-ev resonance which is similar to that observed at higher neutron energies [J.R. Bird, J.H. Gibbons, and W.M. Good, *Physics Letters* 1, 262 (1962)]. These results are of interest for testing the suggestion that direct capture is important in Cu.

Thermal Neutron Capture Cross Section and Resonance Capture Integral of Ce¹⁴⁰ P.M. LANTZ

A measurement has been made of the activation thermal cross section of resonance integral of Ce¹¹⁰ by irradiating Ce¹¹⁰ resulting from the decay of fission product Ba¹¹⁰ in which Cd filters were utilized. The activation product, Ce¹⁴¹, was measured by 4π beta-gamma coincidence counting and beta absorption in Al using a calibrated end window Geiger-Müller tube. The measurements were made in the pneumatic tube facility of the LITR. Values of 0.59 ± 0.06 and 0.48 ± 0.05 b were found for the thermal cross section and resonance integral respectively.

Table 8 Elemental Neutron Capture Cross Sections							
		σ_c , mb					
Ζ	Element	$E_n=30\pm7$ kev	$E_n = 65 \pm 20 \text{ kev}$				
15	Р	7± 1	0.5 <u>+</u> 0.2				
17	Cl	11土 4	4 ± 2				
19	К	16± 2	4 1 1				
20	Ca	10± 1	3 ± 1				
22	Ti	29 ± 3	5 ± 1				
25	Mn	22 <u></u> + 2	9 ± 1				
31	Ga	103 ± 9	56 ± 5				
33	As	350 ± 32	175 ± 16				
34	Se	94 ± 8	51 ± 5				
37	Rb	180 ± 16	89 ± 8				
52	Te	97± 9	35 ± 3				
56	Ba	61 ± 5	33 ± 3				
63	Eu	2560 ± 230	1580 ± 140				
72	Hſ	510 ± 45	3:` ± 30				
75	Re	900 ± 80	5 c 50				
76	Os	300 ± 27	175 ± 16				
77	Ir	795± 70	450 ± 40				

7. Effective Neutron Capture Cross Section of Ce¹⁴¹

P.M. LANTZ, C.R. BALDOCK

The effective neutron cross section of Ce¹⁴¹ has been measured by irradiating Ce¹⁴⁰ in the MTR to form Ce¹¹² by a double neutron capture reaction. The Ce¹⁴⁰ source was very pure having only 9 ppm Ce¹¹² measured by neutron activation and mass analysis. The Ce¹⁴² produced in the 113 and 226-day irradiations, monitored with dilute Co, was determined mass spectrographically and by neutron activation. Measurement of the Ce¹¹² by neutron activation entailed the beta counting of 13.8-day Pr¹⁴³, the daughter of 3-min Ce¹¹³. A value of 30±3 b was found for the effective neutron cross section where Φ_{th}/Φ_r was 12.

Correlated Energy Measurements for Thermal Neutron-Induced 3-Particle Fission of U²³⁵ H.W. SCHMITI, J.H. NEILER, F.J. WALTER, A. CHETHAM-STRODE

Energy correlation measurements of particles emitted in 3-particle fission have been carried out in a three-parameter experiment involving 128 $\times 128 \times 4$ channels. Particles from the thermalneutron-induced fission of U235 were incident on Si surface barrier detectors. Si of 600 ohm-cm was used for the heavy-fragment detectors and Si of 3400 ohm-cm was used for the two third-particle detectors. All detectors were about 4 cm² in area and were operated under essentially optimum conditions [see for example, Schmitt, Neiler, Walter, and Silva, Bull. Am. Phys. Soc. II, 6, 240 (1961)]. The energy of each of the two heavy fragments was recorded in 128 channels; the thirdparticle energics were divided into four groups in the range 6 to 30 Mev. Mass distributions and other correlation data for binary and ternary fission of U²³⁵ are compared. The strong preference for emission of the alpha particles at an angle somewhat less than 90° with respect to the light fragment, as reported by Titterton [Nature 168, 590 (1951)], was observed.

9. Neutron Capture

R.L. MACKLIN, T. INADA, * J.H. GIBBONS

Further measurements of 30 and 65-kev neutron capture cross sections have been made with the 1.2-m liquid scintillator. The results are shown

^{*}Visiting Investigator from NIRS, Chiba, Japan.

in Table 8. Cross sections at 30 kev have been measured for Sm, Sr, and Zr isotopes using the fast Moxon-Rae detector at the ORNL pulsed 3-Mev Van de Graaff. Capture cross sections (from 10 to 55 kev) were measured with Y^{89} , Pb^{206} , Pb^{207} , F^{19} , sulfur, and $Sn^{116-120}$ samples.

10. Evidence Concerning the Importance of "Direct" or "Potential" Neutron Capture at Low Energies J.R. BIRD,* J.H. GIBBONS, W.M. GOOD

The following is an abstract of a paper presented at the International Symposium on Direct Interactions and Nuclear Reaction Mechanisms, Padova, Italy, September 3-8, 1962:

It has been recognized for several years that "direct" capture processes can be important at low energies. Lane and Lynn have shown that an appreciable fraction of certain thermal cross sections may be due to this process. Neutron capture γ -ray spectra have been measured in the resonance region ($\bar{E}_n = 30$ kev) and compared with corresponding thermal capture spectra. Major differences occur for many nuclei. In particular, isotopes of Ni, Cu, and Pb show many γ rays which would be expected following compound nucleus formation, but which are weak or absent in thermal capture. Such results support the conclusion that these mass regions are important in the consideration of direct capture.

11. Gamma Rays From Neutron Capture in Lead J.R. BIRD,* J.H. GIBBONS, W.M. GOOD

The following is an abstract of a paper to be presented at the Cleveland Meeting of the American Physical Society, November 23-24, 1962:

Measurements of 30-kev neutron capture [J.R. Bird, J.H. Gibbons, and W.M. Good, Physics Letters 1, 262 (1962)] have been extended to allow results to be obtained for a variety of neutron energies. A neutron flight path of 50 cm and a time resolution of 12 nsec FWHM (full width at half maximum) makes possible the observation of individual resonances in the energy range 10 to 100 key. A three-dimensional analyzing system with 16×128 channels is used for the simultaneous measurement of neutron and gammaray energy. Targets of natural and radiogenic Pb show resonances in Pb206 at 18, 22(?), 27, and 45 kev as well as the well-known resonance in Pb207 near 45 key. The shape of the latter for the 7.41-Mey ground state transition in Pb208 has been studied and intensities of three transitions in Pb207 have been obtained for each of the other four resonances. These intensities change markedly from resonance to resonance but the average values cannot be explained in terms of the expected multipolarities unless *p*-wave capture is important for these resonances.

Measurement of α for U²³⁵ as a Function of Neutron Energy G. DESAUSSURE, L.W. WESTON

A measurement of $\alpha (=\alpha_c/\alpha_I)$ for U²³⁵ at neutron energies of 30 and 64 kev was performed using a 30-plate fission chamber in the center of a 1.2-m-diam liquid scintillator tank. The chamber was bombarded by pulses of neutrons obtained at the 3-Mev Van de Graaff by the Li⁷(p,n)Be⁷ and T(p,n)He³ reactions at the threshold. The ratio of the scintillator pulse-height spectrum in anticoincidence with the fission chamber to that in coincidence with the fission chamber provides the value of α . The values obtained were

> $\alpha(30\pm10 \text{ kev}) = 0.372\pm0.026$, $\alpha(64\pm20 \text{ kev}) = 0.315\pm0.060$.

The major source of uncertainty of the measurements is associated with the extrapolation of the pulse-height spectra below a bias of about 2-Mev γ -ray energy. (Background radiation below 2 Mev is too large to permit accurate measurement of the pulse-height spectra.)

The results are in good agreement with the result obtained by Hopkins and Diven for the same parameter [*Nuclear Sci. and Eng.* 12, 169 (1962)]. Of course, the two measurements are not entirely independent as the somewhat arbitrary extrapolation of the pulse-height spectra to zero pulse height was obtained, in both experiments, with similar criteria.

13. Fission Cross Section and Fragment Angular Distribution for Fast Neutron-Induced Fission of U²³⁴ R.W. LAMPHERE

The following is an abstract of a paper presented for publication in *Nuclear Phys.*:

The fission cross section of U^{241} has been remeasured to 4-Mev neutron energy with greater detail in order to accurately delineate the extrema. Results are believed to be somewhat more accurate than those previously reported by the author. The fragment angular asymmetry A defined as the ratio of fragment emission at zero degrees to that at ninety degrees to the neutron beam was measured from 0.4 to 3.8 Mev. At 843, 1050, and 3740 kev the 30/60 degree fragment intensity ratio was also measured and normalized to A. Strong sidewise peaking with A =0.50 (normal to the neutron beam) was found at

^{*}Visiting Investigator from AERE, Harwell, England.

500 kev at which point the total fission cross section is 0.50 b and rising smoothly. At 843 kev the cross section passes through a maximum of 1.26 b coincidentally with a maximum of 1.80 in A. From 843 to 1050 kev both cross section and A fall smoothly to minima of 1.10 and 1.13 b, respectively. Above 1050 kev both cross section and A rise somewhat irregularly. A remains very nearly constant at 1.20 between 1.5 and 3.8 Mev.

As suggested by Wheeler the dip in cross section can be explained in terms of enhanced competition from inelastic neutron scattering. A modified Hauser-Feshbach type of analysis indicates that scattering to vibration-rotational levels known to exist above 790 kev in U^{234} serves to depress the cross section for fission.

The changes in A are explained in terms of the theory of A. Bohr which postulates that fission occurs through distinct channels akin to the K-band structure seen in heavy aspherical nuclei at low excitations. On this basis approximately 62% of fission at 500 kev goes via a 3/2 – band while most of the remainder goes via a 1/2 + band. At 843 kev only 14% goes through the 3/2 – band, the rest proceeds via a strong 1/2 – band and the much weaker 1/2 + band. The reason for the strong fall in A between 843 and 1050 kev is unclear. Some possibilities are suggested.

The sequence of K bands indicated for U^{235*} near the saddle point deformation is 1/2+, 3/2-, 1/2-, with separations of the order of a few hundreds of kilovolts.

14. Differential Neutron Cross Sections With a Few kev Energy Spread J.L. FOWLER

Apparatus designed to determine neutron angular distributions with good energy resolution (J.L. Fowler, Program of the Southeastern Section Meeting of the American Physical Society, Abstract 13, 1962) has been used to measure the differential cross sections of neutrons scattered from Pb²⁰⁸ (99.75%) at twenty-one different energies between 700 and 1750 kev. Fourteen of the measurements were at resonant energies [J.L. Fowler and E.C. Campbell, *Phys. Rev.* 127, 2192 (1962)]. For the first several prominent resonances the interference between the resonant phase shifts and potential scattering (predominantly *s*-wave) allows one to assign the *l*-value by inspection. These assignments are as follows:

E_0 , kev	Γ, kev	<u> </u>	<u>l</u>	Parity
723	5.0 ± 1.0	5/2	2	+
769	5.5 ± 1.0	3/2	1	
821	10.0 ± 1.0	5/2	2	+
855	5.0 ± 1.0	3/2	2	+

As the neutron energy increases, potential scattering phase shifts other than s-wave become important, so that a more quantitative analysis becomes necessary. A FORTRAN code has been written for the 7090 computer to calculate theoretical angular distributions as a function of resonance parameters and potential scattering phase shifts in order to compare with the experimental results.

Excitation of Collective States by Inelastic Scattering of 14-Mev Neutrons P.H. STELSON, R.L. ROBINSON

Neutrons of 14-Mev energy from the d-t reaction have been used to excite collective states in Pb, Bi, Ni, Zn, and S. Absolute differential cross sections have been obtained for the excitation of the octupole (2.5 Mev) and hexadecapole (4.1 Mev) states in Pb and of the quadrupole (2.24 Mev) state in S. The results are in general agreement with the predictions of the direct interaction theory of Buck and of Bassel, Drisko, and Satchler.

16. Excitation of Collective States by Inelastic Scattering of 14-Mev Neutrons P.H. STELSON, R.L. ROBINSON

A paper by the above title was presented at the International Symposium on Direct Interactions and Nuclear Reaction Mechanisms, Padova, Italy, September 3-8, 1962.

B. CHARGED PARTICLE REACTIONS

1. (p,n) Cross Sections

J.K. BAIR, C.M. JONES, H.B. WILLARD

Preliminary measurements of (p,n) total cross sections have been made utilizing the Tandem Van de Graaff and the graphite sphere neutron detector. Elements bombarded to date are Li⁶, Li⁷, Be⁹, B¹⁰, and B¹¹.

2. The Optical Model With Nonlocal Potentials

F. PEREY

A paper by the above title was presented at the International Symposium on Direct Interactions and Nuclear Reaction Mechanisms, Padova, Italy, September 3-8, 1962. It has been published [F. Perey and B. Buck, *Nuclear Phys.* 32, 353 (1962)].

3. The Calculation of Elastic and Inelastic Proton Scattering With a Generalized Op≰ical Model B. BUCK

The following is an abstract of a paper submitted for publication in *Nuclear Phys.*:

An extension of the optical model is considered in which a state of quadrupole collective motion is strongly coupled to the nuclear ground state. The calculations include a spin-orbit potential and the simultaneous coupled differential equations of the problem are solved numerically on a high-speed computer. Experimental data on the scattering of medium energy protons from Ti, Cr, Fe, Ni, and Zn are analyzed. A good average optical potential is determined and conclusions are drawn about the energy dependence of the parameters. Evidence is presented for the validity of the collective model. Nuclear deformabilities derived by fitting the inelastic differential cross sections are in good agreement with those determined by electromagnetic methods. Various limitations and ambiguities of the model are discussed and possible improvements are indicated.

4. Analysis of Angular Correlation for Inelastic Proton Scattering on Fe⁵⁶ and Ni⁵⁸ G.R. SATCHLER, E. SHELDON*

A paper by the above title was presented at the International Symposium on Direct Interactions and Reaction Mechanisms, Padova, Italy, September 3-8, 1962.

5. The Elastic Scattering of Alphas by O¹⁸ D. POWERS, J. FORD, T. HAYES, H.B. WILLARD

Differential elastic scattering cross sections have been measured for 2.4 to 3.5-Mev alphas on O^{18} at center-of-mass angles corresponding to the first 4 zeros of the Legendre polynomials. Of the eight resonances previously observed in this energy region by the $O^{18}(\alpha,n)Ne^{22}$ reaction, spin and parity assignments have been made to six levels by the combined experimental data.

6. Coulomb Excitation of Osmium Nuclei F.K. McGowan, P.H. Stelson, R.L. Robinson

Coulomb excitation measurements have been made by proton and α -particle bombardment of metallic targets enriched in the different isotopes of Os. The *B*(*E*2)'s for excitation of the first 2+ state in Os¹⁸⁸, Os¹⁹⁰, and Os¹⁹² are larger than the single-particle estimate by factors ranging from 70 to 100. The B(E2) for excitation of the second 2+ state is about 0.1 of the B(E2) for excitation of the 2+ state. The sign of $\delta = (E2/M1)^{1/2}$ in the 2 \rightarrow 2 transition is negative and the $B(M1,2\rightarrow 2)$'s are exceedingly small, being about 10⁻³ times the single-particle estimate.

States in Os¹⁸⁷ at 74, 75, and 187 kev and in Os¹⁸⁹ at 69.5, 95, and 219 kev are directly Coulomb excited. The predictions of the symmetric rotator model of Bohr-Mottelson with rotation-particle coupling included do not agree with the experimental results for Os¹⁸⁷.

Coulomb Excitation With Ne²⁰ Ions R.C. RITTER, P.H. STELSON, F.K. MCGOWAN, R.L. ROBINSON

The following is an abstract of a paper submitted for publication in *Phys. Rev.*:

Neon ions with energies ranging from 8 to 15 Mev have been obtained by the acceleration of doubly and triply-charged ions in a 5.5-Mev Van de Graaff. These projectiles have been used to study Coulomb excitation in 18 nuclei ranging from Li⁷ to Th²³². In particular, the levels of Ti¹⁷, V⁵¹, Fe⁵⁷, Ni⁶¹, Zn⁶⁷, Ge⁷³, and As⁷⁵ were investigated. New spin assignments were obtained for the 93 and 184-kev states in Zn⁶⁷. A unique spin assignment is obtained for the 320-kev state of V⁵¹ and the multipolarity mixture of γ ray is established.

8. A Comparison of (p,d), (p,t), and (p,α) Reactions Exciting the Same Final States J.B. BALL, C.B. FULMER, C.D. GOODMAN

A paper by the above title was presented at the International Symposium on Direct Interactions and Reaction Mechanisms, Padova, Italy, September 3-8, 1962.

(p,t) Double Pickup Reactions With 22-Mev Protons C.D. GOODMAN, J.B. BALL, C.B. FULMER

Energy spectra and angular distributions of (p,t) reactions on Zr isotopes and neighboring nuclides were measured. Only a few final levels are strongly excited. These are interpretable as the results of pickup of two neutrons from shell model states. Levels are observed which represent the different possible couplings of the angular momenta of the resultant hole states.

^{*}Visiting Investigator from E.T.H., Zurich, Switzerland.

10. (p,d) Pickup Reactions With 22-Mev Protons on Targets Near N=50

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C.D. GOODMAN, J.B. BALL,
C.B. FULMER
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(p,d) energy spectra and angular differential cross sections have been measured and are compared for seven neighboring nuclides. The cross section for the d 5/2 neutron pickup increases as the level fills. Comparison of reduced widths extracted with distorted wave calculations shows an effect of shell model residual interactions. Residual interactions are also observed through other features of the spectra.

Resonances in the C¹² (O¹⁶, α)Mg²⁴ Reaction F.E. DURHAM, M.L. HALBERT, C.D. MOAK, A. ZUCKER

With O¹⁺ ions accelerated by the Tandem Van de Graaff, the excitation function for the reaction $C^{12}(O^{16},\alpha)Mg^{24}$ was measured for the first five states in Mg^{24} . The over-all resolution was 45 kev (center-of-mass), and strong fluctuations in the excitation function were observed throughout the investigated energy region, from 25.10 to 26.10 Mev excitation in the compound nucleus Si²⁸. If the resonances are due to the interference of randomly distributed levels in the compound nucleus, one may conclude that its lifetime is no shorter than 0.7×10^{-20} sec.

12. Charged-Particle Cross Section Compilation F.K. McGowan, W.T. MILNER

The purpose of this activity is to continue the compilation of nuclear cross sections for chargedparticle-induced reactions. In scope and form, the compilation will follow the plan of previous versions in Los Alamos Reports LA-2014 and LA-2424. The "best values" of the cross sections will be presented in graphical form with the grid lines reproduced. In addition, the data will be given in tabular form for all charged-particle-induced reactions, including heavy ions, at all energies.

A literature search for the years 1948-1961 has been completed. The bibliography contains abstracts of the papers from this literature search. Data for the elements Mn through Sm are being compiled in tabular form.

13. ORNL Tandem Accelerator C.D. MOAK

The voltage rating of the Tandem accelerator has been increased from 6 to 7.5 megavolts; thus the proton energy range has been extended from 12 to 15 Mev and data have been taken at 15 Mev. Oxygen ion energy range is increased from 42 to 52.5 Mev. The accelerator has been used to calibrate special fission detectors using Br ions as artificial fission fragments with energies ranging up to 100 Mev. For heavy fragment calibrations, I ions are now being used.

10. PHILLIPS PETROLEUM COMPANY

A. TOTAL CROSS SECTION OF Pa²³³ F.B. Simpson, R.P. Schuman

Measurements on the decayed Pagaa samples were taken in the thermal and resonance regions on the MTR fast chopper in order to determine the amount of U²⁰³ present in the samples and thus the effective sample thickness of Pa233 at the time of measurement. The measurements on Pa233 sample No. 1, which was used to measure the total cross section between 1 and 6 ev, agree within 5% with the number of atoms/cm² calculated from the irradiation time and flux. The measurements on Pa²³³ sample No. 2 do not agree well with such calculations, and indicate that the thermal (0.025 ev) cross section previously reported as ~ 40 b should be connected to a preliminary value of -70b. The data below 1 ev also indicate the presence of a small resonance at 0.38 ev with a peak cross section of ~ 40 b. An additional Th sample has been prepared for irradiation in order to repeat this series of measurements.

B. PREPARATION OF SEPARATED Pa²³³ J.W. Codding

Two experiments have been performed to demonstrate a combination scavenging-extraction process for the recovery of gram amounts of Pa233 from irradiated Th. The first was done using halflevel concentrations of Pa231 and U233, and the second used full concentrations of each. The general recovery scheme is as follows: irradiated Th containing Pa²³³, U²³³, U²³¹, and some fission products is dissolved in a nitric acid-hydrofluoric acid mixture yielding a solution with a protactinium concentration of about 1 g/l. The initial separation of protactinium from U and Th is accomplished by scavenging the protactinium from the dissolver solution MnO₂ formed in situ. Hydrochloric acid dissolution of this precipitant yields a solution from which protactinium can be preferentially extracted with diisopropyl ketone. Back extraction with hydrogen peroxide provides a concentrated protactinium product from which Pa₂O₅ can be prepared for a chopper target. It was found that the full-level concentrations used in the second experiment enhanced protactinium recovery and despite the higher protactinium concentration the scavenging efficiency was not impaired but was actually improved. Alpha pulse height analyses were done on evaporated samples of the feed, precipitate product, and extraction product for run 2. It was found that protactinium was decontaminated from U by a factor of 8.6 during the MnO_4 precipitation step and by a factor of 4.4 during a subsequent hexone extraction. (Diisopropyl ketone was not available for these experiments.) It is expected that the extraction of protactinium will be greatly enhanced by replacing hexone with diisopropyl ketone. Consideration is also being given to including in the process a second precipitation step to take advantage of the higher decontamination available during scavenging.

C. FISSION MASS YIELDS OF U²³⁵ AS A FUNCTION OF NEUTRON ENERGY K.T. FALER, R.L. TROMP

Experimental work in this study was completed with five irradiations of U^{235} (two at 0.04 ev with neutron crystal spectrometer neutrons, two with C-filtered neutrons from the MTR cold-neutron facility, and one consisting of a Cd-covered background determination in the thermal column). All data were processed and the final results are shown in Table 9.

Variation of Peak-to-Valley Ratios for U ²³⁵	
Fission Yields as a Function of Neutron Energy	y

Table 9

Energy, ev	R	Standard deviation
0.0002	0.765	0.044
0.004	0.875	0.042
Thermal	1.000	0.032
0.040	0.880	0.047
0.060	0.783	0.021
0.100	0.796	0.059
0.250	0.730	0.022
0.284	0.746	0.026
0.330	0.708	0.022
0.500	0.841	0.033
All epi-Cd	1.181	0.081

The behavior of the R values (peak-to-valley ratio at energy E normalized to that at thermal) remains an anomaly at very low energies. Such behavior is unexpected in the region where no resonances exist in U²³⁵.

D. FISSION CROSS SECTION OF Pu²⁴¹ T. WATANABE, O.D. SIMPSON

Measurements of the fission cross section of Pu^{24t} near thermal energies have been carried out on the MTR fast chopper at a flight path of 4 m in order to determine more accurately the shape of the thermal fission cross section for Pu^{24t} . The results of these and earlier measurements are being prepared for publication.

E. TOTAL CROSS SECTION OF Pu²³⁸ T.E. YOUNG, F.B. SIMPSON

Measurements on the present Pu^{238} sample have been completed. It was noted that the off-resonance effective cross section of this sample appears to be increasing with time since the sample was purified; presumably this is due to the formation of an impurity such as oxygen or water. It is hoped that chemical analysis of this sample will permit appropriate corrections to be made.

F. PRECISION MEASUREMENTS OF TOTAL AND PARTIAL CROSS SECTIONS ON THE CRYSTAL SPECTROMETER R.R. SPENCER

The general experimental approach in this area has been the application of time-of-flight techniques to the Bragg neutron beam in order to separate the effect of the various orders of Bragg reflection. A Fermi-type chopper was mounted on the arm of the spectrometer and the time-of-flight of the Bragg neutrons over an \approx 2-m flight path was used to separate the orders. Total cross sections were then determined by standard transmission techniques, with two exceptions: backgrounds were determined simultaneously with sample and open counts by observing the detector pulses occurring at flight times not associated with the Bragg orders; also the total cross section was determined at several energies simultaneously by utilizing several Bragg orders. Extension of this system to measurement of partial cross sections is obvious.

For the present expendence three-channel transistorized time-of-fligh . vas developed for use with the chopped n appropriately small counting dead in ... une time channel was set to count only the first order Bragg neutrons, a second was set to include only second order Bragg neutrons, and a third was set to determine the background pulses. Transmission measurements on a standard Au sample are now in progress and will be compared to measurements on the same sample with the MTR fast chopper.

In addition to cross-section measurements the time-of-flight technique was used to study the composition of the Bragg neutron beam from the Be (0002) planes. Forbidden Be (0001) reflections were observed at several crystal orientations. In addition, a forbidden Be (0003) reflection was observed at several orientations. These forbidden reflections are undoubtedly caused by multiple reflection within the crystal lattice and can in some cases constitute a major portion of the Bragg beam.

G. HALF-LIFE DETERMINATION OF LONG-LIVED Ho¹⁶⁶ B. Keish, K.T. Faler

The half-life measurement of the long-lived isomer of Ho¹⁶⁶ was based on a specific activity measurement of a sample irradiated to 5.6×10^{21} n/cm² and on the assumption that all decay goes via the 180-key gamma ray transition. Mass analysis of the irradiated Ho showed that 0.6% was Ho¹⁶⁶. Since no direct measurement of the internal conversion coefficient of 180-key gamma ray had been made, the theoretically calculated value of 0.30 was assumed to be correct. The largest uncertainty in the determination was in weighing the $20-\mu g$ sample. The half-life value calculated with estimated uncertainty is 90,000±18,000 years. This value gives a formation cross section of about 1 b to this isomer, which is consistent with the absorption cross section and with the cross section for formation of the short-lived (27 hr) isomer.

The cross section for formation of 27-hr Ho¹⁶⁶ by neutron activation was found to be 64 ± 6 b. The determination was made using a Co flux monitor and measuring the activity of the Ho¹⁶⁶ with a $4\pi \beta$ - γ coincidence counting system. The decay rate of the source was followed as a check on the purity of the sample.

H. ISOMER YIELD RATIOS B. KEISH

The program for accurately determining yield ratios of isomers produced by neutron activation has been drawn to conclusion and all the data have been prepared for publication. The following values of yield ratios are included in the article. For Sb^{122,122m}, the yield ratio for thermal neutrons was determined to be 0.066 ± 0.008 by $4\pi \beta$ - γ coincidence counting of the two isomers in the same sample. For In^{114,114m}, the yield ratio for thermal neutrons was determined to be 2.1 ± 0.1 and for epi-cadmium neutrons 2.4 ± 0.2 . The measurements were made by counting samples in a standardized position with an end-window β -proportional counter. An absorber was used to prevent counting of electrons from the upper isomeric state while the decay of the isomers was followed. A 100-fold re-irradiation of each sample was necessary in order to obtain good counting statistics for the longer-lived isomer. Au-foil monitors were used to compare the neutron exposures of the two irradiations. Formation cross sections were also determined for the two isomers (for thermal neutrons only) by standardizing the counting set up with a Re¹⁸⁸ source. The best values obtained for these cross sections are: 3.9 ± 0.4 b for the formation of 72-sec In¹¹⁴ and 8.1 ± 0.8 b for the formation of 49-day In^{114m}.

For Rb^{86,86m}, the yield ratio (for thermal neutrons) was determined by first counting "to death" the 560-kev gamma ray emitted in the decay of the 1-min isomer and then (on the same sample) counting the 1080-kev gamma ray emitted by the

	Table	10			
Thermal Cross Deter	Thermal Cross Sections and Resonance Integrals Determined in VH-2 in MTR				
Target nucleus	σ th , b	Resonance integral, b	Cd ratio in VH-2		
Very thin Mn	13.1	14.0	17.4		
2-mg Mn metal	13.4	11.3	21.8		
Very thin Co	39.1	74.6	10.2		
Very thin Au	(98.8)*	(1558)*	2.11		
2-mg Au metal		805	_		
Very thin U ²³⁶	~5.4	381	1.25		

*Gold standards assumed to measure flux.

18.7-day isomer. The yield ratio was found to be 0.12 ± 0.01 . The cross section for the formation (by thermal neutron activation) of the 1-min isomer was determined using the same counting technique but incorporating a Au-foil flux monitor. The cross section was found to be 0.061 ± 0.006 b. The cross section for the formation (by thermal neutron activation) of the 18.7-day isomer was determined by $4\pi \beta - \gamma$ coincidence counting of a weighed sample and by using a Co flux monitor. The value obtained was 0.46 b but this must be considered tentative until confirmatory experiments are completed.

I. MEASUREMENT OF RESONANCE INTEGRALS J.R. Berreth, R.P. Schuman

Resonance integrals were measured by irradiating samples of very thin Co, Au, Mn, thicker Mn and Au, and U^{236} inside a 1-mm-thick Cd shield in the VH-2 vertical hydraulic rabbit in the MTR. An unshielded irradiation of the same materials was also made in the same position.

Preliminary values of resonance integrals, thermal cross sections, and Cd ratios are given in Table 10. The activation of Co, Au, and Mn was determined by absolute gamma counting of the 1.33, 0.845, and 0.412-Mev gamma rays, respectively. The U²³⁷ in the U²³⁶ was determined after purification of the U. The U²³⁶ was determined by alpha counting and alpha pulse analysis of the purified U. The U²³⁷ was determined by absolute gamma counting of the 0.208-Mev gamma peak and by $4\pi \beta \gamma$ counting. The U²³⁶ resonance integral is somewhat higher than the value of 310 b calculated from the resonance parameters. The resonance integral of Co agrees well with the expected value of 75 b determined by Eastwood and Werner at AECL.

J. LATTICE VIBRATIONS IN BERYLLIUM R.E. SCHMUNK, R.M. BRUGGER, P.D. RANDOLPH, K.A. STRONG

A paper with the following abstract has been accepted for publication in the *Phys. Rev.*

Measurements of the dispersion relations for waves propagating in the [0001] and $[01\overline{1}0]$ directions in Be have been made using the MTR phased chopper slow-neutron velocity selector. In the $[01\overline{1}0]$ direction only one of the transverse modes was available for investigation, that having atom displacement normal to the basal plane. Two distinct frequencies were observed at the center of the Brillouin zone for the optical branches, and the corresponding branches are referred to as upper optical and lower optical. For both symmetry directions, the upper optical branch corresponds to the mode of vibration having the polarization vector parallel to the hexagonal axis. Pertinent frequencies in units of 1013 sec-1 are: (at the center of the zone) upper optical, 1.99 ± 0.07 ; lower optical, 1.33 ± 0.04 ; (at the zone boundary in the [0001] direction) lower optical and transverse acoustical, 1.01 ± 0.06 ; upper optical and longitudinal acoustical, 1.57±0.07; (at the zone boundary in the [0110] direction) upper optical, 1.69±0.09; lower optical, 1.63 ± 0.08 ; longitudinal acoustical, 1.54 ± 0.08 ; transverse acoustical, 1.21 ± 0.05 . The mode of vibration for a particular phonon was determined from the region of reciprocal space in which the transition was observed. The initial slopes of the acoustical branches agree well with the elastic constant data, except for the longitudinal branch in the [0001] direction. Lattice dynamics models of Begbie and Born and of Slutsky and Garland (the latter extended to include interactions with fourth and fifth nearest neighbors) give limited agreement with the present data only when the force constants in the models are evaluated from the neutron scattering data.

K. PHASING TWO CHOPPERS FROM A MOTOR GENERATOR SET R.M. BRUGGER, K.A. STRONG

A paper with the following abstract has been accepted by Nuclear Instr. & Methods.

Two Fermi-type neutron beam choppers have been successfully phased when driven by fractional horsepower synchronous motors with power supplied by a motor generator source. A simple and accurate method of varying the phase is described. Results indicate that this relatively inexpensive chopper drive system is as satisfactory for certain neutron time-of-flight experiments as a system employing an oscillator and power amplifiers.

L. SCATTERING OF SLOW NEUTRONS FROM LIQUID SODIUM P.D. RANDOLPH

The processing of the data for scattering of neutrons of 0.025, 0.07, and 0.1 ev from samples of liquid Na (5% scatterer) at 100°, 150°, and 200°C continues. The agreement between these data when integrated to give the differential cross section $d\sigma/d\Omega$ and neutron diffraction data obtained by Heaton is good. From preliminary interpretations of the data, the following tentative conclusions are drawn: (a) The convolution approximation of Vinyard is not valid. (b) The extrapolation method of Egelstaff does not give a unique $p(\beta)$. (c) Considering only the data at large momentum transfers and Fourier transforming to the intermediate function, a unique $\rho(t)$ is obtained. For a wider range of α , this is not true. This says that over a limited range of the self correlation function $\sigma(r,t)$ is gaussian in r while over the extended range of r, $\sigma(r,t)$ is not gaussian. The shape of $\rho(t)$ indicates that at small times, the motion of a Na atom behaves like a free gas while at longer times, the atoms behave like solids. Still longer times where $\rho(t)$ behaves like a diffusing liquid were not accessible in this experiment. (d) Finally, evaluation of the zero'th and first moments at different values of momentum transfer gave values of 1.3 and 3 times the theoretical values, respectively. The zero'th moment is in reasonable agreement with the theoretically predicted value of 1, while the first moment is in marked disagreement with the theoretically predicted value. Energy and angular resolution have been excluded as causes for this discrepancy.

M. C₂H₆, n-C₄H₁₀, H₂S, and NH₃ R.M. Brugger, Y.D. HARKER

Data at 0.025, 0.07, and 0.1 ev for samples of C_2H_6 , n- C_4H_{10} , H_2S , and NH_3 have been obtained and converted to the scattering law presentation. The data are internally consistent and agree in magnitude with total cross section measurements. Correlation between these data and the dynamics of the molecules is being pursued.

N. COLD METHANE R.M. Brugger, Y.D. Harker

Data at 0.025, 0.07, and 0.1 ev for a sample of methane gas at -148°C have been obtained and converted to the scattering law presentation. The data show interesting differences compared with room temperature methane data. Explanations of these differences are being pursued. A liquid methane sample holder has been constructed, and scattering measurements with this sample should start in October.

O. POLYCRYSTALLINE BERYLLIUM R.E. Schmunk

Preliminary data for a 10% scatterer of powdered Be have been obtained at 0.1, 0.07, and 0.025 ev. These data are being processed.

P. COLD NEUTRON FACILITY K.A. Strong

Using the phased chopper velocity selector at the MTR cold neutron facility, data for scattering at 90° from samples of H₂, NH₃, CH₄, C₂H₆, C₃H₈, and C₄H₁₀ have been obtained. These data are being compared with previously obtained data for CH₄ and C₃H₈. If the agreement is satisfactory, data at other angles will be obtained.

Q. SCATTERING OF NEUTRONS BY LARGE MOLECULES H.L. MCMURRY, L.J. GANNON, D. SPEAS

The slow neutron scattering from polyatomic molecules is strongly influenced by the vibrational motions. Calculations which take proper account of quantum effects can be laborious when the neutron energy exceeds the characteristic energy for one or more of the normal modes. Studies in this laboratory suggest that when the neutron energy exceeds a characteristic vibrational energy sufficiently, the mode may be treated classically. This greatly reduces the work required to calculate the scattering by high energy neutrons, particularly when one or more modes have characteristic energies near kT.

A program has been written for the IBM 7090 which takes advantage of this simplification. The

Criteria for Treating Vibrations Classically*			
Range of $B_{\lambda} = E_{\lambda}/kT$	Conditions on $B_o = E_o/kT$		
$0 \leq B_{\lambda} \leq 1$	$0 \leqslant B_{\mu}$		
$1 < B_{\lambda} \leq 2$	$B_{\lambda} \leq B_{\rho}$		
$2 \leq B_{\lambda} \leq 4$	$2B_{\lambda} \leqslant B_{\rho}$		
$4 \leq B_{\lambda} \leq 8$	$3B_{\lambda} \leqslant B_{\rho}$		
$8 < B_{\lambda}$	$4B_{\lambda} \leqslant B_{\mu}$		

input data for any molecule include the characteristic energies of the normal modes, together with the elements in the transformation matrix which relates the displacements of the atoms to the normal modes. Criteria are built into the program such that the machine decides when a classical treatment can be used. The first criteria tried are shown in Table 11. Based on calculations on CH₄, C₃H₈, and some other molecules, they are adequate only when there are no modes with B_{λ} near to or less than one. Here, $B_{\lambda} = E_{\lambda}/kT$ and E_{λ} denotes the characteristic energy of the mode.

A more satisfactory criterion appears to be a relation which should insure the validity of the short collision time expansion. It is

$$(m_{\nu}/m)^{3/2}(m\delta_{\nu\lambda})^{1/2}E_{\lambda} < cE_o\phi.$$
(1)

In Equation (1) the $\delta_{r\lambda}$ is the factor which relates the square of the displacement Δr of atom ν to the λ normal coordinate. The ϕ is given in terms of the incident neutron energy E_o , the scattered neutron energy E and the cosine of the scattering angle, μ , by

$$\phi = (E - E_o)/E_o + 2 - 2\mu\sqrt{E/E_o} .$$

In determining the mass m_r , the translational and rotational degrees of freedom are treated like normal modes. For molecules in the gas phase, all these modes have zero frequency. In the liquid or amorphous solid phase they can be treated as oscillations, or as free motions depending on the model used to describe the liquid. The mass m is computed from

$$(1/m_{\nu}) = (1/m) + \frac{1}{3} \Sigma_{\lambda} \delta \nu_{\lambda} . \qquad (2)$$

In Equation (2) the sum on λ includes only those modes with zero characteristic frequency. In the gas phase, this includes the rotational and translational degrees of freedom and then m_v is just the value obtained from the Sachs-Teller mass tensor.

The problem is to find what value of the constant, c, makes Equation (1) a valid criterion. The equation is being tested by means of calculations on CH₄, C₃H₈, and other molecules.

R. SCATTERING FROM LIQUID METHANE G.W. GRIFFING

The experimental results of Stiller and Hautecler on the scattering of neutrons by liquid meth- 10 3

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appears necessary to assign other degrees of freedom by which the neutron and liquid can exchange energy. It is not planned to carry this work further until experimental results which will be conducted at the MTR become available.

ane can be qualitatively understood according to a model in which the molecule is free to rotate as in the gaseous state and in its translational motion it drags a number (perhaps as high as 50) of molecules along with it. For a detailed comparison, it

11. RICE UNIVERSITY

A. LOW BACKGROUND SYSTEM FOR NEUTRON AND GAMMA RAY EXPERIMENTS WITH TANDEM ENERGIES J. RICKARDS, B. BONNER, G.C. PHILLIPS, P. STELSON

In order to obtain low background levels the tandem proton beam is stopped in a neutron sink lined with a borax shield, placed 30 ft away from the target. The targets employed are thin enough to prevent excessive scattering of the beam onto the vacuum tube walls. The beam is aligned with the aid of a remotely retractable quartz viewer. For further precision in the beam focussing and alignment, a remotely operated plunger was installed on which the beam current is measured. The current is minimized on a Ta disk with an 1/8-in-diam orifice and maximized on a slug behind it. After passing through the analyzing magnet exit slits and a shielding wall, the beam has no significant obstruction except a ³/₄-in.-diam cross section region where it passes through a magnetic



Figure 13. Slow neutron background with and without Ni⁵⁸ target in beam.

focussing lens. A sphere counter was used to monitor neutrons along the beam tube, and indicated that the focussing limitations are strict and that the worst background source was the magnetic focussing lens located 15 ft in front of the target. Best results are obtained for energies above 7 Mev when the beam is lined up both electrically, as described above, and with a minimum counting rate in a monitor neutron counter placed at the magnetic lens. Tests made by stopping the beam in a 99.94% enriched Ni⁵⁸ slug behind the target indicated that the neutron background is higher by a factor of 30 at 9 Mev [below the Ni⁵⁸(p,n) threshold] than that from the unobstructed system. The results at various energies are shown in Figure 13.

The technique now seems to be adequate to allow the determination of a very large number of ground state and excited state (p,n) threshold measurements.

B. NEUTRON GROUPS FROM THE PROTON BOMBARDMENT OF C¹³, Al²⁷, AND Ni⁶² J. Rickards, B. Bonner, G.C. Phillips

By using the technique of stopping the tandem proton beam in a neutron sink 30 ft away from the target, neutron thresholds from the proton bombardment of C13 have been observed. The special slow and fast counter ratio showed a peak corresponding to the ground state of N13 and one broad peak corresponding to the second and third excited states, which are about 50 kev apart. It should be noted that all excited states of N13 are proton unstable. No evidence was found for the first excited state. The experiment was carried up to an energy of 10 Mev covering the energy range where the mirror nucleus C13 has been found to have two excited states; however, no further thresholds were observed. The excitation curve from both counters followed the general shape determined at the University of Wisconsin up to 7 Mev where neutron background became excessive. By using the ground state Q value as calibration, the excitation energy of the second state was found to be 3.464 Mev.







Figure 14. Slow/fast neutron counter ratio with $C^{13}(p,n)$ reaction.



Figure 15. Slow/fast neutron counter ratio with Ni⁶² (p,n)Cu⁶² reaction.



Figure 16. Slow neutrons at 0° from Ni⁶² (p,n)Cu⁶² reaction.

There is no obvious explanation of the failure to observe the first excited state thresholds. An Al foil ≈ 4 kev thick was used for observation of thresholds in the Al²⁷(p,n)Si²⁷ reaction. Thresholds were measured for levels from the ground state to the fourth excited state. The excitation energies obtained for the first four excited states are 0.782, 0.958, 2.166, and 2.651 Mev, respectively, in very good agreement with spectra obtained from the Si²⁸(He³, α)Si²⁷ reaction.

A thin Ni⁶² foil 98.7% enriched was obtained from ORNL for an exploration of excited states in Cu⁶². The energy was varied in 7-kev steps from threshold to about 2.5 Mev excitation. Thresholds were observed for the ground, first, and second excited states only, although more states are expected and have been observed by gamma decay of Cu⁶². The ground state threshold is at 4.809 Mev bombarding energy and the first and second excited states are at 0.042 and 0.295-Mev excitation, respectively. The 0° excitation curve showed a very complicated structure, with at least 40 resonances evident in the region studied, which covered from 10.8 to 13.1 Mev excitation energy in Cu⁶³. Figures 14-16 show some of the curves obtained.

C. RADIATION FROM THE TANDEM VAN DE GRAAFF R.R. PERRY, H.D. SCOTT

Operation of the tandem Van de Graaff with deuterons has been delayed because of the increased radiation hazard compared with the operation with protons. The radiation was found to be primarily produced at the accelerator terminal. Walls of concrete blocks have been built at the following locations: a) in the high energy end of the accelerator room; b) against the outside wall opposite the accelerator terminal; and c) across the gap between the control room and the experimental room. To absorb thermalized neutrons, holes in the concrete blocks have been packed with borax. The gas stripper was modified so that the beam hit only Ta instead of Be and Al at the entrance to the stripper. It was then found that operation of the accelerator with 10-Mev protons produced no neutrons at the terminal. However, the gamma radiation at a position 1 ft away from the nearest tank wall to the stripper entrance was 1 rem/hr.

D. PROJECT TO USE C12 AND NI58 AS TARGET BACKINGS AND BEAM SLITS IN THE TANDEM G.C. PHILLIPS

To date no sizable quantities of C^{12} of suitable form have been prepared by the Isotopes Division; however, the data of Section A above points out the extreme chemical cleanliness required for the material.

Presumably the Ni⁵⁸ disks, prepared at Oak Ridge, were as clean as possible yet they produced intense yields of neutrons below the Ni⁵⁸(p,n) threshold indicating that they were somewhat contaminated by other elements.

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E. ENRICHED SILICON JUNCTION COUNTERS T.A. RABSON, G.C. PHILLIPS

No actual progress has been made on this project except that the laboratory facilities for counter preparation have been obtained and the construction of counters from ordinary Si will commence shortly.

F. INTERNATIONAL CONFERENCE IN FAST NEUTRON PHYSICS

An International Conference in Fast Neutron Physics will be held at Rice University, February 26-28, 1963, celebrating the Semicentennial of Rice University and honoring the late Professor T.W. Bonner.