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FOREWORD

This Summary Report on the work of the Physics Division of the Argonne National Laboratory is presented for the information of members of the Division and a limited number of other persons interested in the progress of the work.

It is merely an informal progress report. The results and data therefore must be understood to be preliminary and tentative.

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

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* This project is inactive. Further reports will be made when work is resumed.

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*This project is inactive. Further reports will be made when work is resumed.

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I. EXPERIMENTAL NUCLEAR PHYSICS

H/16 - 5667

1-13 The Argonne Fast-Neutron Velocity Selector (5220)

Lowell M. Bollinger, Robert E. Cote' and George E.
Thomas
Reported by Robert E. Cote'

During the period of this report work has continued on the new rotor, described in the last report; and construction was started on a new detector station.

So far, slits have been cut in two pieces of the rotor. The slits in the central uranium core have been finished and the slits have been cut through the uranium ring which surrounds the central core. Work is under way to taper the slits in the ring. Design work has been completed on a new damper assembly for this rotor.

The flight path is being increased in order to improve the resolution of the system. The reasons for waiting until now to do this are twofold. Firstly, the resultant loss in counting rate will be less serious than formerly due to the increased flux now available at CP-5; and secondly, the overlap of consecutive neutron bursts from the new rotor (which gives 2 bursts per revolution instead of 4) will be small enough so that corrections for it may be made easily, whereas this would not be so if the present rotor were used with the increased flight path. This modification of the system requires that a new detector station be built and that the helium-filled flight tube be extended.

A new detector station was designed and is now about seventy-five

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percent complete. It is located about 120 m from the chopper. The building is about twelve feet square, of frame construction, and divided into two rooms. One of these, about six feet square, will be insulated and air conditioned. Its purpose is to house the detector and the shielding necessary for its proper operation. The remainder of the building will be used to house the associated electronic equipment.

The job of extending the flight tube is about fifty percent complete.

2-13 Neutron Detectors (5220)

Lowell M. Bollinger, Roland J. Brown, Adnan Saplakoglu
and George E. Thomas
Reported by George E. Thomas

The neutron-detection characteristics of silver-activated zinc sulfide in fused anhydrous boric oxide are being investigated. These scintillators are fabricated by a previously known technique¹, being heated at 540°C and pressed into wafers of a diameter as large as 14 cm. Scintillators were made with thicknesses varying from 0.5 mm to 2.6 mm and with zinc sulfide concentrations from 5% to 50%. These were successively affixed to a Dumont 6292 photomultiplier, and the counting rates for thermal neutrons were observed. The most efficient thickness is 0.90 ± 0.01 mm. Increasing the thickness to greater than 1.0 mm causes the efficiency to drop rapidly. The lower limit of the thickness is less certain. An optimum concentration is $33 \pm 5\%$. These values are in substantial agreement with those previously reported from Brookhaven.² Currently under investigation is a modified arrangement whereby single layers of quartz or lucite are alternated with

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single layers of boric oxide-zinc sulfide scintillators whose planes are oriented normal to the photomultiplier face; but work is insufficiently advanced to be reported at this time.

The possibility of being able to differentiate between two types of radiation by their decay times was suggested in the last summary report. An experimental attempt to separate the gamma and neutron pulses using a boron-loaded liquid scintillator was set up; but our inability to detect any differences in decay time between these two pulses made the above mentioned scheme impossible.

The 16" long, boron-loaded, liquid scintillation detector previously mentioned in a summary report has been tested and proven satisfactory.

Mechanical Characteristics

- (a) Counting area 2-1/4" x 16"
- (b) Counter thickness 1"
- (c) Counter material 1/32" Armco iron
- (d) Four photomultipliers equally spaced along the length of the detector facing the 2-1/4" x 16" counting area. The first and third photomultipliers are wired in parallel, also the second and fourth.

Optical Properties

- (a) The inside of the detector is coated with a highly-reflecting porcelain. On top of this is sprayed a mixture of aluminum oxide (Linde A) and water glass.
- (b) The pulse-height distribution is approximately triangular with a width at half maximum that is 80% of the energy at which the maximum occurs.

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The purpose of this relatively long detector should be noted. The reduction in flux due to increasing the flight path to 120 meters necessitates a larger detector area in order to maintain the neutron counting rates. To use many small detectors would be impractical due to the large amount of electronic equipment necessary.

The boron-loaded, liquid scintillation detectors which have been filled within the past year have had distinctly poorer resolution than those previously used. Whereas the energy distribution of thermal neutrons previously had a width at half-maximum of about 85%, the more recent ones had widths of at least 100% of the energy at which the peaks occurred. After an investigation of the scintillators used, it was found that the chemicals used recently were less pure than the original ones. Preparing new scintillators with chemicals of high purity improves the resolution to about 65%, using the same detectors. This improvement has been reflected in all of the liquid detectors we use. It should be stressed that for liquid scintillator work one should use chemicals of high purity (scintillation grade) purchased from a company highly regarded in the manufacture of this type of chemical.

A special type of boron-plate detector has been constructed and is being used with the fast chopper to measure the absolute cross section.

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1. S. B. Gunst, J. C. Connor, and R. T. Bayard, Rev. Sci. Instrum. 26, 894 (1955).
 2. C. O. Muehlhause, Brookhaven National Laboratory Report, BNL-242 (T-38), Nov., 1953.

3-13

Cross-Section Measurements with the Fast Neutron Velocity Selector (5220)

Lowell M. Bollinger, Roland J. Brown, Robert E. Cote',
Jeanne P. Marion, Adnan Saplakoglu and George E. Thomas
Reported by Lowell M. Bollinger

a) FISSION CROSS SECTION OF Pu^{239}

Fission cross-section measurements on Pu^{239} have continued, using the technique of counting fission rates by detecting fission neutrons rather than the conventional method of detecting fission fragments. Some of the results obtained are compared in Fig. 1 with data previously obtained by detecting fission fragments. (The two sets of data were obtained in approximately equal effective running times.) The great improvement in the statistical accuracy of the new results, caused by the much greater thickness of sample that can be used when fission neutrons are counted, is

Fig. 1. Comparison of fission cross-sections obtained by detecting fission neutrons with those obtained by detecting fission fragments. The two runs were for approximately equal effective counting times.

obvious in the figure. This improvement in quality has enabled us to determine $\sigma_0 \Gamma_f$, and hence Γ_f , for three small resonances (23.9, 23.2, and 35.3 ev) that were almost unobservable in our earlier measurements in which fission fragments were detected. Furthermore, a good measure was obtained for off-resonance fission cross sections at energies less than 40 ev, even though the cross section dips below 1 barn in some places. It is felt that these results establish the new method of measuring fission cross sections as being the best technique available for some applications.

b) CROSS SECTION OF Pu^{242} and Am^{243}

The neutron transmissions of small samples of Pu^{242} (approximately 25 mg) and Am^{243} (approximately 5 mg) have been measured. The use of the fast chopper to study such small samples is an example of its application to a problem for which it is uniquely suited. Our experience in these measurements has shown that, in special cases, it would be possible to work with a sample having an area as small as 1 sq mm.

This investigation on Pu^{242} and Am^{243} is of interest chiefly because the epi-thermal cross sections of both materials had not been measured previously. The preliminary results obtained are in qualitative agreement with what would be expected on the basis of data previously obtained for neighboring nuclides. The measurements on Am^{243} have been completed and the data are being treated; the measurements on Pu^{242} will be continued.

c) CROSS SECTION OF NIOBIUM

The possibly anomalous behavior of the neutron cross section for niobium, as suggested by the extremely small transmission dips produced

by its resonances, indicated the desirability of a study more complete than those previously performed. Therefore the neutron transmission of four different samples was measured over a wide energy range. Resonance parameters were obtained for 12 levels. It is found that to some extent the small size of the transmission dips observed in earlier studies of niobium is caused by the chance occurrence of atypically-small resonances at low energies. The average resonance is, nevertheless, unusually narrow and the value obtained for $\overline{\Gamma}_n^0/\overline{D}$, about $0.9 \times 10^{-5} \text{ ev}^{-1/2}$, is the smallest yet reported. In other respects the cross section is not unlike that of neighboring nuclei. The level spacing is typical and the measured radiative-capture width of 0.20 ev is close to the value of 0.22 that was obtained by interpolating between known values of $\overline{\Gamma}_\gamma$ for other materials.

I-4-1 Mass Distribution in Fission (5220)

Lowell M. Bollinger, Louis W. Roeland and George E. Thomas
Reported by Louis W. Roeland

Some recent developments^{1,2} in the theory of fission indicated a possibility of finding the J values associated with resonances in the fission cross section. In general, the compound nuclei will be formed in two different states, differing in their relative yields of symmetric fission. In the case which is of main interest to us, the neutron-induced fission of U^{235} , the compound nucleus is formed in the 3^- and 4^- states. It is predicted that the 3^- state is inherently unable to give rise to symmetric fission; whereas for the 4^- state symmetric fission could occur, although with a

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small yield.

Both this small yield and the rather low flux within our resonance make it clear that, in order to have a reasonable counting rate, one wants a large counter. For the proposed measurements on U^{235} , a back-to-back Frisch-grid ionization chamber was designed with a sensitive area of 8" x 12". The Frisch grid consists of 10-mil stainless steel wires spaced 0.2" apart. The distance from the high-voltage electrode to the grid is 2", that from the grid to the collecting electrode 1". The construction of the counter is nearly completed.

The greatest problem in this project is the preparation of the sensitive area. It will consist of a formvar foil ($14 \mu\text{g}/\text{cm}^2$) mounted on a collimator. The foil must be coated with a much thicker ($200 \mu\text{g}/\text{cm}^2$) film of U^{235} . Because of the huge dimensions of the foil, evaporating would be too time consuming. Attempts were made to spray or paint a uranyl nitrate solution. This failed due to destruction of the foil. Experiments are going on in the direction of spraying, painting or electroplating the U^{235} onto an aluminum-coated formvar film.

For preliminary measurements on U^{233} , a similar but smaller chamber has been designed and sent to the shop.

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1. A. Bohr, International Conference on the Peaceful Uses of Atomic Energy, Geneva, (July 1955), p. 911.
 2. J. A. Wheeler, Gatlinburg Conference on Neutron Physics, November 1956.

6-12

Spiral Velocity Selector for Slow Neutrons (5220)

Rauf Nasuhoglu and Roy Ringo
Reported by Roy Ringo

This selector has been modified to stop diffusion of thermal neutrons through it and now appears to operate satisfactorily. It has been used to make measurements of the spectrum of thermal neutrons in the wavelength range between 10 and 20 Å.

Several materials were tried at the inner end of the CP-5 thermal column from which the beams analyzed by the velocity selector were extracted. These included a piece of polystyrene 1 cm thick, a 10-cm square can of D₂O, and a piece of graphite 30 cm long. In the wavelength range mentioned, all the observed spectra decreased with increasing wavelength much more rapidly than the Maxwellian distribution. The differences among the different materials at the source point were not large, but D₂O appeared to give the largest low-energy flux.

Consideration is being given to cooling the source point to liquid N₂ temperature.

8-1

Fission Yield at Different Neutron Absorption Resonances
(5220)

Lawrence Glendenin (Chemistry Div.) , Rauf Nasuhoglu,
Sol Raboy, Roy Ringo and Ellis Steinberg (Chemistry Div.)
Reported by Roy Ringo

Any variation of the distribution curve of yields of fission products from one resonance for slow-neutron-induced fission to another would be of considerable significance to the theory of fission. (Such differences would presumably be associated with the particular spin state of the compound nucleus,

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formed by neutron capture, which was involved in the fission.) It would even have a certain modest interest to show that there is no such difference between the two possible spin states.

It is proposed to make a measurement of the fission yield at different resonances by irradiating samples of U^{235} with monoergic neutron beams from the crystal spectrometer. The energies used would be selected to correspond to the known fission resonances and the fission yield would be determined by making a chemical separation and counting certain convenient fission products at interesting positions on the fission-yield curve.

The spectrometer has been prepared for these irradiations and chemical facilities for processing the several grams of U^{235} needed are now ready.

11-13 Installation and Operation of the Van de Graaff (5220)
Generator

Robert Holland, F. Paul Mooring and Jack Wallace
Reported by Jack Wallace

This report covers the operation of the Van de Graaff Generator in D-203 for the period September 1, 1956 to December 31, 1956.

The generator was used to accelerate protons, deuterons, and alpha particles. In the course of one experiment during this period the generator was operated at 4.225 Mev. This is the highest operating voltage to date for this generator.

The following time distribution shows both the division of time and the types of experiments being performed with the Van de Graaff generator.

No effort has been made to show any efficiency factor for the time allotted to the various experimenters. These are actual generator running times in hours per experiment.

	Hours
1. Lifetime Measurements of Nuclear States (Hanna, Krone, Meyer)	64.4
2. Angular Distribution of γ -Rays (Hanna, Meyer)	256.9
3. Resonance Measurement of Neutron Energies (Lee, Mooring)	158.3
4. Neutron Spectra of $Mn^{55}(p,n)Fe^{55}$ by Time of Flight (Holland)	119.6
5. Angular Distribution of Protons (Lee, Schiffer)	75.6
6. Total Neutron Cross-sections (Hibdon)	109.9
7. Li Plate Irradiation (Krohn, Ringo)	8.5
8. Photo-fission Cross-sections of the Heavy Elements (Clark)	63.3
9. Beam Squeezer (Lane)	17.8
10. Counter Calibration (Smith)	10.5
Total	884.8
Time Available	1517.0
Start up and daily maintenance	60.0
Machine repairs and improvements, and experimental setup	572.2

Due to the great variety of experiments performed and their difference in demand as to voltage and type of accelerated particle needed, there was much time lost in making these changes on the generator.

We believe much time will be saved if we can develop a good gas-switching device that could be operated from outside of the pressure tank.

Several designs have been tried, but proved unsuccessful. Another design of

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gas-switching device is now being tested.

New target assemblies have been constructed and have expedited the setting up of the experiments.

The new electronic circuits for the magnet and energy control have not been delivered.

Tests on the Titanium Evapor-ion pump have been suspended while it undergoes constructional changes in the Central Shops.

14-12 Pulsed Neutron Beams for the Van de Graaff Generator (5220)

Robert Holland

Neutron groups from $Mn^{55}(p,n)Fe^{55}$ have been studied by measuring their time of flight. The measurements were made with the externally-pulsed beam of the Van de Graaff machine which was chopped with a 3.5 Mc/sec sine wave to get 2-m μ sec pulses. Neutrons from the reaction were detected in a piece of Pilot B scintillator placed 36 inches from the target, and the resulting phototube pulses were fed to a time-to-pulse-height converter of Los Alamos design.¹ With a proton energy of 3.26 Mev, neutrons corresponding to the formation of Fe^{55} in the ground state and first two excited states were observed. The full-width at half-maximum of the gamma-ray peak was 2.8 m μ sec when the slow single-channel discriminator was set to accept pulses corresponding to Compton electrons of 200 to 300 kev. For neutrons of 1.5 Mev the full-width at half-maximum was 3.5 m μ sec for the same slow channel setting.

Preliminary values for the excitation energy of the first two excited

states of Fe^{55} are 450 kev and 960 kev, both of which are about 20 kev higher than more accepted values.

1. Weber, Johnstone and Cranberg, Rev. Sci. Instr. 27, 166 (1956)

15-9 Stopping Cross Sections of Gases for Heavy Ions (5230)

Merle T. Burgy

A preliminary report on the results obtained in this project was made in a paper, presented at the Thanksgiving meeting of the American Physical Society, entitled "Stopping Powers of Various Gases for Helium and Lithium Ions", Bull. Amer. Phys. Soc., 1, 342 (1956). In addition to the results of this project, the paper included similar measurements made with lithium ions by Prof. S. K. Allison and C. S. Littlejohn at the University of Chicago.

The final report on this project is still in preparation and should be completed during the next reporting period.

18-4 Differential Cross Section for Neutron Resonance Scattering
(5220)

Raymond O. Lane and James E. Monahan
Reported by Raymond O. Lane

Measurements of the angular distribution of neutrons scattered in the vicinity of resonances are made with the apparatus described in the topical report, ANL-5567 (1956). The analysis of these data provides information on the properties of the energy levels of the compound nucleus as well as the behavior of the potential scattering.

The detector tanks are now on a circular track to allow measurements at more angles. To obtain better focusing of the proton beam from the electrostatic accelerator, a magnetic alternating-gradient strong-focusing lens designed by R. E. Holland has been constructed and tested. The lens, together with other new auxiliary equipment, is being installed for future measurements.

A Monte Carlo calculation is being initiated which will make multiple-scattering corrections to present data on resonance scattering in plates.

20-13 Energy States of Light Nuclei from Charged-Particle Reactions
(5220)

Stanley S. Hanna, David R. Inglis, Linwood
L. Lee, Jr. and John P. Schiffer
Reported by Linwood L. Lee, Jr.

The existing track mounting for the 180° magnetic proton spectrometer has been observed to sag slightly under the weight of the magnet, making it inadequate for accurate angular-distribution measurements. Since measurements of this type are contemplated, a new mount is considered necessary. After investigation of alternative designs, an improved track is being designed and will be constructed. The new track will be a full circle in order to obtain greater rigidity and provide access to a wider range of angles than was previously available.

Stanley S. Hanna and Luise Meyer-Schützmeister

Reported by Stanley S. Hanna and Luise Meyer-Schützmeister

The angular-distribution measurements on the gamma-rays in the $\text{Li}^7(\alpha, \gamma\gamma)\text{B}^{11}$ reaction have been essentially completed. Fig. 2 shows the energy-level diagram for the reaction. The angular distributions obtained for the 9.28 and 6.81-Mev gamma-rays at the 960-kev resonance are given in Fig. 3. A summary of all the measurements appears in Table I.

A thorough study of the theoretical angular distributions is now in progress. It is quickly demonstrated that the

Fig. 2. Energy level diagram for the reaction $\text{Li}^7(\alpha, \gamma\gamma)\text{B}^{11}$.

Fig. 3. Angular distributions of the 9.3 and 6.8-Mev gamma-rays at the 0.96-Mev resonance. At the top are shown two typical pulse-height spectra from which the angular distributions were obtained.

simple assumption of "pure" transitions for the alpha-particles and gamma-rays is inadequate. Accordingly, all reasonable mixtures of l_α and l_γ have been treated. Despite the ambiguity inherent in the "mixed" distributions, a large number of spin and parity assignments can be eliminated. Table II gives a resumé of the conclusions for the 960-kev resonance.

TABLE I

MEASURED VALUES OF A_2 IN THE EXPRESSION $(1 + A_2 \cos^2 \theta)$
FOR THE REACTION $\text{Li}^7(\alpha, \gamma\gamma)\text{B}^{11}$.

Gamma Ray Mev	A_2^{γ} at Resonance		
	960 kev	820 kev	400 kev
9.0	-0.46 ± 0.03	-0.20 ± 0.05	-0.20 ± 0.04
6.81	0.47 ± 0.06	0.36 ± 0.08	
4.5	≥ 1.25	≥ 0.36	
4.46	≤ 0.26	≤ -0.30	

TABLE II

Assignments for the 960-kev resonance. Assignments marked (N) are eliminated because of failure to satisfy the stipulated requirement. Those labeled (Y) are possible with parameters satisfying the given conditions. $I_{\alpha}(\ell)$ is the relative intensity of the alpha-particle wave with orbital angular momentum equal to ℓ .

Assignment to state at		Requires
9.28 Mev	4.46 Mev	
7/2 ±	Any	$\cos^4 \theta$ in 9.28-Mev distribution (N)
1/2 ±	Any	isotropy in 9.28-Mev distribution (N)
Any	1/2-	isotropy in 4.46-Mev distribution (N)*
3/2 ±	7/2-	M2 or E2 radiation for 4.82-Mev (N)
3/2+, 5/2 +	3/2-	same distributions for 9.28 and 4.82-Mev (N)
5/2 +	7/2-	$A_2 < -0.05$ for 4.82-Mev distribution (N)
5/2 +	5/2-	$A_2 < 0.90$ for 4.82-Mev distribution (N)
5/2 -	7/2-	$A_2 < 1.10$ for 4.82-Mev distribution (N)
5/2 -	5/2-	$[I_{\alpha}(4)/I_{\alpha}(2)] > 0.50$ (Y)
5/2 -	3/2-	$[I_{\alpha}(4)/I_{\alpha}(2)] > 0.16$ (Y)
3/2 +	5/2-	$A_2 < 0.16$ for 4.82-Mev distribution (N)
3/2 -	5/2-	$[I_{\alpha}(2)/I_{\alpha}(0)] > 0.25$ (Y)
3/2 -	3/2-	$[I_{\alpha}(2)/I_{\alpha}(0)] > 0.16$ (Y)

* From result for 820-kev resonance.

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22-4

Scattering of Charged Particles (5220)

Jan Yntema

The scattering table has been graduated. The angular accuracy of the table, when mounted on the spindle, is better than 30 seconds of arc.

A system for inserting absorbers in front of the detectors has been constructed. It permits from 0.001" to 0.125" of absorber to be inserted by remote control.

The final assembly of the chamber has been started. It is expected that a focussed external beam will be available in the experimental tunnel near the end of January.

23-2

Resonant Detection of Neutron Energy Groups (5220)

Linwood L. Lee and F. Paul Mooring
Reported by F. Paul Mooring

The ratio of the number of neutrons scattered to the number transmitted by a resonant scatterer can, in some instances, be used to study neutron groups from a source. The experimental details have previously been described¹, and the method has been used to study the reaction $\text{Mn}^{55}(\text{p}, \text{n})\text{Fe}^{55}$ using lithium as the resonant detector. Preliminary results have been presented¹.

1. ANL-5609, Report I-23-1, p 19.

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More recent studies including observations at both 0° and 60° with respect to the incident proton beam have led us to revise our earlier results. Fig. 4 shows our revised results and compares them with measurements made by other authors^{2,4}. Our values for the ground state Q-value (-1.016 ± 0.008 Mev) and the excitation energy of the first excited state were obtained by transmission measurements rather than by the ratio technique. Efforts to use resonant detectors other than lithium have failed to date.

A paper on this subject was presented at the Chicago meeting of the American Physical Society³.

ARGONNE ⁵⁵ Mn (p,n) ⁵⁵ Fe	RICE ⁵⁵ Mn (p,n) ⁵⁵ Fe	MIT ⁵⁴ Fe (d,p) ⁵⁵ Fe
2147 ± 10	2165 ± 15	
1406 ± 10		
1314 ± 15	1327 ± 9	1.302
927 ± 10	925 ± 5	932
436 ± 20		413

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Fig. 4. Comparison of energy level diagrams of Fe^{55} as determined at the Argonne National Laboratory, at the Rice Institute and at the Massachusetts Institute of Technology.

2. Chapman, Marion, and Slattery, Bull. Am. Phys. Soc. 1, 95 (1956).
3. F. P. Mooring and L. L. Lee, Jr., Bull. Am. Phys. Soc. 1, 327 (1956).
4. Sperduto and Buechner, Bull. Am. Phys. Soc. 1, 223 (1956).

2024-4 The Decay of Sn^{123} (125 days) (5220)

S. Bradley Burson, David W. Martin, Loren C. Schmid
Reported by S. Bradley Burson

There are no new results to report during this period, but the study is to be continued.

25-1 Angular-Distribution Measurements of Charged-Particle Reactions (5220)

Linwood L. Lee and John P. Schiffer
Reported by John P. Schiffer

A small, 6-inch diameter, angular-distribution chamber has been constructed with provision to observe reaction products with CsI detectors at angles ranging from 0° to 165° at 7.5° intervals. Utilizing deuterons from the Van de Graaff accelerator, preliminary measurements have been made of the $\text{Ca}^{40}(\text{d},\text{p})\text{Ca}^{41}$ reaction. Although the angular distributions fluctuate violently with energy, indicating numerous narrow resonances in the compound nucleus, a general forward peaking seems to persist throughout the bombarding energy range of 2.0 to 4.2 Mev. Further measurements of angular distributions of (d,p) , (α,p) and (He^3,p) reactions are planned, with a view toward studying reaction mechanisms as well as level parameters in particular nuclei.

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26-1

Measurement of Proton Strength Functions (5220)

Linwood L. Lee, Jr. and John P. Schiffer

Reported by John P. Schiffer

The strength function (the average reduced reaction width divided by the average level spacing) is of importance in theories dealing with gross nuclear properties¹. Experimental measurements of this parameter have hitherto come primarily from neutron experiments.

The thick-target yields of gamma-rays for inelastic scattering of protons by even-even nuclei should give a reasonably accurate measure of the strength function, $\overline{\gamma^2}/\overline{D}$, for the channel of s-wave inelastic protons from the compound nucleus. The conditions are that the energy of the inelastically scattered protons should be small enough in comparison to the Coulomb barrier that the value $\ell = 0$ is strongly favored for outgoing protons and that the inelastic scattering should occur from a 0^+ ground state to a 2^+ excited state.

It appears from measurements on nine isotopes² between $A = 44$ and

64, that $\overline{\gamma^2}/\overline{D}$ is constant within 50%. (Fig. 5) This may be compared with the resonance in $\overline{\Gamma}_n^0/\overline{D}$ found in neutron scattering experiments on nuclei in this region.

Fig. 5. Measured values of the proton strength function vs atomic number.

1. Feshbach, Porter and Weisskopf, Phys. Rev. 96, 448 (1954).

2. This work is a continuation of experiments started at the Rice Institute. See J. P. Schiffer, R. H. Davis and F. W. Prosser, Jr., Bull. Am. Phys. Soc. 2, 60 (1957).

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32-3 Decay of $^{65}_{28}\text{Ni}$ (2.56 hours) (5220)

S. Bradley Burson

There are no results to report on this study at this time. Experiments will be resumed during the next few weeks.

35-1 The Decay of 9-Hour Eu^{152} (5220)

S. Bradley Burson and Loren C. Schmid
Reported by Loren C. Schmid

Europium has two stable isotopes, Eu^{151} and Eu^{153} , with abundances of 48% and 52%, respectively. Neutron capture produces two radioactive isotopes, Eu^{152} and Eu^{154} , both of which have half-lives of about 14 years. Each of these isotopes decays by both β^- emission and K-capture. In addition, Eu^{152} has an isomeric state of 9-hour half-life which also has competing K-capture and β^- branching. There is little agreement among the various decay schemes reported for these activities.

Recently, enriched stable isotopes of europium have been made available by the Oak Ridge National Laboratory. It is hoped that with the enriched isotopes, some of the discrepancies between the reported schemes can be removed and thereby a clear picture of the decay schemes will be obtained. Because of the shorter half-life in Eu^{152} , this isotope was chosen in order to utilize the 256-channel analyzer and CP-5 to best advantage.

A ten-second irradiation of a sample of enriched Eu^{151} in the "rabbit" of CP-5 produced a usable source which was free of the longer-lived europium. So far, the results confirm the decay scheme proposed by Grodzins

and Kendall¹ although four of the gamma-rays are found to have slightly different energies. These are: following K-capture, 0.841 and 0.963 Mev, instead of, 0.854 and 0.976 Mev; and, following β^- -decay, 0.702 and 0.972 Mev, instead of 0.725 and 0.983 Mev. Except for the 0.7-Mev gamma-ray, the error in the above values is ± 5 kev. There is some doubt whether the 0.7-Mev gamma-ray exists. More experimental evidence is necessary before it can be concluded that there are gamma-rays present in addition to those reported by Grodzins and Kendall. However, at present it is believed that three gamma-rays having energies of 0.33, 0.55, and 0.62 Mev also follow the β^- -decay.

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1. L. Grodzins and H. Kendall, Bull. Am. Phys. Soc. 1, abstracts B10 and B11, 163-164 (1956).

42-1 Underground Construction of Power Reactors (5220)

David R. Inglis and Roy Ringo
Reported by David R. Inglis

From the point of view of national strength, in order to facilitate the reconstruction of some recognizable remnant of the country after nuclear attack and thus to diminish the probability of such attack, vigorous preparation for industrial defense seems desirable. It is proposed that a useful step in this direction, and one which is practicable because of the lack of fixed precedent and vested interest, would be the underground construction of industrial power reactors. Some feasibility considerations of a very preliminary nature, touching on the questions of cost, strength, access, drainage and avoiding contamination of ground water, have been

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assembled in the form of an Unclassified Topical Report, ANL-5652.

This will be the only report on this project.

49-6 The Decay of $_{50}\text{Sn}^{125}$ (9.7 day and 9.4 min.) (5220)

S. Bradley Burson and David W. Martin
Reported by S. Bradley Burson

This program is complete and the results have been submitted for publication.

This paper has appeared in Phys. Rev. 105, 625-633, (1957).

52-13 Gamma-Rays from Fission Induced by Thermal Neutrons
(5220)

Charles M. Huddleston and Carroll C. Trail
Reported by Charles M. Huddleston

In the study of the gamma-rays from fission, a gas scintillation counter detects fission fragments and a sodium-iodide crystal detects gamma-rays. The experimental arrangement is shown in Fig. 6. A thermal-neutron beam emerging from CP-5 strikes a U^{235} foil, which is 0.1 mg/cm^2 thick, inside a gas scintillation counter. Another crystal

Fig. 6. Experimental arrangement for study of γ -rays from fission.

lies directly below the fission foil (on a line normal to the plane of the drawing) about the same distance from the foil as the crystal in the horizontal position. The outputs from the photomultiplier

tubes are fed to a single-channel analyzer and a multi-channel analyzer.

Fig. 7 shows the energy spectrum obtained with the gas scintillation counter. The figure shows the usual double-humped shape expected in a fission spectrum, but it should be noted that this energy spectrum is not a simple inversion of the mass spectrum.

Fig. 8 gives the gamma-ray coincidences per fission as a function of fragment energy. This curve was obtained with the sodium-iodide crystal, which lies in the plane of the uranium foil. Thus, no angular correlation effects show up because of the symmetry of the arrangement. The variation in the coincidence rate is a result of a variation in gamma-ray yield. Relative numbers of gamma-rays in the energy intervals of 200 - 600 kv 600 - 1200 kv, and greater than

Fig. 7. Energy spectrum of fission fragment in gas scintillation counter.

Fig. 8. Coincidences per fission in the vertical counter.

Fig. 9. Mass spectrum of fission fragments.

Fig. 10. Gamma-rays per fission as a function of fission mode.

variation in gamma-rays per fission as a function of fission-fragment mass.

1200 kv were measured and found to be independent of the energy of the fission fragment.

A particular energy of fission fragment does not correspond uniquely to a particular mass of fission-fragment. Brunton and Hanna¹ give the probability that a fission fragment of a particular energy has a particular mass.

Fig. 9 shows the mass distribution obtained by applying their probability curves to the present work. The solid curve is the usual fission-mass spectrum obtained from chemical analysis.

Fig. 10 gives the

1. Brunton and Hanna, Can. J. Research 28A, 190 (1950).

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Fig. 11 shows the gamma-ray coincidences detected by the sodium-iodide crystal lying on the opposite side of the uranium foil from the gas cell. When this curve is corrected for the variation in the number of gamma-rays with the energy of the fission fragment, Fig. 12 is obtained. These results show that the gamma-ray is emitted preferentially in the same hemisphere as the light fragment.

Fig. 11. Coincidences per fission in the horizontal counter.

Fig. 12. Angular correlation effect in the horizontal counter.

55-5

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Capture Gamma-Ray Spectra for Neutrons with
Energies from 0.1 to 10 ev. (5220)

Bernard Hamermesh, Rauf Nasuhoglu, Sol Raboy,
Roy Ringo and Carroll C. Trail
Reported by Roy Ringo

Construction work on the shield, crystals and electronic parts of the apparatus continued in this quarter but nothing was advanced enough for final tests at the end of the period.

56-4

Compton-Electron Magnetic Spectrometer for
Neutron-Capture Gamma-Rays (5220)

Richard S. Preston

Modification of the test spectrometer has been completed. The instrument is now very similar to that of Groshev, Adyasevich and Demidov¹, in that forward Compton electrons are deflected through a total of 270° by the magnetic field before being detected. It still differs in that the detected electrons are counted in coincidence with recoil photons scattered at approximately 180° .

The 1.6-Mev gamma ray from La^{140} has been detected with this instrument with a line width corresponding to 2% resolution in the momentum of the electron. The transmission of the instrument is considerably lower than the calculated value. This is attributed to the fact that a rather sensitive adjustment of the orientation of the magnetic part of the spectrometer is needed to make it accept Compton electrons emitted in the direction determined by the angle at which the

1. L. V. Groshev, B. P. Adyasevich, A. M. Demidov, International Conference on the Peaceful Uses of Atomic Energy, A/Conf. 8/P/651 USSR, 5 July, 1955.

recoil photons are detected. Without this proper adjustment, such electrons can be accepted by the magnetic spectrometer only if they happen to be scattered into exactly the right direction before they leave the Compton radiator.

No attempt has been made to carry out such an adjustment because the permanent magnet used with this test spectrometer makes it fundamentally unsuitable for precision measurements, and the effort would take time. Instead, experimentation with this spectrometer has been discontinued, and detailed design studies for a new 270° spectrometer have been started.

57-3 Lifetime Measurements from Recoil Studies (5220)

Stanley S. Hanna

The Doppler-shift technique has been used to obtain additional information relating to the lifetime of the first excited state of Na^{23} at 440 kev. In the inelastic scattering of protons by Na^{23} , excited Na^{23} nuclei are projected into a forward cone. Observation of the gamma-rays is made first in a forward and then in a backward direction, thereby producing a Doppler energy shift if the radiation originates from a moving nucleus. If, however, the nucleus has come to rest before radiating, the shift is eliminated. The experiment consists in finding a material in which the stopping time for the nucleus is comparable with its lifetime.

Previously it was found that the Doppler shift persisted when the nuclei were stopped in a gas, but that it was eliminated when the nuclei were brought to rest in the solid material, tantalum. Various solids

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with $11 \leq Z \leq 73$ have now been tried and it was found that the Doppler shift was eliminated in all of them. On the other hand, various thicknesses of sodium chloride, all less than the range of the nuclei, were used to reduce the velocity of the nuclei and thereby diminish the Doppler shift. From these measurements one obtains a value of 2.0×10^{-12} sec. for the lifetime of Na^{23*} with an accuracy of about a factor of 2.

58-3 Energy of Delayed Neutrons from Fission (5220)

Gilbert J. Perlow and Andrew F. Stehney (Rad. Phys. Div.)
Reported by Gilbert J. Perlow

Delayed Neutrons from 15.5-sec Br^{88}

In the previous report¹ concerning measurements on the delayed neutrons which follow β -decay of 54-sec Br^{87} , it was pointed out that this activity could be obtained with a purity of $\gtrsim 90\%$ if, after "chemical purification", the active gas were allowed to pass down a drift tube in which the very short-lived activities decay. It was somewhat puzzling however that this much impurity ($\sim 10\%$) should remain.

In the trap which follows the irradiation cell, the solution for chemical removal of iodine was changed from permanganate to bromate. Although laboratory tests indicated that the bromate was very effective in scrubbing bromine free of an iodine contamination, the residual impurity persisted. Accordingly it was made the subject of a separate investigation. The chief alterations in technique were to make approximately a 5-fold reduction in the volume of solution being irradiated in the pile, and to improve

1. ANL-5609, I-58-2, page 44.

the somewhat haphazard arrangement for taking decay curves. The former change means that, on the average, an active atom spends less time in the solution and therefore the shorter-lived activity is less seriously attenuated before observation. In addition, by stopping the flow of gas before full activity has been built up in the carbon tetrachloride cell, the shorter-lived activity is relatively enhanced.

Fig. 13 illustrates the result of such a run. The time $t=0$ corresponds to the instant at which the gas flow stops. At $t=0$ the "contamination" activity contributes the same counting rate as the 54-second activity. Its half-life is 15.6 seconds (15.5 $\pm$ 0.3 from several runs) so

the activity is to be identified with Br^{88} , whose period has been measured by radiochemical techniques to have just this value. From runs taken under equilibrium conditions for the activity in the carbon tetrachloride cell, an extrapolation back to the time of formation may be made. The 15.5-second period then turns out to have three or four times the yield of the 54-second one. Since previous chemical separations of the bromine precursors of delayed-neutron activity had been slower than the present method, only a trace of this new Br^{88} activity persisted, and this trace

Fig. 13. Decay of neutron activity from fission-product bromine. Air flow stopped at $t=0$.

was mistakenly ascribed to 22-sec iodine contamination. In the experiments without chemical separation, it would be difficult to separate this period from those of the iodine group.

This delayed-neutron activity is remarkable in that the Kr^{88} , to which Br^{88} decays by beta emission, is the first even-even nucleus which has been found to be a neutron emitter.

60-13 7.7-Meter Bent-Crystal Spectrometer (5220)

Bernard Hamermesh and Robert K. Smither
Reported by Bernard Hamermesh

During the past quarter the instrument has been used for further studies of the gamma-rays emitted by a gold source. The source is a foil $10 \times 2 \times 0.05$ cm placed inside a straight-through beam hole in CP-5.

CAPTURE GAMMA-RAYS

In addition to the lines reported in ANL-5609 the following lines have been found (energy in kev): 55.10, 454.2, 492.4, 508.9, 525.0, 537.5, 546.6, 565.1, 571.0 and 598.2. The study has been extended to 1.75 Mev, and 20 more lines have been found between 600 and 1750 kev. The most energetic gamma-ray that has been diffracted so far is at about 1.71 Mev.

K-X-RAYS FROM GOLD AND MERCURY

The cascade gamma-rays from gold give rise to x-rays following internal conversion. The 412-kev gamma-ray in Hg^{198} , which follows beta decay of Au^{198} , also gives rise to x-radiation. The K-radiations from Au and Hg are in the energy range 65-85 kev. A study was made of these

radiations since very few experimental data are available.

Using our secondary method of measuring energies, which is accurate to 1 part in 10^3 , we find the results shown in Table A and also in Figs. 14, 15 and 16.

Table A
Energies (kev) of K-X-Rays from Au and Hg

K-line	Argonne B. C. S. (kev)	*Previous Results (kev)
<u>Au</u>		
α_2	66.99 ± 0.07	66.988 ± 0.007
α_1	68.78	68.801
β_3	77.53	77.579
β_1	77.97	77.982
β_2^{II}	80.16	{ 80.075 80.184
β_2^{I}		
$K_{\text{O}}^{\text{II, III}}$	80.67	80.666
<u>Hg</u>		
α_2	68.83	68.874 ± 0.02
α_1	70.76	70.790

* Au — E. Ingelstam, Nova Acta Reg. Soc. Sci. Upsal. (4), No. 5, (1936).

* Hg — D. Saxon, Thesis, Univ. of Wisconsin, 1954 (unpublished).

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Fig. 14. K x-rays from gold.

Fig. 15. K x-rays from gold and mercury.

Fig. 16. The $\text{K}\alpha_1$ x-ray line of gold and the $\text{K}\alpha_2$ line of mercury.

DECAY SCHEME OF Hg^{198}

Evidence has been found indicating that the second excited state of Hg^{198} is really a very close doublet. This state is about 1.09 Mev above the ground state. It decays to the ground state either directly or through the first excited state at 412 kev. In the latter case a gamma-ray of about 675 kev is emitted. This line has been found to be a doublet. It consists of one line at 671.1 kev and one line at 678.9 kev. The first line is about three times as intense as the second line. In addition the line at 1.09 Mev has been studied and preliminary measurements indicate that it is too wide to be a single line.

OPERATION OF SPECTROMETER

It is expected that the spectrometer will be operating in a fully automatic manner in the next quarter.

70-13 Measurements of Nuclear Moments by Angular Correlation
(5220)

Victor Krohn and Sol Raboy
Reported by Sol Raboy

The gyromagnetic-ratio measurements of the 10^{-8} sec state in Ta^{181} have been completed. An article is being prepared for publication.

Work has started on the measurement of the gyromagnetic ratio of the 3.5×10^{-9} sec state in Tc^{99} . Tc^{99} , the daughter product of the 68-hour Mo^{99} β -emitter, is formed in several excited states which decay by subsequent gamma-ray emission to the ground state. We have selected for our study the coincidences between the 740-kev and 181-kev gamma-rays, the latter of which corresponds to a transition to the ground state from the

181-kev state with 3.5×10^{-9} sec half-life.

Because of the short life of the intermediate state, very high magnetic fields are required to perturb the angular correlation pattern appreciably. We have definitely changed the pattern with fields ranging from 10 000 to 21 000 oersteds. A successful conclusion to this measurement is anticipated, although it is too early to give definite results.

80-13 Molecular Beam Studies (5220)

William Childs, John Dalman, and Leonard S. Goodman
Reported by William Childs

Atomic-beam magnetic-resonance studies have been continued in the present quarter. A general outline of the procedure followed in these experiments is available in the literature¹.

Our recent effort has been directed largely toward further measurements of the nuclear magnetic moment of the 1.7-hr, 393-kev metastable state of In^{113} , and a report on our progress was presented at the Chicago meeting of the American Physical Society on November 24, 1956². The radio frequency required for refocussing was measured for considerably larger "C" field intensities, permitting a more precise evaluation of the magnetic moment. A value of either $+0.2098 \pm 0.0004$ or -0.2105 ± 0.0004 nuclear magnetons was obtained. The latter value for the moment, and the known³ nuclear spin of $1/2$, are consistent with the

1. Goodman and Wexler, Phys. Rev. 99, 192 (1955).

2. Bull. Am. Phys. Soc. 1, 342 (1956).

3. ANL-5609, I-80-12, 49 (1956).

nuclear shell model. Because of intensity considerations, further measurements intended to permit a determination of the sign of the moment have been postponed pending the arrival of a freshly irradiated source.⁴

Measurements were delayed on a number of occasions because of instrumental difficulties, and several modifications have been introduced to improve the situation. A permanent "A" magnet assembly, mechanically variable in intensity, replaces the coils formerly used, and a similar assembly for the "B" magnet is being designed. The greatly reduced drift of the magnetic fields should prove an enormous advantage.

The electron-bombardment assembly for heating the oven has also been improved, and electrical failures from this source have been sharply reduced.

Some time was devoted to preparing for the next isotope to be studied, In¹¹⁴. It is proposed to measure the electric quadrupole moment of In¹¹⁴ in its 50-day metastable state, for which the nuclear spin is known to be 5 and the magnetic moment approximately +4.7 nuclear magnetons. In addition, we expect to study the 72-second ground state, which is fed from the 50-day isomeric state. For this purpose, a new apparatus was designed to permit counting samples within seconds after collection.

4. The moment has since been found to be negative.

81-1 Review Paper on Deposition of Atomic Beams (5220)

Sol Wexler

A review paper on deposition of atomic beams on solid substrates is in progress. The work is an elaboration of a paper presented at the Conference on Molecular Beams, Brookhaven National Laboratory, August, 1954.

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90-13

Cross Sections for 14-Mev Neutrons (5220)

Harvey Casson, Leonard S. Goodman and Louis A.
Rayburn
Reported by Louis A. Rayburn

GENERAL REMARKS

One of the problems of machine maintenance has been the rapid contamination of the fore-pump oil which has necessitated frequent replacement. Following a recommendation of the Van de Graaff group, the diffusion pump oil (Octoil S) used hitherto was replaced by another type of oil (Molecular Lubricant, Type C) supplied by Litton Industries, Inc. This change has eliminated the problem of oil contamination.

A 256-channel pulse-height analyzer was received and set up to analyze the amplified output of the time-of-flight-to-pulse-height converter. The 256-channel analyzer is gated by either a slow coincidence (with a resolving time of about 2 to 3 microseconds) between the outputs of the alpha and neutron single-channel analyzers or a triple coincidence between the outputs of the alpha and neutron single-channel analyzers and a "priority selector" circuit which will be described below.

A considerable amount of time was expended attempting to improve the stability and time resolution of the time-of-flight circuitry and in trying to reduce the accidental background rate. The results of these attempts are described in the following paragraphs.

Our old alpha scintillator, a plastic containing tetraphenylbutadiene, was replaced by a scintillator made of Pilot Plastic-B (Pilot Chemical Co.) containing diphenylstilbene. Analysis of the 3.5-Mev

alpha-particle pulses indicated an increase of more than 50% in light output and an improvement in amplitude resolution so that the full-width of the peak at half-maximum is now about 28%.

The circuit to convert from time-of-flight to pulse height measures the amount of overlap of two essentially square pulses (about 2.5 volts in magnitude and about 60 millimicroseconds in duration) which originate at the anodes of the alpha and neutron photomultipliers, respectively. The accidental coincidence rate may be cut in half by eliminating one of the two possible ways in which these pulses may overlap to produce the same pulse-height output. The "priority selector" circuit produces an output pulse only in those events in which the alpha pulse precedes the coincident neutron pulse. The priority selection is performed by feeding suitably shaped alpha and neutron pulses into a millimicrosecond coincidence circuit.

An investigation was carried out to find the most suitable material to use to shield the neutron counter from the neutrons coming directly from the neutron source. Attention was confined to materials that were readily available, and to a shield configuration near the neutron source rather than around the neutron counter. The best results were obtained with a shield consisting of about 24 inches of paraffin followed by 4 inches of lead. The background due to direct neutrons is about 20% smaller when this shield is used than it was when using the old 24-inch lead shield. This results in a corresponding 20% reduction in the accidental coincidence rate.

Using small plastic scintillators, the best time resolution of the time-of-flight circuit, using Co^{60} gamma-rays, gave a full-width at

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half-maximum of 1.5 to 1.8 millimicroseconds. A full-width at half-maximum of 3 to 4 millimicroseconds has been obtained using alpha particles and neutrons from the $H^3(d,n)He^4$ reaction. The neutron detector was a plastic scintillator 3 inches in diameter by 6 inches long.

It is expected that measurements on the inelastic scattering of 14-Mev neutrons will be resumed shortly.

ANGULAR DISTRIBUTION OF ELASTICALLY SCATTERED 14-MEV NEUTRONS

The values of the differential elastic-scattering cross section of lead shown in Table IV have been measured with an angular resolution of about ± 3.5 degrees. These values are preliminary; no corrections have been applied to them.

TABLE IV

Differential Elastic-Scattering Cross-Sections of Lead

<u>Laboratory Angle (degrees)</u>	<u>Differential elastic-scattering cross section (millibarns/steradian)</u>	<u>Estimated percent error</u>
8.6	9330	7
10	7840	4
15	4200	4
20	1480	5
25	294	15
30	399	15
35	519	12
40	584	10
45	337	15
50	212	15

Further measurements will be resumed shortly.

91-13

Neutron Transport Cross Sections; Angular
Distribution of Scattered Neutrons (5220)

Alexander S. Langsdorf, Jr.

The material already reported in ANL-5567 is being prepared for publication in a journal.

A steering magnet has been built to allow the beam to reach the required position of the neutron source. In the position occupied before installation of the circular track, no such magnet was needed.

The angular analyzer uses neutron-collimating devices. The question arises as to the degree to which the desired beam coming directly through the opening is contaminated by neutrons scattered in the shielding material, or in the walls of the collimating hole. Some approximate calculations indicate that, with a suitably designed collimator, as little as 0.1% of the degraded energy flux may be in the full-energy direct beam. This is less than most persons have previously considered likely. More exact calculations and experimental tests, if possible, are indicated. If the present calculations are correct, collimators should be much more useful than has been generally believed in the past.

92-1

Intercalibration of Neutron Sources (5220)

Raymond O. Lane and Alexander Langsdorf, Jr.
Reported by Alexander Langsdorf

Three Ra - α - Be neutron sources were intercompared using the angular-analyzer equipment (see report I-91-13, p. 41). Two were Los Alamos sources, numbers 73 and 129, and the third was Argonne number 312. The result was in agreement to 1% with prior interlaboratory

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calibrations, which had determined that the source-strength scale at the Argonne National Laboratory is 5% higher than the Los Alamos scale. However, the data of the present intercomparison contain internal evidence for possibly serious uncertainty in the results, due to inelastic scattering in different source containers leading to different neutron spectra. The accuracy of the intercomparison depended on the similarity of the spectra and is thrown in doubt by indications of such spectral differences. It is suggested that source containers, including all secondary (and tertiary) protective outer containers, should be standardized in design to avoid this trouble.

No further reports are planned on this subject.

98-12 Total Neutron Cross Sections in the Kev Region (5220)

Carl T. Hibdon

I. MODIFICATION OF COUNTING EQUIPMENT

A new paraffin-filled drum for the neutron counter (elephant) has been constructed to contain fifty $B^{10}F_3$ proportional counters. The counters are 1-1/2" in diameter and have an active length of 20". They are intended for eventual use in the dual shielded detector that is now being constructed. Recent measurements indicate that the new counting system improved the counting rate by at least a factor of two.

II. TRANSMISSION MEASUREMENTS ON ALUMINUM

The neutron transmission cross section of Al has been measured from about one to 140 kev by the same method as was used for Cr and Fe^1 . The neutron resolution width used varied from 400 to 800 ev.

1. ANL-5554, Report I-98-10, p. 55.

Samples of Al of 99.9% purity were supplied through the courtesy of E. L. Foster of the Battelle Memorial Institute. The metal was re-melted by the Metallurgical Division at Argonne so that suitable samples could be machined.

Variations in the cross section show the presence of three peaks in the region covered. The peak near 35 kev was well resolved with a minimum of 0.5 barns near 27 kev and a measured peak height of 28 barns. The low minimum and asymmetrical shape assign with certainty the value $\ell=0$. This resonance has an apparent width of 1.5 kev.

The resonance near 89 kev has a measured peak height of 18.2 barns and a minimum of 1.4 barns before the resonance. This minimum, together with the asymmetrical shape, indicates an s-wave interaction. A somewhat flat peak and an apparent width of approximately 9 kev indicate that this peak may consist of two or more closely spaced resonances.

The two resonances at 35 and 89 kev were previously observed² with apparent widths of 15 and 35 kev, and measured peak heights of 10 and 7 barns, respectively.

During the present measurements, a new resonance at 121 kev was resolved to a peak height above 10 barns. The width appears to be about 2.5 kev. Since the resonance is nearly symmetrical in shape and does not have a pronounced minimum on the low energy side, an s-wave neutron interaction is ruled out. Tentatively it is attributed to a p-wave interaction, since its width is large for a value of $\ell > 1$.

2. BNL 325, p. 98 (July 1, 1955).

A minimum of 1.3 barns was observed at 130 kev. At higher energies the cross section rises to a value near 7.5 barns at 142 kev.

Further measurements of the cross section of Al will be made and the resonances analyzed to obtain the parameters.

III. ANALYSIS OF s-WAVE NEUTRON SCATTERING RESONANCES

A method known as the interference method has been used in the past to determine the widths of resonances due to s-wave neutron interaction. The method was recently included in a paper by Levin and Hughes³. Only points in the wings of a resonance, for which $(E - E_r)/(\Gamma/2) \gg 1$, are useful in this method.

It is desirable to use a method that permits the use of most of the points of a resonance. Such a method, based on the theory of Breit and Wigner, was suggested by L. A. Turner. In its present form the method is applicable to neutron scattering resonances of the s-wave type. Equation (1) gives the single-level expression⁴ for an isolated resonance if $\Gamma_n = \Gamma$.

$$(1) \quad \sigma_s = \sigma_p + \pi \lambda^2 g_J \frac{\Gamma^2 (1 - 2 \sin^2 \delta_l) + 4 \Gamma (E - E_r) \sin \delta_l \cos \delta_l}{(E - E_r)^2 + \Gamma^2 / 4}$$

where

$$\sigma_p = \sum_l (2l + 1) 4\pi \lambda^2 \sin^2 \delta_l, \text{ and } g_J = \frac{2J + 1}{(2I + 1)(2s + 1)}$$

This g_J is the statistical weight factor due to the spins of the interacting particles which form the compound state with spin J. The sign of the term involving δ_l corresponds to the definition given by Fesh-

3. Levin and Hughes, Phys. Rev. 101, 1328 (1956).

See also ANL-5498, Report I-98-9, p. 52.

4. R. K. Adair, Rev. Mod. Phys. 22, 249 (1950).

bach, Peaslee and Weisskopf⁵ rather than the one of opposite sign used by Adair⁴. The other symbols have their usual meaning. Equation (1) can be written in the more convenient form

$$(2) \quad \sigma_s = \sigma_{\min} + 4\pi\lambda^2 g_J \frac{[(\Gamma/2) \cos \delta_\ell + (E-E_r) \sin \delta_\ell]^2}{(E-E_r)^2 + \Gamma^2/4}$$

where $\sigma_{\min}$ is written for $\sigma_p - 4\pi\lambda^2 g_J \sin^2 \delta_\ell$. This $\sigma_{\min}$ can be shown to be the minimum value of the cross section on the low-energy side of the resonance; and for $\ell=0$ it is very nearly $(1 - g_J)\sigma_p$. By expressing Γ, E_r and δ_ℓ in terms of Γ_m, E_m and δ_m , where m designates the values of the quantities at the energy for which σ_s attains its maximum value, σ_m , Eq.

(2) may be rewritten in the form:

$$(3) \quad Y = a \Gamma_m/2 + b \tan \delta_m (E - E_m)$$

where

$$(4) \quad Y \equiv \pm \sqrt{\frac{\sigma_s - \sigma_{\min}}{\sigma_m - (\sigma_s - \sigma_{\min})(E/E_m)}} |E - E_m|,$$

$$(5) \quad b \equiv [1 - (\Gamma_m/2E_m) \tan \delta_m]^{-1}, \text{ and}$$

$$(6) \quad a \equiv b (1 + \tan^2 \delta_m)$$

In the expression for Y , the negative sign is used for those energies below the minimum of the resonance and positive values everywhere else. In computing Y , the theoretical value of σ_m and the experimental value of $\sigma_{\min}$ are used.

Equation (3) shows that for a perfectly-resolved, completely-isolated resonance, the plot of Y vs E would yield a straight line; but in practice the experimental points deviate from the line because of imperfect

4. R. K. Adair, Rev. Mod. Phys. 22, 249 (1950)

5. Feshbach, Peaslee and Weisskopf, Phys. Rev. 71, (1947)

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resolution and of interference from other resonances. Since $\underline{a} \Gamma_m/2$ is the value of Y at $E = E_m$ and since $\underline{a}$ does not differ greatly from unity, a tentative value of Γ_m may be obtained from the plot. The slope, $\underline{b} \tan \delta_m$, of the line is very nearly $\tan \delta_m$ since $\underline{b}$ differs only slightly from unity. From these preliminary values of $\tan \delta_m$ and Γ_m , a more accurate value of $\underline{b}$ may be computed from Eq. (5). When this more accurate value of $\underline{b}$ is substituted in the expression for the slope, an improved value of $\tan \delta_m$ results. Then a correspondingly good value of $\underline{a}$ may be found from Eq. (6), after which Γ_m may be recalculated from Eq. (3). Finally σ_p may be calculated by the familiar formula, making use of the facts that $\delta_0 = \delta_m$. $E_{\min}$ is the value of E at $Y = 0$.

A typical plot is shown in Fig. 17 for the 85.5-kev resonance

Fig. 17. Analysis of the 85-kev resonance in Fe^{56} . Values of $\Gamma_m = 980$ ev, $E_{\min} = 84.1$ -kev and $\sigma_p = 3.1$ barns were obtained from this plot as explained in the text.

of Fe^{56} . From this plot, values of $\Gamma_m = 980$ ev, $\sigma_p = 3.1$ barns and $E_{\min} = 84.1$ kev were obtained.

The value of σ_p computed from

$$\sum_{\ell} (2\ell + 1) 4 \pi \lambda^2 \sin^2 \delta_{\ell} \text{ is } 3.45 \text{ barns}$$

for $\delta_0 = R/\lambda$ and $R = 0.14A^{1/3}$

$\times 10^{-12}$ cm.

In cases where the level spacing is so small that an analysis is not feasible, the widths can be estimated by the aid of the

expression⁶

$$\Gamma = (E_m - E_{\min}) \sin 2\delta_l$$

IV. THE LEVEL SPACING D_J of Cr^{52} and Fe^{56}

According to theory the natural width, Γ_n , of a neutron resonance is given by the expression⁷ $\Gamma_n = T_n^l \frac{D_J}{2\pi}$, where D_J is the basic nuclear factor, approximately equal to the average level spacing for the nucleus, and T_n^l is the transmission coefficient, which for s-wave neutron interaction is given by the expression^{7,8}

$$T_n^0 = \frac{4kK}{(k+K)^2} = \frac{4\lambda_0 (\lambda_0^2 + \lambda^2)^{1/2}}{[\lambda_0^2 + (\lambda_0^2 + \lambda^2)^{1/2}]^2},$$

where λ_0 , the wave length of a neutron inside the nucleus, may be taken as 10^{-13} cm. D_J has been computed for each resonance of Cr^{52} and Fe^{56} on the assumption that all of the resonances are attributable to s-wave interactions. Average values of the D_J for Cr^{52} and Fe^{56} are 36 and 35 kev compared to an observed average distance between levels of 35 and 30 kev, respectively. The results are summarized in Table V in which E_r and D_J are expressed in kev and Γ_n in ev.

V. PAPERS

This work was reported at the Thanksgiving meeting of the American Physical Society in Chicago under the title: "Total Neutron Cross Sections in the Kev Region: Cr and Fe".⁹ A full report on the methods and results of this research is nearly ready for publication.

6. ANL-5554, Report I-98-10, p. 57.

7. Blatt and Weisskopf, Theoretical Nuclear Physics.
(John Wiley and Sons, New York, 1952)

8. B. T. Feld in Experimental Nuclear Physics Vol. II.
(John Wiley and Sons, New York, 1953).

9. Carl T. Hibdon, Bull. Am. Phys. Soc. 1, 346 (1956).

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TABLE V

Cr^{52}			Fe^{56}		
$E_r(\text{kev})$	$\Gamma_n(\text{ev})$	$D_J(\text{kev})$	$E_r(\text{kev})$	$\Gamma_n(\text{ev})$	$D_J(\text{kev})$
51	1200	43	29.2	900	41
98	3200	85	75.6	900	27
120.4	600	15	85.5	980	28
138	1000	23	127.7	500	12
142	1200	27	138	800	18
146	800	18	145	800	18
152	800	18	162	875	19
243	1500	27	188	1000	20
325	2500	41	219	600	11
366	2500	39	272	2000	35
406	4000	60	316	4000	64
			360	3000	47
			388	5000	76
			406	5000	74
$\overline{D_J} = 36 \text{ kev}$			$\overline{D_J} = 35 \text{ kev}$		

VI. REMOTE CONTROL SAMPLE CHANGER

The equipment for changing transmission samples in front of the neutron counter (elephant) by remote control is nearly completed.

All parts have been machined and assembled. One set of microswitches proved unsatisfactory because they scored the indexing wheels. A different type appears to be satisfactory. Some additional wiring and debugging are necessary before the equipment can be installed and used.

106-2 Calibration of a NaI Crystal and a Long Counter (5220)

F. Paul Mooring

Work on this project is virtually complete and a report will be made when the data have been analyzed.

108-7 An He^3 Neutron Spectrometer (5220)

Frank Lynch

A proportional counter which measures the total ionization produced by the reaction $\text{He}^3(n,p)\text{T}$ is under development. Since the detector must be filled to a high gas pressure, great care must be taken to eliminate electronegative gases from the detector. Work has been concentrated on the construction of a detector which can be outgassed at 500-600°C and can be filled to 300 psi, and on the development of an efficient gas-purification and filling system.

1. Detector using a ceramic-to-metal brazed insulator assembly. — After one of the insulator assemblies was broken, new ceramic parts for a more rugged assembly were ordered last August. Although the parts were due

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in October, those ordered from Coors have not been received yet. A duplicate order has recently been placed with Frenchtown.

An all-metal vacuum furnace designed for temperatures up to 1300°C with a vacuum of 10^{-6} mm Hg has been constructed and tested for leaks. Provision has been made for introducing pure hydrogen and other gases. The heating element is a molybdenum sheet, and thermal insulation is by means of nickel radiation shields. Although successful seals have been made heretofore, using titanium hydride, molybdenum trioxide has been obtained which will be used in metallizing the alumina ceramic using the molybdenum process.

2. Disassembly of epoxy-resin seals.— We have attempted to disassemble the epoxy-bonded quartz-to-invar insulator assemblies and to reassemble them with fresh epoxy resin. Although the insulator assemblies have been soaked in a commercial epoxy solvent for over a month, apparently the solvent does not penetrate sufficiently to destroy the bond. It will be necessary to heat the assembly to 250°C to destroy the bond, and it is probable that the differential expansion between the quartz and invar will crack the quartz.

3. Gas purification and filling system. — A one-pass filling system has been constructed in which the water vapor is removed by Linde molecular sieves, and the oxygen by hot uranium and NaK. A plugged valve caused NaK to be blown throughout the system. The system was disassembled, cleaned and reassembled. A hot magnesium purifier has been substituted for the NaK bubbler. The reconstructed system has been leak tested and is now gas tight.

117-2 Measurement of Neutron Half-Life Using a Diffusion
Cloud Chamber (5220)

Nicola D'Angelo, Harry Bryant, Giuseppe Caglioti
and Charles M. Huddleston
Reported by Charles M. Huddleston

A project is underway to measure the half-life of free neutrons by photographing neutron decays inside a diffusion cloud chamber. The photographic problems involved have been studied with particular reference to determining the three coordinates of the origin of electron tracks arising from neutron decays. The diffusion cloud chamber has operated satisfactorily with methyl alcohol in air at atmospheric pressure, giving a sensitive layer about two inches deep. Work is in progress to operate the chamber with methyl alcohol in gases other than air, such as helium and carbon dioxide.

134-5 Atomic Excitation Following β -Decay of Tritium (5230)

Sol Wexler

Work on this project has been temporarily halted because my entire efforts are being directed toward completion of the mass spectrometer for use in the study of the dissociation products from nuclear transformations. It is hoped that this study may be taken up again next summer. Reporting will be discontinued until work is resumed.

135-12 Electron-Neutron Interaction (5220)

Marshall F. Crouch, Victor E. Krohn and Roy Ringo
Reported by Victor E. Krohn

A considerable quantity of data has been obtained on the scattering of thermal neutrons from Kr, Xe and A but none of the results

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have been analyzed as yet. It is expected that additional data will be obtained during the next quarter but a final result for the electron-neutron interaction will have to be delayed until the calculation of the correction for the motion of the center of mass has been completed. This calculation has proved to be difficult and it may be necessary to wait for the new computer, GEORGE, before it can be done in a reasonable length of time.

138-2 Characteristics of Multiplier Phototubes (5230)

Warren L. Buck and Robert K. Swank
Reported by Robert K. Swank

Work has continued on the investigation of the spectral response of photomultipliers. In fact, this has been the principal effort for the authors during this period. In addition, a major contribution is being made by F. N. Hayes and D. G. Ott of Los Alamos Scientific Laboratory. The experimental work is in its later stages and, barring some unforeseen difficulty, will be completed in the coming quarter. Joint publication with Hayes and Ott is planned.

The objectives of this project have been slightly modified since our last report. The work is now divided into two phases:

Phase I is a study of the statistical distribution in spectral response of a large number of commonly used phototubes. For this purpose, a complete spectrum is not determined, but only the ratio of observed pulse heights of two liquid scintillators. These scintillators are (1) toluene + 5 g/l terphenyl and (2) toluene + 5 g/l terphenyl + 0.5 g/l POPOP. The scintillators are so chosen that their spectral emission brackets the

wavelength range in which most commonly used scintillators lie, i. e., 3600A to 4300A. The experimental work for phase I is almost completed.

Phase II is concerned with the measurement of the absolute light-output ratios for nine liquid scintillators. These scintillators were selected on the basis of (1) commercial availability of the components of adequately high purity, and (2) a sequence of emission wavelengths extending from approximately 3300A to 4600A. Since there are many sources of error in the measurement of light-outputs in such a manner that the results are independent of wavelength, two independent methods will be used.

In the first method, a calibrated phototube is used. The tube is being calibrated by Milton Adelman, Naval Material Laboratory, Brooklyn, N. Y. Also, the emission spectra of the solutes are required. These are being determined by Hayes and Ott. From the above results, one can then calculate the relative quantum efficiency of the tube for the emitted spectrum of each solution. The relative pulse heights of the solutions are also obtained with the calibrated photomultiplier, using excitation by the internal conversion electrons from Cs^{137} , an evaporated aluminum optical reflector, and a quartz cell. The observed pulse height divided by the efficiency gives the light output of the solution. (One solution is taken as an arbitrary standard.) This work is still in progress.

In the second method, a calibration of the phototube is unnecessary. The scintillating solution, contained in a quartz cell, is irradiated by an intense gamma-ray source. Since all the solutions used have the same density, the rate of absorption of gamma-ray energy is the

same for all. The average rate of light emission from a scintillator is taken as a measure of its efficiency. However, the light is not measured by the phototube directly, but is reabsorbed in a fluorescent solution which completely surrounds the scintillator. Only the light re-emitted by the fluorescent solution can reach the phototube. It is only necessary to know the spectrum of the scintillator approximately, to insure that it will be totally absorbed by the fluorescent solution. The nine scintillators were measured with each of three fluorescent solutes dissolved in ethyl alcohol. When suitably pure fluorescent solutions were obtained, the results for the nine scintillators were the same on all three fluorescent solutes to $\pm 2\%$. This gives strong support to the basic assumption of this method—that the fluorescence yield of the absorbing solution is independent of the wavelength of the absorbed light. It is also assumed that the emission spectrum of the absorbing solution is independent of the wavelength of the absorbed light.

Once the relative light outputs of the solutions have been determined, it will be possible to use them in the future as scintillation standards. Errors due to differing response characteristics of different phototubes will be minimized by comparing "unknown" scintillators with a standard having nearly the same emission spectrum.

139-5 Liquid Scintillators (5230)

Warren L. Buck and Robert K. Swank
Reported by Warren L. Buck

This project is concerned with determination of the characteristics of various compositions of liquid scintillators, development

of more useful liquid scintillators, and investigation of the migration and quenching of electronic excitation energy in solutions. Earlier results of this study and descriptions of some of the techniques employed may be found in ANL-5554, I-139-3 and ANL-5609, I-139-4.

During the period covered by the present report, principal effort has been devoted to the determination of absolute light-output ratios for a number of different liquid scintillators. This work is described elsewhere in this report, under project I-138-2.

The fluorescence emission spectra of a number of liquid scintillators were determined using ultraviolet excitation and a Hilger quartz-prism spectrograph. These spectra were needed in connection with other aspects of the project.

Relatively little attention has been devoted during the period of this report to the problem of liquid scintillators containing heavy elements. It was noted, however, that p-xylene solutions appear to be slightly less quenched by the presence of diphenylmercury than are toluene solutions. Also it was confirmed that naphthalene is not effective in reducing the quenching produced by diphenylmercury in solutions containing p-terphenyl as the activator, whereas biphenyl does prove to be effective in this situation. This is thought to indicate a lack of effective energy transfer from naphthalene to terphenyl.¹

A quartz sample cell of appropriate design has been obtained for incorporation in the liquid-scintillator apparatus described in ANL-5554, I-139-3. With it, it is possible to excite the scintillator solutions with ultraviolet light of selected wave-length from a mono-

1. M. Furst and H. Kallmann, Phys. Rev. 97, 583 (1955).

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chromator, instead of with beta-particles as in previous work. Since various constituents of a solution can be excited selectively by proper choice of wavelength, it is hoped that this technique may lead to a better understanding of the processes of energy migration and quenching.

140-9 A Gaseous Scintillation Counter (5230)

Charles Egger and Charles M. Huddleston
Reported by Charles Egger

The investigation is aimed at developing a method or methods of using the photon emission of de-excitation of excited atoms or ions resulting from the slowing down of charged particles in a gas. Necessarily connected with this problem is the study of the mechanism and spectra of de-excitation, and the efficiency of detection. The detector efficiency involves studies of color shifting, reflectors, and photo surfaces of the electrical detector.

Proven uses of the scintillation counter to date include alpha counting with an energy resolution of approximately 10% and the detection of fission. Probably the major claims to fame are the rapid rise time of the pulse which is in the neighborhood of $5 \text{ to } 10 \times 10^{-9} \text{ seconds}$ and the relative insensitivity to gamma-rays. An interesting application would be the measurement of low neutron energies, 0 to 1 Mev, by way of the $\text{He}^3(n,p)\text{H}^3$ reaction.

142-7

Electron Accelerator (5220)

Robert K. Swank

There has been no activity on this project during the present quarter. However, the new fast oscilloscope has been received, and work is expected to be resumed shortly.

143-7

Plastic Scintillators (5220)

Louis J. Basile

The fluorescence spectra of some plastic scintillators excited by ultra-violet light have been determined. A summary of the results is given in Table VI.

The samples whose fluorescent spectra were determined are the same samples that were measured for light output under beta excitation. The fluorescence was examined with a Hilger intermediate quartz spectrograph using panchromatic plates. The sample was arranged so that the fluorescence passed through the plastic into the spectrograph. Thus the shorter wavelength peaks were reduced in intensity or missing entirely. It is felt that the spectra analyzed in this manner should most nearly resemble the scintillation fluorescence.

No attempt was made to study the change in fluorescent spectrum of the sample with changing concentration of solutes. While such a change does occur, it is felt that this variation occurs well within the region of maximum sensitivity of the photomultiplier tube used.

For the most part the spectra obtained represent those of the secondary solutes. The small differences in the spectral distributions are within the experimental uncertainty due to the inherent errors in the

photographic process used, or to slight differences in the concentration of the solutes.

TABLE VI

Wavelength at the peak of the fluorescence spectrum, and the range of fluorescent emission when polyvinyl toluene containing the specified solutes is irradiated by ultraviolet light from a mercury lamp. The percentages of solute are based on the total weight of the plastic.

Composition of solute	Wavelength at Peak of Fluorescent Spectrum	Range of fluorescent emission
4% TP	3600 A	3400 - 4100 A
2% PBD	3775	3600 - 4400
0.1% DPS	4075	3900 - 4600
4% TP + 0.1% DPS	4075	3900 - 4700
2% PBD + 0.1% DPS	4075	3900 - 4700
0.1% BBO	4125	4000 - 4600
4% TP + 0.1% BBO	4075	3900 - 4600
2% PBD + 0.1% BBO	4075	3900 - 4500
0.5% PPO	3825	3550 - 4400
3% TP + 0.1% PPO	3650	3500 - 4300
2% PBD + 0.1% PPO	3800	3600 - 4300
0.4% POPOP	4225	4100 - 4800
4% TP + 0.1% POPOP	4200	4000 - 4800
3% PBD + 0.1% POPOP	4225	4000 - 4800
2% α NPO	4325	4000 - 4800
4% TP + 0.1% α NPO	4025	3850 - 4500
2% PBD + 0.1% α NPO	4000	3850 - 4400

Raymond J. Munick

Some data were obtained which illustrate the description, given in the last report¹, of the production of transient electric currents

Fig. 18. Indication of transient electric current from Plexiglas as a result of the temperature change from 39.96° to 51.28°C. o = electric current. ■ = temperature. Dashed lines indicate steady state values (at 1390 min). The dotted line indicates the exponential approach of the current toward equilibrium after a steady temperature has been reached.

by means of changes in temperature.

In Fig. 18 is shown the behavior of the current from a specimen of Plexiglas as the temperature was raised. With an emf of 312.5 v across the specimen, the steady state current at 39.96°C was 6.46×10^{-14} amp. After the temperature of the specimen had been raised to 51.28°C and held there for 1300 minutes, the steady state current was 48.5×10^{-14} amp. As the temperature was raised, the current did not exhibit the monotonic increase to be expected from the current-temperature data taken under steady state conditions.

1. ANL-5609, I-148-6, p. 81.

Instead the current at first decreased and then increased in such a manner as to be less than the equilibrium value at all intermediate temperatures. This anomalous variation of current with temperature appears to be associated with polarization currents rather than with the conduction current. Such an interpretation has been given by Gross and Denard².

An article has been written which presents the significant results of the study of electrical conduction through Plexiglas, including the aftereffects of gamma irradiation described in I-152-4.

Because of the termination of the author, this will be the final report on this program.

2. B. Gross and L. F. Denard, Phys. Rev. 67, 253 (1945).

149-5 Dynamic Condenser Magnetometer (5220)

S. Bradley Burson and David W. Martin and Loren C. Schmid
Reported by S. Bradley Burson

ADJUSTABLE COUPLING FOR THE PHASING OF SIGNALS

In this magnetometer, the rotor of the dynamic condenser is mounted on the same shaft as the coil which rotates in the magnetic field being measured. When the "field signal", $A \sin \omega t$, from the coil is bucked against the "comparison signal", $-B \sin (\omega t + \varphi)$, generated by the dynamic condenser, the "error signal" is the resultant wave:

$$C \sin (\omega t + \theta) = A \sin \omega t - B \sin (\omega t + \varphi),$$

where φ is the phase of the comparison signal relative to the field signal,

and the amplitude C and phase θ of the error signal are given by:

$$C = \sqrt{A^2 + B^2 - 2AB \cos \varphi}$$

$$\theta = \tan^{-1} \frac{B \sin \varphi}{B \cos \varphi - A}$$

For the ideal case, in which the two voltages which are bucked against each other are exactly 180° out of phase, $\varphi = 0$ and consequently the amplitude of the error signal passes through zero as the value of the comparison voltage passes through the voltage generated by the field coil. That is, a true "null" occurs. In addition, for any value of imbalance, the phase θ of the error signal remains constant at either zero or π , passing discontinuously from one to the other when $A = B$.

For an arbitrarily small angular misalignment, φ , between the sensing coil and condenser rotor, the magnitude of the residual error signal, representing the minimum value obtainable, is given to the first order of approximation by: $C_{\min} = B\varphi$.

Thus in order to reduce the amplitude of the observed minimum error signal to a value equal to the true error signal which is observed for $A = (1 \pm 10^{-4})B$ and $\varphi = 0$, it is necessary that

$$\varphi \leq C_{\min} / B = 10^{-4} \text{ rad} \approx 20 \text{ sec of arc.}$$

To accomplish this adjustment of the phase, a special variable coupling has been constructed and installed between the shaft of the rotating condenser and that of the sensing coil. The coupling consists of two concentric cylinders, one fitted closely into the other. The outer cylinder is

mounted on the shaft of the condenser and the inner cylinder is mounted on the shaft of the sensing coil. A steel pin which passes transversely through the inner cylinder lies in a corresponding slot which is machined in the bottom of the outer cylinder. The latter is provided with four adjusting screws which turn in opposing pairs along parallel tangents and come to bear on the side faces of the transverse pin near its ends. Four screws are used instead of two in order to increase the mechanical rigidity of the adjustment. The symmetry of this arrangement also results in maintaining the dynamic balance. One complete revolution of the screws effects a relative motion of 2.4° .

It can be shown from the equations that for an arbitrary phase error, ϕ , a phase shift of $\pi/2$ always occurs at the point corresponding to the minimum error signal. The rectifier will always translate this output voltage as a "null" although a substantial residual error signal may still be present. To further facilitate the phase adjustment, the electronic system has been revised to permit measurement of the uncommutated output of the amplifier by means of an auxiliary vacuum-tube voltmeter. Thus, when the vacuum-tube voltmeter is connected, the coupling is adjusted until the indicator reaches its minimum.

It should be mentioned that a slight error in the phase relationship between the two signals does not introduce any non-linearity in overall performance. The result is rather to change the slope of the graph of magnetic field vs dial setting of the magnetometer. Apart from calibration

considerations, it is necessary to achieve sufficiently good phasing to be certain that the amplitude of the minimum error signal is well below the level which would overload the amplifier.

ELECTRONIC SYSTEM

The amplifier and the voltage supply for the stator originally provided for this instrument were found to be inadequate and the entire system has been rebuilt to higher standards.

PREAMPLIFIER

The dynamic condenser constitutes a high-impedance voltage source requiring a very high input impedance in the preamplifier. It must also have a low output impedance in order to drive the cable carrying the signal to the main chassis. The feed-back amplifier employed has a loop-gain of about 2000. The resulting effective input impedance is approximately 2×10^{10} ohms. The output impedance is at most a few ohms. The net gain is very nearly unity.

FILTER SYSTEM

As has been mentioned in previous reports, the wave form generated by the dynamic condenser contains small amounts of various harmonics of the 30-cycle fundamental. Although the 30 cycle fundamental vanishes in the "null" condition, the residual harmonics remain; at high field strength they are sufficiently strong to overload the amplifier. There is also an appreciable amount of random noise at the preamplifier output

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whenever the motor is running, probably due to mechanical vibration and microphonics. Therefore, the amplifier is preceded by a filter system designed to suppress all high frequencies in general, and 60, 90, and 150 cycles in particular. This system involves a standard type of low-pass filter and three "parallel-T" networks tuned to the frequencies mentioned. The signal from the preamplifier passes first through the 150 cycle filter and then through the low-pass filter system. For best performance, it is desirable that the output of this system work into a high impedance load. Therefore a cathode-follower, whose cathode load resistor constitutes the gain attenuator for the entire amplifier, is interposed at this point. The output of the attenuator passes through the 60 cycle "parallel-T" filter and thence into the high-gain pentode stage of the amplifier. This arrangement removes not only the 60-cycle harmonic content of the signal, but any "hum" which might be picked up by the preceding circuitry. As a result, when the entire system is connected but the motor is not running, residual hum at the output is less than 3 mv.

THE SIGNAL AMPLIFIER

The input stage consists of a 6J7-type pentode operated at a voltage gain of about 137. This stage is followed by a direct-coupled phase-splitter feeding into a push-pull output stage. This amplifier has an over-all voltage gain of about 1440. The 30-cycle signal suffers an attenuation of about a factor of 16 in the filter network, so that the over-all gain of the entire circuit is about 87 at 30 cycles. Every precaution

was exercised in the design to reduce hum and noise pick-up to a minimum. With the motor running and the field and comparison signals carefully balanced out, both in phase and amplitude, about 50 mv of output signal is attributable to the residual harmonics and "front-end noise" when the amplifier is set for maximum gain. For a magnetic field of about 20 gauss, this "noise" corresponds to the error signal produced by an imbalance of one part in 10^4 . At larger values of field the gain is reduced, so that the "front-end noise" becomes relatively less important. The residual harmonics, of course, increase with the general signal level, and remain at a level of somewhat less than 50 mv rms at the output. Thus the total spurious signal is always less than the minimum desired error signal for all but very low field values. With the synchronous rectification provided by the commutator, the error signal is readily distinguishable from a spurious signal of comparable amplitude.

The meter used for the final indicator deflects one division, out of 20 divisions full scale, for an error signal corresponding to an imbalance of about 1.5 parts in 10^4 .

THE STATOR VOLTAGE SUPPLY

The over-all accuracy of the magnetometer depends directly upon the stability of the stator voltage. It is desired that symmetry of the positive and negative outputs about ground potential be accurately preserved for all settings. To accomplish this, the supply is constructed so that the only grounded point is the center terminal of the voltage divider. In the original version of the voltage supply, a "Sola" type transformer was used.

The stator-voltage supply is mounted on the main amplifier chassis and it was found that the intense stray magnetic fields associated with this type of power transformer was responsible for a substantial part of the "hum". This source of noise was eliminated by replacing the "Sola" transformers with conventional ones at the sacrifice of the higher regulating properties of the former. This loss of regulation was more than compensated by greatly increasing the regulation factor of the electronic regulator system which precedes the two series groups of gas regulator tubes. In addition, both the main string of regulator tubes and the cathode reference tubes were enclosed in an insulated box. This "oven" is maintained at a temperature of $149^{\circ} \pm 1^{\circ}\text{F}$ by means of a heater and thermostat. After several days of warm-up and "ageing" the voltage was found to hold constant to within one part in 10^4 over a period of several days. Provision is also made to monitor the voltage from time to time with an external L & N Type "K" Potentiometer. A fine "trimmer" adjustment is provided to permit calibration so that the main dial will read directly in gauss.

AUTOMATIC SERVO OPERATION

Completely adequate automatic operation has been achieved with the new electronic system and the appropriate selection of the coupling resistor through which the magnetometer output voltage is fed to the current supply. The output circuit of the amplifier is now wired so as to effect a considerable increase in the "loop gain" when connected for

automatic operation. The current supply faithfully follows small changes in magnetometer setting and, even for very large sudden changes in the setting of the dial, the current adjusts with only one "overshoot" and reaches equilibrium within a few seconds.

The authors wish to express their appreciation to Mr. F. J. Lynch and Mr. J. B. Baumgardner of the Argonne Physics Division for their many helpful suggestions and assistance in designing and constructing the electronic system herein described.

Except for a few minor modifications and final tests, the instrument may be considered complete. A detailed description is being prepared and will be submitted for publication in the near future.

152-4 Radiation Damage to Dielectrics (5230)

Raymond J. Munick

After an accumulated dose of 10^7 r of gamma radiation, Plexiglas M3 had been heated overnight at 120°C without apparent harm¹. After an additional dose of 1.53×10^7 r, the same specimen was kept at 120°C for several hours, but this time the edges of the specimen drooped under their own weight and bubbles appeared under the evaporated aluminum electrodes. This result is in agreement with previous work² on the effects of radiation upon polymethyl methacrylate, which shows that there

1. ANL-5609, I-152-3, p. 87.

2. P. Alexander, A. Charlesby, and M. Ross, Proc. Roy. Soc. (London) 223A, 392 (1954).

is chemical degradation, giving rise to bubbles, and which implies that there is a lowering of the softening point.

With the second specimen, Plexiglas M2, precautions were taken to avoid heating. It was irradiated at an ambient temperature of 25°C , and throughout the electrical measurements it was kept at 30°C . It was given successive doses of 1.32 and $0.55 \times 10^7 \text{ r}$ for an accumulated dose of $1.87 \times 10^7 \text{ r}$. After standing for 2 days following the second irradiation, the current through the specimen was observed throughout

Fig. 19. Currents from Plexiglas at 30°C , after gamma irradiation. Emf of 315.2 v was applied 2 days after irradiation, giving positive current Δ ; removed 9 days after, giving negative current ∇ ; reapplied 16 days after, giving positive current $\circ$; and removed 23 days after, giving negative current $\times$.

four successive 1-week intervals with the results shown in the corresponding curves of Fig. 19. (a) A steady voltage of 315.2 v was maintained across the specimen for 7 days $\approx 6 \times 10^5 \text{ sec}$. The current flowed in the direction of the applied voltage (the positive direction). (b) For the following 7 days the voltage was kept at zero. The current flowed in the opposite (negative) direction. (c) The 315.2 v difference of potential was again maintained for 7 days. The current was again positive. (d) The voltage was kept at zero for a

final 7 days. The current was in the negative direction.

In three ways the currents shown in Fig. 19 indicate that part of the radiation-induced conductivity decays with the lapse of time after the exposure to radiation is stopped. First, the positive and negative currents obtained on the first application and removal of the voltage (Curves a and b) were greater than the respective currents obtained after the second application and removal (Curves c and d). Secondly, the first positive current (Curve a) decreased throughout the 7 days of voltage application whereas the second positive current (Curve c) attained a steady value. In the third place, the difference between the positive current and its final value was greater than the corresponding negative current in the first instance, but it was equal to it for the first 10^5 seconds in the second instance. The behavior of the positive and negative currents after the second application and removal of the voltage is similar to that before irradiation, and therefore it indicates that a permanent condition has been reached, in which the positive and negative currents are $25 \pm 5\%$ greater than the corresponding currents from unirradiated Plexiglas.

The temporary increase in the currents after irradiation is thought to be due to an excess of ions, which were removed by various processes such as neutralization at the electrodes or recombination within the volume of the specimen. The apparently permanent increase is thought to be a result of the greater freedom of movement afforded ions and dipoles as a consequence of the chemical degradation produced by the gamma radiation.

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If so, it should be proportional to the dose of gamma radiation and could be expressed as an increase of 1.33% over the unirradiated value for each dose of 10^6 r.

Results of others on the increase in conduction current during the x-irradiation of polymethyl methacrylate³ and the gamma- or x-irradiation of similar plastics⁴ indicate that, at the dose rates of 1 to 4×10^4 r/min employed in this work, the increase in conduction current during irradiation should have been of the order of 10^4 . Hence, the after-effects described above are very small compared to the effects which presumably would have been observed while the specimen was being irradiated.

(Because of the termination of the author, this is the final report on this program.)

3. J. F. Fowler and F. T. Farmer, Nature 175, 516 (1955).

4. S. Mayburg and W. L. Lawrence, J. Appl. Phys. 23, 1006 (1952); A. J. Warner, F. A. Muller, H. G. Nordlin, J. Appl. Phys. 25, 131 (1954); R. A. Meyer, F. L. Bouquet, and R. S. Alger, J. Appl. Phys. 27, 1012 (1956).

II. MASS SPECTROSCOPY17-8 Long-Lived Activities (5220)

David C. Hess and Mark G. Inghram

Reported by David C. Hess

One sample has been returned, but pressure of other work has prevented any measurements on it. Reporting on this project will be discontinued until further results have been obtained.

18-5 Lead Ages of Meteorites (5220)

David C. Hess and Royal Marshall*

Reported by David C. Hess

Several lead samples have been prepared from meteorite samples by a dithizone extraction technique.

Preliminary lead runs have been made on Ma 23, recording the counting rate from a 16-stage multiplier. Further measurements are in progress.

* Enrico Fermi Institute for Nuclear Studies.20-1 Tritium Age Measurements of Meteorites (5220)

Frederick Begemann*, Johannes Geiss* and David C. Hess

Reported by David C. Hess

Our investigations of the argon from meteorites indicated anomalies in the isotopic abundances. This led us to investigate the He^3 in meteorites and, as indicated in the abstract, certain measurements were made on both the He^3 and the tritium content.

This work has been prepared for publication. An abstract of the

* Enrico Fermi Institute for Nuclear Studies.

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proposed publication follows:

The tritium and He^3 contents of the Norton County stone meteorite were measured. At the time of fall (1948) the tritium activity of two different specimens were (0.28 ± 0.02) and (0.25 ± 0.02) dpm/g. The measured He^3 contents were (2.27 ± 0.11) and $(2.35 \pm 0.11) \times 10^{-6}$ cc STP respectively.

Experiments were made which indicate that there has been no appreciable loss of He^3 .

To accumulate the observed amount of He^3 at the rate at which it is produced from H^3 would require irradiation by cosmic rays of the present intensity for an apparent period of between 420 and 480 million years. If a plausible assumption is made as to the direct production rate of He^3 by spallation, the age reduces to between 240 and 280 million years. In contrast, the $\text{A}^{40} - \text{K}^{40}$ age of this meteorite is 4200 ± 700 million years.

29-7 Gaseous Species in Equilibrium at High Temperatures (5230)

(formerly "Gaseous Species in Equilibrium with Metal-Metal Oxide Systems")

Joseph Berkowitz (U. of Chicago), William A. Chupka
and Mark G. Inghram
Reported by William A. Chupka

The mass-spectrometric technique described in previous reports¹ has been used in the study of oxides of titanium, vanadium, and tungsten; titanium and aluminum carbides, and boron metal.

1. W. A. Chupka and M. G. Inghram, J. Phys. Chem. 59, 100 (1955).

I. TITANIUM-OXYGEN SYSTEM

The concentration of gaseous species in equilibrium with various compositions of the solid Ti - TiO₂ system have been studied by analysis of the molecules effusing from a Knudsen cell containing the solid. The evaporation of TiO(s) produced mostly TiO(g) molecules but also an appreciable quantity of Ti(g) atoms. Thermodynamic treatment of data on ion intensity yields $\Delta H_{298} = 139 \pm 5$ kcal/mole for the reaction $\text{TiO(s)} \rightarrow \text{TiO(g)}$.

The vaporization of TiO₂ produced mostly TiO₂(g) with appreciable amounts of TiO(g) molecules. The data were used to calculate $\Delta H_{298} = 146 \pm 5$ kcal/mole for the reaction $\text{TiO}_2(\text{s}) \rightarrow \text{TiO}_2(\text{g})$.

In the case of vaporization of Ti₂O₃, the composition of the vapor (and therefore presumably that of the solid) varied with time and the process could not be interpreted quantitatively. TiO₂(g), TiO(g) and Ti(g) were observed in the products of vaporization.

These results have been described in a paper which will soon be submitted to the Journal of Physical Chemistry.

II. VANADIUM-OXYGEN SYSTEM

V₂O₅(s) was vaporized from a platinum Knudsen cell and the vapor analyzed mass spectrometrically. The vapor was found to contain V₄O₁₀, V₆O₁₄, V₆O₁₂ and possibly V₄O₈ and V₂O₄ molecules. However, the total vapor pressure and the relative amounts of the various species varied with time at constant temperature and no quantitative data could be obtained.

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The vaporization of VO(s) , on the other hand, produced partial pressures of V(g) , VO(g) and $\text{VO}_2\text{(g)}$ which remained constant with time and were reproducible. The data were treated thermodynamically to yield 6.4 and 12.8 ev for the atomization energies of VO(g) and $\text{VO}_2\text{(g)}$ respectively.

A paper describing the work has been submitted to the Journal of Chemical Physics.

III. TUNGSTEN TRIOXIDE

$\text{WO}_3\text{(s)}$ was vaporized from a platinum Knudsen cell and the vapor was found to consist predominantly of $\text{W}_3\text{O}_9\text{(g)}$ with lesser amounts of $\text{W}_4\text{O}_{12}\text{(g)}$ and $\text{W}_5\text{O}_{15}\text{(g)}$. The relative concentrations of W_3O_9 , W_4O_{12} and W_5O_{15} at 1492°K were 561: 168: 1. From measured partial pressures of these species and their variation with temperature, ΔH° , ΔF° and ΔS° of vaporization for $\text{W}_3\text{O}_9\text{(g)}$ and $\text{W}_4\text{O}_{12}\text{(g)}$ were obtained. The values of ΔH_{1400} of sublimation were found to be 130 and 151 kcal/mole for W_3O_9 and W_4O_{12} , respectively.

The vaporization of WO_3 was found to be very closely analogous to that of MoO_3 , and the experimentally determined ΔS° of vaporization were nearly the same for the analogous polymers of both systems.

A paper describing these results has been accepted for publication by the Journal of Chemical Physics.

IV. TITANIUM AND ALUMINUM CARBIDES

Although the vaporization of metallic carbides is thought to occur by decomposition in most cases, there is some evidence for gaseous carbides of titanium and aluminum. In order to detect a possible titanium carbide molecule, titanium metal was placed in a graphite Knudsen cell and evaporated. The vapor was found to consist of Ti(g) , C(g) , $\text{C}_2\text{(g)}$ and $\text{C}_3\text{(g)}$. No TiC(g) was detected and, if present, was shown to constitute less than 1% of the vapor. X-ray diffraction of the material removed from the cell after the experiment showed that most of the graphite had been converted to TiC and that no free titanium remained. The measured vapor pressures of Ti(g) and C(g) were used to calculate the heat of formation of TiC(s) . This calculated value agreed within 2 kcal with the accepted value.

Studies of the Al-C system show that Al(g) is the predominant species in the vapor phase, with an ion of mass 78 also present. From the appearance potential and isotopic structure we have tentatively ascribed this ion to an Al_2C_2 molecule effusing from the cell.

This work was reported at the January meeting of the American Physical Society in New York².

V. BORON

A pressed crucible of pure elemental boron was placed in a graphite liner of a Knudsen cell and the effusing vapor was studied. Large quantities of B_2O_2 and BO gas were vaporized during the early part of the

2. W. A. Chupka, Joseph Berkowitz and Mark G. Inghram, *Bull. Am. Phys. Soc.* 2, 44 (1957).

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runs. A preliminary study of the $B_2O_2(g) \rightleftharpoons 2BO(g)$ equilibrium was made.

After longer heating, the vapor consisted almost entirely of B(g) atoms. The absolute pressure and temperature dependence were measured in the temperature range 1600° to 2330° K and yielded independent values of 128 and 130.5 kcal/mole for ΔH_o° of sublimation of boron.

The $B_2(g)$ molecule was undetected in the above run and was only found when the temperature was raised to 2447° K. From the relative amounts of B(g) and $B_2(g)$ the dissociation energy of $B_2(g)$ was calculated to be 2.7 ev.

Chemical analysis of the remains of the boron crucible showed that it contained about 9% carbon after the experiment which determined the heat of sublimation of boron. Another analysis showed that the boron which had been heated to 2247° K contained about 14% carbon. There was no appreciable decrease in boron vapor pressure during these runs, which indicates that the inclusion of carbon up to 14% does not greatly affect the activity of boron.

34-11 A⁴⁰ -K⁴⁰ Dating of Meteorites (5220)

Johannes Geiss* and David C. Hess
Reported by David C. Hess

Measurements on this project have been completed and the material will be prepared for publication.

* Enrico Fermi Institute for Nuclear Studies.

37-5 Ion Bombardment of a Solid Target (5220)

Henry E. Stanton

Since the last report the yield of beryllium ions from a solid target under bombardment of gaseous ions has been redetermined as a function of the mass of the bombarding ions. The original findings could not be checked, and a different functional relationship between the yield and bombarding mass was found. This newer determination, shown in the upper curve of Fig. 20, indicates that the yield of beryllium ions increases approximately as a simple power of the mass of the bombarding ion. The curve represents an average of several determinations of the dependence on the mass, taken under experimental conditions which were considerably improved over those under which the earlier results were obtained. The target was kept at a temperature in excess of 100°C at all times, and should have been quite clean.

The simple power-law relationship found in the upper curve of Fig. 20 was due, partially if not wholly, to secondary electrons which were emitted from the target and which were recorded as an in-

Fig. 20. Yield of Be^+ ions as a function of the mass number of the bombarding ion. Bombarding voltage = 1000 v.

creased target current. In order to verify this point, measurements were made to try to approximate the number of secondary electrons liberated since this was known to depend upon the mass of the impinging particles.

Provision was made to adjust the electrical potential between the target and the surrounding electrode (J_1), and measurements were made as the potential difference between the target and J_1 was varied between ± 15 volts. With the target positive with respect to J_1 , most of the secondary electrons should be trapped in the target, and the indicated target current should be approximately the ion-beam current. With the target negative with respect to J_1 , all of the secondary electrons should leave it, registering a higher target current. The variations in target current with the potential between the target and J_1 is shown in Fig. 21 for different values of the bombarding beam current. The beam in this

Fig. 21. Secondary emission from beryllium target under bombardment by He^+ ions. Bombardment voltage = 1000 v.

case was mostly He^+ ions, and clearly secondary electrons contributed a large fraction of the indicated target current at zero potential. Unfortunately, it was not possible to operate the machine with the target at a positive potential relative to J_1 , primarily because the beam was so badly diffused in the target chamber that practically

no ions were detected; and even if a detectable beam had been obtained, there would have been increased uncertainties as to the energy of the ions that would have emerged. The

upper curve of Fig. 22 shows the quantity α (defined as the ratio of the target current when the target is negative with respect to J_1 to the target current when positive with respect to J_1) as a function of the mass number of

the bombarding ions. The quantity $(\alpha - 1)$, representing the number of

secondary electrons emitted per incident ion, is plotted as the middle curve in Fig. 22; and finally the simple relationship of the inverse square root of the mass of the impinging ions is shown for comparison. (The latter has been widely used as a rough approximation to the number of secondary electrons emitted under such conditions.) When this correction for the secondary electrons is applied to the upper curve of Fig. 20, the result is the lower curve of Fig. 20, which shows almost no dependence of the beryllium yield on the mass number of the bombarding beam.

Since the yield is apparently independent of the mass of the bombarding ions, a simple collisional theory is quite clearly inappropriate, and some form of thermal theory is indicated.

Fig. 22. Correction for secondary emission of electrons.

At the suggestion of M. G. Inghram, the kinetic-energy distribution of the beryllium ions (published in the last quarterly report, ANL-5609, II-37-4, p. 100, and reproduced here for convenience as Fig. 23) was analyzed as a continuous linear combination of Maxwell distributions corresponding to evaporation at the rapidly-falling tempera-

tures of a hot spot. Attempts have been made to formulate a theory along this line.

Fig. 23. Distribution of kinetic energies of Be^+ ions resulting from bombardment by neon ions. Bombardment voltage = 1000 v.

If one assumes (a) a local hot spot at the point of impact of a bombarding ion, (b) the subsequent spreading from this point of a sort of wave of temperature, and (c) evaporation of target ions where conditions are favorable, then the yield of ions as a function of their energy E can be visualized as the linear combination of a continuous sequence of Maxwell distributions over a wide range of temperatures, with suitable coefficients, $g_o(T)$.

If $f(E)$ represents the yield at energy E and $g_o(T)$ is a suitable coefficient corresponding to the emission at the particular temperature T , then the

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idea may be formulated mathematically as

$$f(E) = \int_0^{\infty} g_0(T) E e^{-E/kT} dT$$

The problem is to determine the coefficient function $g_0(T)$ from the experimental data. The necessary mathematical manipulations involve the use of inverse Laplace transforms and empirical fitting.

The determination of g_0 is far from unique and several possibilities are shown in Fig. 24. One sees, however, that with reasonable assumptions the data may be explained on this basis; and while the temperatures required by this theory are high, they are not unreasonable so. Furthermore, it is clear that at high temperatures the curves show a common tendency to fall off as an inverse power of the temperature.

Finally, effort was devoted to trying to explain some of the salient features of these coefficient curves with a thermodynamic model involving evaporation from the hot area which is expanding and cooling, but presumably

Fig. 24. The coefficient $g_0(1/T)$ which is used when the yield of Be^+ ions resulting from bombardment by Ne^+ ions is expanded in terms of a continuous sequence of Maxwell distributions. Bombardment voltage = 1000 v.

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doing so at a rate which is slow compared to the time of evaporation of a single ion. Using the Clausius-Clapeyron vapor-pressure equation one can derive an inverse T^2 dependence which is quite compatible with the curves of Fig. 24.

This material was presented in a paper at the American Physical Society meeting in Chicago¹.

1. H. E. Stanton, Bull. Am. Phys. Soc. 1, 341 (November, 1956).

38-3 Mass Spectrometric Study of Charged Atomic and
Molecular Products of Nuclear Transformation (5230)

David C. Hess and Sol Wexler
Reported by Sol Wexler

During this period the gas-inlet line for the spectrometer, the vacuum line for preparation of the radioactive gases, a 90° spherical electrostatic deflector, and a 16-stage electron multiplier were constructed. The entire apparatus, with the exception of the electrostatic deflector and source, was assembled. After leak testing, the spectrometer could be evacuated to a pressure of 2×10^{-7} mm or less.

By use of a neodymium ion beam from a surface-ionization source, the magnetic-analyzer section and the detector were tested. The resolution obtained was approximately that expected theoretically. The 16-stage electron multiplier detected individual ions, as was desired. However, the 11-stage multiplier salvaged from MA-15 failed in this respect because of insufficient gain.

The deflecting and focussing characteristics of the spherical electrostatic deflector were studied by means of an electron beam from a hot filament placed at the object position and a fluorescent screen at the image position. The measured effective angular deflection was 95° for exact focus. However, the electron beam could be deflected through 90° with only slight distortion by proper selection of the voltages of the plates and filament. The deflection exceeds 90° because of the fringing field of the analyzer. This field appears to extend out from either edge of the condenser to the field-limiting plates, set 0.135" from the deflector. This distance had been selected as a result of application of Herzog's¹ relations for limiting the electrostatic field to the physical dimensions of a cylindrical condenser.

In order to facilitate fabrication of the source cone it has been decided to seal the numerous lead-ins by an epoxy resin. If the resin is not to interfere with the success of the experiment, however, its vapor pressure must not exceed 10^{-6} mm. Since no data on vapor pressure of cured epoxy resins were available, we proceeded to measure one. A greaseless, all-glass system was used. Measurements were made with a Veeco ionization gauge, the procedure used avoiding error due to pumping by the gauge. A Bakelite Company C-8 epoxy resin (No. BR-18774 with Curing Agent BR-18807) was chosen because of its successful use in electron multiplier tubes. In all of the several measurements the indicated equilibrium

1. R. Herzog, Z. Physik 97, 596 (1935); 89, 447 (1934).

value of the static vapor pressure was equal to or less than 5×10^{-7} mm. Although the gauge is calibrated for air, no correction need be made for the organic vapor present in the gas phase. The gauge is operated sufficiently above the appearance potential that the probabilities of ionization of air and organic molecules may be considered equal.

The conical source was assembled and sealed with the epoxy resin. During the evacuation the resin persisted in cracking in the seals at the front and rear ends of the cone. This unfortunate effect is probably due to flexing of the cone under vacuum. The two sections have been redesigned to avoid use of the resin, and the necessary alterations are being made.

V. THEORETICAL PHYSICS, GENERAL2-13 Excited States of Light Nuclei (5220)

Dieter Kurath

The survey of M1 and E2 transitions for the nuclei in the 1p shell has been completed. In general the agreement between this intermediate-strength spin-orbit coupling model and experiment is not strikingly good. There are transitions in Be^8 and C^{12} for which agreement is excellent. There are, however, cases in B^{10} and B^{11} for which there is either disagreement or only rough similarity. A frequent occurrence is that the computed strength of the E2 transition is too small by factors which vary between two and ten. This may be an indication that introducing some collective behavior into the model might remove many of the discrepancies. A summary is being submitted for publication.

3-3 Dynamics of Nuclear Collective Motion (5220)David R. Inglis and Kiuck Lee
Reported by David R. Inglis

Asymmetric fission, odd rotational states of even nuclei, and emission of alphas from the sides rather than the ends of elongated nuclei may all be associated with an energetic preference for pear-shaped deformations of heavy nuclei. There may be favorable symmetries in such a shape since it may result from a partial formation of two unequal and nearly spherical closed shells (one with 82 neutrons and one with 50) in contact and glued together by a few extra nucleons. An attempt is being made to determine

whether an initial trend toward such a deformation can be obtained from a perturbation theory.

4-10 Investigation of Nuclear Structure (5220)

Maria Goeppert Mayer

I. A STATISTICAL THEORY OF FISSION

A talk was given at the Conference on Statistical Mechanics of Irreversible Processes at the Free University of Brussels, August 29, 1956. It will be published in the Proceedings of the Conference. The talk was based on the work of Peter Fong for his Ph. D. thesis at the University of Chicago.

II. IRROTATIONAL FLOW IN TWO DIMENSIONS

The Bohr-Mottelson model of the nucleus ascribes many nuclear properties to the irrotational flow of the nuclear fluid. Since the mathematics of the Bohr approach is involved, a calculation was made for a two-dimensional model, in which one can see clearly what happens and can draw pictures of flow patterns.

We know that Bohr's model is not in complete agreement with all experimental facts. The two-dimensional analogue removes none of the difficulties. One only hopes that a clear understanding of Bohr's model may enable one to find out how it has to be modified.

A paper has been written on the subject but it has not yet been submitted for publication.

5-1 Intermediate Surface Coupling in Even-Even Nuclei (5220)

B. James Raz

In order to investigate the transition region between weak and strong coupling in the Bohr-Mottelson collective model¹, a series of calculations using intermediate surface coupling has been initiated. This study is aimed at explaining the observed deviations from pure rotational spectra by examining the variation of theoretically predicted spectra of even-even nuclei with changes in a) the two-particle interaction and b) the strength of surface coupling.

Specifically, the spectra of two equivalent particles with $j = 7/2$ are being calculated, taking account of the two-particle interaction found suitable for Ca^{43} and including varying strengths of surface interaction.

During this report period, the matrices for $I = 0$ and 2 have been calculated. The remaining two matrices for $I = 4$ and 6 will be completed in the near future. The $I = 0$ case has been carried out both up to 3 and up to 4 phonons of surface excitation, in order to check the range of validity of the calculations. Due to the large size of the matrices, the cases of $I = 2, 4$ and 6 are considered only up to three phonons.

The eigenvalues and eigenvectors for the matrices are being evaluated on the AVIDAC using the diagonalization and extraction code developed by D. Kurath for his problems.

Detailed results are not yet available.

1. A. Bohr and B. R. Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. 27 No. 16 (1953).

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6-3 Polarization of High-Energy Protons by Scattering (5220)

Maria Goeppert Mayer

Calculations on the polarization of protons by inelastic scattering have been made in the Born approximation. Calculations by phase-shift methods are very complicated. It seems advisable to postpone these until more experimental data on polarization of protons by inelastic scattering are available. Hence reporting will be discontinued until work is resumed.

7-1 Spin-Orbit Coupling in Light Nuclei (5220)

Kiuck Lee

A study is being made to explain the experimental spin-orbit splitting in light nuclei by taking into account a relativistic effect of nuclear forces on the spin-orbit coupling. A preliminary calculation with the droplet model gives 2 to 5 Mev for the coupling constants (for $A = 5$ to 15). In earlier work¹ it has been shown that these values lead to low-lying levels in good agreement with experiment.

An attempt also has been made to explain the difference in doublet-splitting in mirror nuclei, which is usually assumed to be due mainly to the charge effect². A simple calculation with the droplet model gives the right sign of the observed differences. Further investigation is under way.

1. D. Kurath, Phys. Rev. 101, 216 (1956).2. J. M. Blatt and V. F. Weisskopf, Theoretical Nuclear Physics (John Wiley and Sons, New York, p. 257 (1952).

8-3

Double K-Capture

(5220)

Maria Goeppert Mayer

The calculations have been finished. Since it is now known that the neutrino and the antineutrino are different particles, the half life in a rather favorable case (Cd^{106} to Pd^{106}) is about 2×10^{24} years. Since this is presumably outside the range of measurement, there is no point in further theoretical study.

This project is finished.

12-6

Investigation of Neutron Scattering under the (5220)
Feshbach-Porter-Weisskopf Model of the Nucleus.

Morton Hamermesh and Paul Fischer

Reported by Paul Fischer

An attempt was made to improve the fit of measured and calculated angular distributions by adding a spin-orbit interaction to the FPW square-well potential. This procedure effectively adds one additional parameter to the formalism, but its effect on the results is not simple. After several cases were run by hand it was apparent that a complete restudy would be necessary to optimize the parameters. Since the original FPW program was marginal for the AVIDAC, the modified formalism will have to be programmed for GEORGE.

This project is therefore on the inactive list until at least

June 1, 1957.

14-3

Analysis of the (d,p) Reactions

(5220)

B. James Raz

During this report period the article entitled "Angular Momentum Coupling and the Internucleon Interaction in the Calcium Isotopes," written with J. B. French, Dept. of Physics, University of Rochester, appeared in the Physical Review, 104, 1411 (1956). A report on this work entitled "Reduced Particle Widths and the Effective Nucleon-Nucleon Interaction in Nuclei" was given by J. B. French at the Nuclear Reactions Conference in Amsterdam, July 2 - 7, 1956. An abstract of this appeared in the Proceedings of the Conference: J. B. French and B. J. Raz, Physica 22 No. 11, 1157 (1956).

A report was given at the Chicago meeting entitled "An Interpretation of New (d,p) Experimental Data in Terms of the j-j Coupling Shell Model," Bull. Am. Phys. Soc. 1, 336 (1956).

The preliminary results of the O^{17} (d,p) O^{18} experiment done by O. M. Bilaniuk¹ at the University of Michigan, have been analyzed and compared with the expected results calculated using Redlich's² wave functions for O^{18} . At present there is some slight indication that O^{18} is closer to pure j j coupling than indicated in Redlich's results.

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1. O. M. Bilaniuk, Bull. Am. Phys. Soc. 1, 326 (1956), and private communication.
 2. Martin G. Redlich, Phys. Rev. 99, 1427 (1955), and private communication.

15-3 Energy-Level Density of a System of Fermi Particles (5220)

Norbert Rosenzweig

The original, and still the ultimate, goal of this program is to give a detailed theory of nuclear level densities. There are two aspects to the problem: (a) which model to use, and (b) the way to carry out the calculations. Most of our effort to date has been connected with the second aspect which is, however, based on the general assumption that the levels of an excited nucleus may be obtained by the occupation of a suitable set of individual particle levels. The following contributions to the mathematical formulation and treatment of the so-called "statistical theories" have been made during the period of this report:

The level-density problem has been formulated in terms of a Darwin-Fowler integral which avoids the doubtful assumption of "approximate differentiability."

We have arrived at a conjecture regarding the error made in the saddle-point approximation. The conjecture, which can be supported by plausibility arguments, has been verified in one particular case, but a proof for it is still lacking.

A paper entitled "The Level Density of a System of Fermi Particles" has been accepted for publication in the February 1957 issue of the Physical Review. In that paper the modifications of the theoretical level density with increasing excitation are discussed in the "continuous approximation."

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In some instances the continuous approximation need not be made (since the infinite series can be summed). In one such case we obtained the level density in a closed form which also shows the influence of the shell structure of the ground state.

17-2 Analysis of Angular Distributions and Correlations (5220)

William C. Davidon

The angular-correlation and energy-spectrum data of T. Novey on Re^{186} are being analyzed using the AVIDAC to determine the most likely values for the matrix elements involved in the transitions. The previous procedure used in seeking a minimum converged too slowly under certain conditions to permit exploration for all the possible sets of matrix elements that might fit the experiments. To correct this, the procedure was modified to make more complete use of the information obtained in the course of the calculation. The new procedure is particularly advantageous when the ratios of the eigenvalues of the error matrix are large, i.e., when some linear combinations of the parameters to be determined are much better determined than others.

The new code is essentially completed and analysis of the data will be resumed.

19-2 Ingoing - Wave Condition in Scattering Theory (5220)

Melvin Hack

A formulation based directly on the wave equation leads to a new time-dependent derivation of the ingoing-wave theorem. The method is uniformly applicable to ionization problems and problems of scattering by combined potentials. This treatment does not require the use of complete expansions in terms of basis functions and provides a natural introduction of the boundary conditions on scattering eigenfunctions. Further applications are being studied.

20-1 Angular Distribution of Inelastically-Scattered Deuterons (5220)

Paul Fischer and Morton Hamermesh
Reported by Paul Fischer

A preliminary investigation has been started in an attempt to improve the fit to some data on deuteron scattering reported recently by Haffner¹. [In Haffner's paper, the distributions resulting from a nuclear-surface interaction involving only the neutron (i. e. a stripping-type interaction) and an electric multipole interaction of the proton with the scattering nucleus are separately compared with the measured data.]

Initially we are merely treating these interactions coherently; numerical work is in progress but results are not yet available.

1. J. W. Haffner, Phys. Rev. 103, 1398 (1956).

40-2 Quantum Mechanical Ergodic Theorem (5230)

Hans Ekstein

A preliminary draft of a paper has been completed. Preprints are available.

ABSTRACT

The existing form of the Quantum-Mechanical Ergodic Theorem, due to Von Neumann, deals with a closed macroscopic system and only macroscopic observables. Certain unsatisfactory features of this theorem are probably due to the overly-strong idealization of a completely isolated system.

The present theorem deals with a system (many or few degrees of freedom) and observables (macroscopic or microscopic) during interaction with a temperature bath. The bath is described precisely and explicitly by a Hamiltonian. The model of the bath is obtained by taking the Gibbs ensemble seriously, i. e., as a set of N identical systems interacting through a potential λV .

The theorem states: The time-average of the quantum mechanical expectation value of any observable with respect to any initial state whatsoever, is equal to its statistical average, in the double limit $N \rightarrow \infty$, $\lambda \rightarrow 0$, for almost all potentials V . The proof is given in the paper.

41-2 Scattering in Field Theory (5230)

Hans Ekstein

The study is completed. The results are reported in a paper entitled "Scattering in Field Theory", Nuovo Cimento X, 4, 1017 (1956).

ABSTRACT

A precise statement of the scattering problem, general enough to include composite particles in field theory, is proposed. The four Heisenberg operators P_μ which represent the total energy-momentum vector, can be expressed asymptotically ($t \rightarrow \pm\infty$) as integrals of mutually commuting operators $A_r(\pm)^\dagger(k) k_{r\mu} A_r(\pm)(k)$ which represent the four-momenta of the incident and outgoing particles, both elementary and composite. For a theory given in terms of bare-particle creation operators $a_r^\dagger$, the problem consists in finding the asymptotic operators $A(\pm)$ as functions of the a_r and $a_r^\dagger$. A system of linear equations is derived for this purpose. Alternatively, the S-matrix can be obtained by solving a bilinear equation, the inhomogenous term of which consists essentially of products of one-particle state vectors.

42-2 Irreversible Processes in Quantum Mechanics (5230)

Hans Ekstein and N. Rostoker (General Dynamics, San Diego)
Reported by Hans Ekstein

The writing of the paper has been concluded. Except for minor editing work, the project is terminated. Preprints are available.

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ABSTRACT

Systems driven by a periodically time-dependent external force ultimately attain a "periodic state" which is independent of the initial state. A precise definition of the observables in this state is proposed. The approximation suitable to this problem consists in a combination of perturbation calculus with the determination of the "final" state. This latter problem is, in the simplest case, identical with the transport equation which thereby is made a part of a deductive quantum-mechanical approximation scheme. Electric conductivity and ferromagnetic relaxation are discussed as applications.

44-6 Fixed-Source Meson Theory (5230)

Hans Ekstein, James C. Swihart and Katsumi Tanaka
Reported by Katsumi Tanaka

Two preprints entitled "Representationless Formalism in the Field Theory of Fixed Nucleons" by Ekstein, Swihart and Tanaka, and "Properties of the Fixed-Source Meson Theory" by Tanaka are available.

The former contains the calculations of the point nucleon interacting with scalar charge-symmetric mesons and the magnetic nucleon moment in the static cut-off model with pseudo-scalar coupling, and the latter contains the calculations of the renormalized p-wave coupling constant from experiments and the total number, total charge and energy of the mesons in the nucleon cloud and the self energy of the physical nucleon.

A report on the latter subject was presented at the 1957 New York Meeting of the American Physical Society¹.

1. Katsumi Tanaka, Bull. Am. Phys. Soc. 2, 61, (January 1957).

45-6 Renormalizable Field Theory (5230)

Katsumi Tanaka

This research is completed and the results, of which a summary was given in the previous report ANL-5609, are scheduled to be published in a paper entitled "Meson-Nucleon Scattering in the Tamm-Dancoff Method," Physical Review 105 (1957).

This will be the final report on this program.

46-3 Scattering of Pions by Complex Nuclei (5210)

Melvin Ferentz and Morton Hamermesh
Reported by Melvin Ferentz

We have continued the AVIDAC calculation of the scattering of pions. Several thousand additional cases have been computed. The results are consistent with the calculations reported earlier¹ and in disagreement with experiment. In an attempt to fit the experiment we are changing several parameters to see the effects of the changes on the distributions in angle and energy. In particular, we are investigating whether a change in the mass of the nucleon inside the nucleus^{2,3} will improve the fit to experiment.

1. ANL-5554, page 139.

2. K. A. Brueckner, Phys. Rev. 97, 1353 (1955).

3. H. A. Bethe, Phys. Rev. 103, 1353 (1956).

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48-2 Dispersion Relations (5210)

William C. Davidon and Marvin L. Goldberger (University of Chicago)

Reported by William C. Davidon

The comparisons made between pion-nucleon scattering experiments and dispersion relations have been completed for the present and the work has been described in Phys. Rev. 104, 1119 (1956). It is not anticipated that additional work on this project will be performed for the next several months.

55-2 Spectra of UF_6 , NpF_6 and PuF_6 (5230)

Maria Goeppert Mayer

The calculations have been finished, but not yet compared with the experimental data.

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VII. APPLIED MATHEMATICS

Electronic Computer Programs

Donald A. Flanders

In recognition of the constantly broadening scope of our activities and of the need to expand them, the Applied Mathematics Section of the Physics Division was transformed into the Applied Mathematics Division on November 1, 1956. Consequently, future reports of our work will be issued by the Applied Mathematics Division. The first of these will cover the period from September, 1956, through March, 1957, thus preserving continuity with the last previous report, contained in the Physics Division Summary Report, ANL-5609.