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Louis A. Turner, Division Director

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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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I. EXPERIMENTAL NUCLEAR PHYSICS

1-11 The Argonne Fast Neutron Velocity Selector (5220)

Lowell M. Bollinger, Roland J. Brown, Robert E. Cote'
James M. LeBlanc, Jean P. Marion and George E. Thomas
Reported by Robert E. Cote'

Several small modifications were made to the fast chopper so that the chopper could be run at full speed (15,000 rpm) indefinitely.

These were the following:

- a) a bronze bushing in the damper was replaced by a ball bearing. This step apparently removed the mechanism which caused the vibrations which had limited operation to 10,000 rpm.
- b) water cooling was added to cool the drive motor, since the motor ran too hot at full speed.
- c) a thermistor and an accompanying trip circuit were added to sense any rise in temperature of the motor above its normal operating temperature and to stop the chopper in such an event. This tends to prevent a bearing failure from causing any major damage.

The 1024-channel time analyser which was installed at the beginning of this report period has been used regularly since its installation. Some minor difficulties which were found in actual operation were

corrected and the analyser now shows excellent reliability. Data have been recorded in the analyser in channel widths that range from $1\ \mu\text{sec}$ to $32\ \mu\text{sec}$. The old 100-channel analyser has been kept in service and the two time-analysers have been used regularly to record data from two detectors simultaneously. In some instances the 1024-channel analyser has been split to receive the counts from two detectors and this feature of the analyser has proven satisfactory.

2-11 Neutron Detectors (5220)

Lowell M. Bollinger and George E. Thomas
Reported by George E. Thomas

The boron-loaded liquid scintillation neutron detector described in the last quarterly, having detector proper dimensions of $1\text{''} \times 16\text{''} \times 2\text{-}1/4\text{''}$, has been completed and is being tested. Results are as yet inconclusive as to the quality of this detector.

A noble gas scintillation fission chamber of the type described in the last quarterly has been constructed and is in use at the fast chopper. The detector uses two R. C. A. 6342 photomultipliers, optically isolated from each other, each facing a plutonium-coated nickel foil, .002" thick, with an area $5.6\text{ cm} \times 9.4\text{ cm}$. The foils are coated by a painting technique to a thickness of 1.4 mg/cm^2 . Each foil is four inches from the face of the photomultiplier. By placing the foils at this relatively large distance from the photomultiplier better resolution may be obtained with a sacrifice of pulse height. The pulse is taken directly out of the photomultiplier into a

pulse height discriminator consisting of a biased silicon diode. With this circuit it is not necessary to use a fast amplifier system. The detector operates at atmospheric pressure using a continuous flow system with roughly a 30% nitrogen - 70% argon mixture. In the future, krypton gas may be used as it will produce a shorter pulse and make it possible to more easily discriminate the alpha-pile-up pulses from the fission-fragment pulses.

The multiple-plate fission-detector described in the last quarterly has been completed and after testing found to be quite satisfactory.

A boron-coated plate-and wire type detector has been constructed and is in use at the fast chopper. The high voltage electrode consists of five nickel foils coated with enriched boron to a thickness of $.2 \text{ mg/cm}^2$ over a $2\text{-}1/2" \times 7"$ area by a painting technique. The collecting electrode consists of four frames with $.002"$ diameter stainless steel wires spaced every one-half inch along the length of the frames. A suitable diameter wire must be used in order to obtain gas multiplication in the detector. It is filled to atmospheric pressure with an argon-carbon dioxide mixture. This detector is used for relative flux measurements. Other detectors of this general type are under construction.

3-11 Cross Section Measurements with the Fast Neutron Velocity Selector (5220)

Lowell M. Bollinger, Roland J. Brown, Robert E. Cote',
P. Hubert, James M. LeBlanc, Jean P. Marion and
George E. Thomas

a) Transmission Measurements on Bromine and Selenium

Reported by Robert E. Cote'

These measurements have been completed and a paper is being prepared for publication in the Physical Review.

b) The Energy Dependence of ν for Pu²³⁹

Reported by Lowell M. Bollinger

The dependence of ν , the number of neutrons per fission, on the incident neutron energy was measured for Pu²³⁹ over the range from 0.02 ev to a few hundred ev. From thermal energy thru the first resonance at 0.3 ev, it was found that ν varies by less than 1/2 per cent. For the 9 resonances and 4 groups of resonances that were isolated at higher energy, ν was found to be constant to within an average statistical error of 3 per cent. Further details are given in an abstract by Bollinger, Cote', Hubert, LeBlanc, and Thomas in Bulletin of the American Physical Society, Series II, Vol. 1, 165 (1956).

c) Neutron Cross Sections of Pu²³⁹ Near Thermal Energies

Reported by Lowell M. Bollinger

The best available cross-section data for Pu²³⁹ in the energy range from 0.025 to 0.4 ev have contained a serious discrepancy between the energy variation of η as measured directly and the variation deduced from the fission and total cross sections, where η is the number of secondary neutrons produced per primary neutron absorbed. In an attempt to resolve this difficulty, we have independently measured the quantities η , σ_f , and σ_t in the energy range from 0.015

to 0.5 ev. Within the statistical accuracy of the data, these three sets of data are entirely consistent, as is illustrated by the following ratios:

by direct measurement of η

$$\frac{\eta \text{ at } 0.30 \text{ ev}}{\eta \text{ at } 0.0253 \text{ ev}} = 0.839 \pm .012$$

from σ_f and σ_t for a constant ν

$$\frac{\eta \text{ at } 0.30 \text{ ev}}{\eta \text{ at } 0.0253 \text{ ev}} = 0.84 \pm .04$$

d) Cross Sections of Pu²³⁹ for Epi-thermal Neutrons

Reported by Lowell M. Bollinger

A program for the measurement of σ_f and σ_t over the energy range of 1 to 50 000 ev has been started. For total cross sections, a resolution of about 0.04 μ sec/m is being used and for fission cross sections, 0.10. Resonances have been observed at the energies 7.8, 10.9, 11.9, 14.3, 14.6, 15.5, 17.6, 22.2, 23.9, 26.6, 27.3, 32.3, 35.3, and 41.4 ev, with a very complicated structure at higher energies. Parameters are being deduced for these resonances.

e) Resonances in Pu²⁴⁰

Resonances that were observed at 20.4 and 38.2 ev in a study of Pu²³⁹ have been assigned to the isotope Pu²⁴⁰. Analysis of these resonances under the assumption of a value of 0.040 ev for Γ_γ gives the

following preliminary values for the parameters:

<u>E_o</u>	<u>σ_o</u>	<u>$\frac{1}{\sigma_o}$</u>
20.4 ev	20 500 barns	0.048 ev
38.2	17 000	0.054

6-10 (Spiral Velocity Selector for Slow Neutrons) (5220)

R. Nasuhoglu (SNSE) and G. R. Ringo
Reported by G. R. Ringo

Work on this apparatus has been revived and it has been set up for running tests.

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

1. Operational Experience - Reported by Jack Wallace

During this period (October 31, 1955 to March 31, 1956) the Van de Graaff generator has been operating at various energies as called for by the different experimenters. Proton, deuteron and alpha particle beams were used.

The following time distribution shows the division of time and also the types of experiments being performed with the Van de Graaff generator. There has been no effort made to show the efficiency factor for the times allotted to the various experimenters.

1. Inelastic Scattering - Mooring, et. al.	203.4 hr
2. Energy Losses in Various Gases - Burgy	98.3
3. $S^{32} (d, \alpha) P^{30}$ - Lee, Mooring	85.0
4. Li Plate - Krohn, Ringo	32.7
5. Total Cross Sections - Hibdon	102.8
6. Resonance Scattering - Lane	218.2
7. Proportional Counter - Perlow and Redman	65.1
8. Lifetime Measurement of Excited States - Hanna	25.2
TOTAL	830.7

Time Available

(107 days x 15 hours) + 44 hours (Sat. and Sun.)	1649.0 hours
Start up time and daily maintenance (112 x 0.5 hour)	56.0
Experimental set up time which ties up generator, and experimental equipment breakdown	309.2
Generator out of action	284.0
Air Conditioning installation	59.5
Machine improvements (Belt tension system)	38.5
Machine available but not used	65.9

For the results of the various experiments performed on the Van de Graaff generator see the respective authors' individual reports.

A large share of the generator out of operation time can be attributed to trouble developing out of the use of sulfur hexafluoride as an additive to the insulating gas used in the generator.

We decided to try SF_6 instead of $\text{C Cl}_2\text{F}_2$ as an additive gas to the nitrogen because of some undesirable traits associated with Freon ($\text{C Cl}_2\text{F}_2$). Sulfur hexafluoride according to tests made by G. E. and people at MIT has better insulating properties than $\text{C Cl}_2\text{F}_2$ with possibly less corrosive effects. We were well satisfied with its insulating properties although we made no absolute comparisons with former operations with Freon ($\text{C Cl}_2\text{F}_2$).

After only a very short time of using SF_6 we developed troubles of a new sort. There was a deterioration of rubber and neoprene parts such as shock mounts, tank gaskets, charging belts, V-drive belts etc. With SF_6 as an additive to the insulating gas the lifetime in the machine of these parts was so short that it was impractical to continue its use. We have now returned to Freon gas and feel that with care as to our selection of metals going into the machine we can minimize our out-of-operation time.

We have also re-designed and built several Van de Graaff component parts to improve their reliability and length of useful operating time with minimum maintenance. These items are:

1. Probe supply for H. V. platform
2. Belt tension system and indicators
3. Wobble target
4. Better system for checking accelerating tube alignment
5. New control circuits

This work was accomplished by joint cooperation of various members of the Van de Graaff Generator group.

12-1 Integrator of Current in an Ion Beam (5220)

Frank Lynch and Alexander S. Langsdorf, Jr.
Reported by Frank Lynch

After six years of service at the Van de Graaff generator, the dynamic condenser integrator of the ion beam continues to be reliable. Measurement of an RC time constant over the last two weeks show a standard deviation of less than 0.02% from the average RC. Because of the high inherent consistency of the instrument, a technical report is being prepared for submission to the Review of Scientific Instruments.

Although the operation of the beam integrator is largely trouble-free, another one will be constructed because its use is basic for the effective use of the Van de Graaff machine. When the new one is finished the present instrument will be kept as a spare. The new instrument will have an improved synchronous detector which will discriminate more effectively against microphonic disturbances and hum.

14-10 Pulsed Neutron Beam for the Van de Graaff Generator (5220)

Robert Holland

A new circuit for converting time intervals to pulse height is under construction. From tests on individual components, the performance of this circuit is expected to be considerably better than the original

circuit. The design of a small bunching magnet to provide a beam five to ten times as intense as the one now available is under consideration.

15-7 Stopping Cross Sections of Gases for Heavy Ions (5230)

Merle T. Burgy

During the past six months, the apparatus has been used again with the Van de Graaff accelerator.

Nearly all the scheduled time was required to get the apparatus in working order. The alignment of the 25° electrostatic analyser with the beam from the 90° analyser again proved to be time consuming. Many "bugs" were found and eliminated from the high voltage control apparatus and the particle detection apparatus. During the short time left for taking data, the McLeod gauge became unreliable by virtue of the mercury columns sticking in the capillaries. Some data were taken using a helium ion beam with air as the stopping gas. The uncalibrated alphasatron gauge was used for measurement of gas pressure. The results obtained compare well with stopping powers gotten from the range-energy relation given by Bethe and Ashkin¹. It has proved practical to leave the 25° analyser in position until time at the Van de Graaff is again available, so that re-alignment may not be necessary.

1. "Experimental Nuclear Physics", Vol. I, E. Segre', Ed. J. Wiley and Sons, New York

Subsequently, Prof. S. K. Allison offered the use of his Cockcroft-Walton accelerator (kevatron) in the Enrico Fermi Institute for Nuclear Studies of the University of Chicago for measurements at energies below 900 kev. The kevatron develops 450 kv and its r.f. ion source gives usable amounts of doubly charged helium ions.

The apparatus available in Prof. Allison's laboratory for these measurements was similar to that used by P. Weyl². The gas cell provided for differential pumping in the same manner as that used in the ANL work but was shorter, the inner cell length being 20.6 cm as compared with 76.5 cm.

The beam from the kevatron was magnetically deflected 15°, passed through the gas cell and then through a 90° electrostatic analyser of 15-cm mean radius. The beam then struck a ZnS phosphor on a glass window which was viewed by a photomultiplier tube. The output of the photomultiplier was amplified and applied to the vertical deflection plates of an oscilloscope. The horizontal plates of the oscilloscope were driven by a 60-cycle/sec sinusoidal voltage which was also applied to the electrostatic analyser in addition to a steady deflecting voltage. For approximately correct steady deflecting voltages, the beam would be swept across the analyser exit slit and an energy spectrum of the beam would appear on the oscilloscope. The steady deflecting voltage would be adjusted to bring the

2. P. Weyl, Phys. Rev. 91, 289 (1953)

peak of the spectrum to a fiducial line in making an energy measurement.

As the He^{++} beam passes through the gas cell, a large fraction of the ions are converted to He^+ ions by electron capture from the atoms of the stopping gas, even in the evacuated state when the inner cell pressure is about 1 micron. To avoid interference from molecular hydrogen ions present in the He^{++} beam, the range of analyser voltage was so chosen that only the He^+ ions emerging from the gas cell were observed.

Measurements were made with hydrogen, helium, air and argon as stopping gases. The results of preliminary reduction of the data obtained are given in Figure 1. The uncertainties of the stopping cross sections are estimated to be about 5%. Some of the results obtained by Weyl² at lower energies are given in Figure 1 for comparison. A discrepancy is apparent for argon as the stopping gas.

16-4 A New Neutron Counting System (5220)

Alexander S. Langsdorf, Jr., F. Paul Mooring
Reported by F. Paul Mooring

The preliminary design studies are nearing completion. New counter assemblies based on the results of these studies will be designed.

17-4 The Energy Spread of Neutrons from Lithium Targets (5220)

F. Paul Mooring

No further targets have been studied during the past quarter. A new gyrating target assembly, designed to eliminate sliding oil seals,

FIGURE 1

has been constructed and tested. One should now be able to prepare more nearly oil-free targets.

18-2 Differential Cross Sections for Neutron Resonance Scattering
(5220)

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

Resonance scattering measurements made with the Van de Graaff accelerator using the five large detectors (ANL-5317, p. 37) together with theoretical analyses of the data are described as follows:

Na:

The proximity of other interfering resonances has made the analysis too complicated to pursue further at present. The experimental data obtained with approximately 30-kev resolution are shown in Figure 2.

Be⁹:

An analysis of earlier data (10-15-kev resolution) indicated that the experiment should be repeated with better resolution. On the second run lithium target thicknesses were measured from scattering data on the narrow 585-kev resonance in S^{32} ($\Gamma \approx 1.5$ kev) in addition to using rise curve data. Angular distribution measurements were repeated on the 7.37-Mev level in Be^{10} with 6-8-kev resolution and on the 7.54-Mev level with 4-5-kev resolution. At several points three thicknesses of scatterer were used in an attempt to estimate the effects of multiple scattering. Since the method of Langsdorf and Monahan is not directly applicable to resonance scattering in light nuclei, extrapolation of the above data to zero thickness was taken to get corrected values. Data

FIGURE 2

obtained on the 7.37-Mev level are shown in Figure 3.

On the basis of the angular distribution of the proton groups from the $\text{Be}^9(d,p)\text{Be}^{10}$ reaction, Green and Middleton¹ assign spin and parity 2^+ or 3^+ for the 7.37-Mev level in Be^{10} . The results of an analysis of the above data in the neighborhood of this are also shown in Figure 3.

If the differential cross section is written in the form

$$\sigma(\theta) = \sum_L B_L P_L(\cos\theta)$$

we obtain on the basis of a 3^+ assignment

$$B_1 = \frac{7}{4} \lambda^2 \sin \delta_{20}^{(2)} \cdot \sin \delta_{21}^{(3)} \cdot \cos \left(\delta_{20}^{(2)} - \delta_{21}^{(3)} \right) + \left(\text{terms which are very nearly independent of energy} \right),$$

and for a 2^+ assignment:

$$B_1 = 10 \lambda^2 \left[\sin \delta_{10}^{(1)} \sin \delta_{11}^{(2)} \cdot \cos \left(\delta_{10}^{(1)} - \delta_{11}^{(2)} \right) + \sin \delta_{20}^{(2)} \sin \delta_{21}^{(2)} \cdot \cos \left(\delta_{20}^{(2)} - \delta_{21}^{(2)} \right) \right] + \left(\text{terms which are very nearly independent of energy} \right).$$

Here $\delta_{sl}^{(J)}$ is the phase shift for channel spin s , relative angular momentum l , and level spin J . In the first case ($J = 3^+$) the phase $\delta_{21}^{(3)}$ is resonant, and in order to fit the data ($B_1 \sim \text{constant}$) it is necessary to assume $\sin \delta_{20}^{(2)} = 0$. For $J = 2^+$, the phases $\delta_{11}^{(2)}$ and $\delta_{21}^{(2)}$ can be resonant. In

1. Proc. Phys. Soc. A69, 28 (1956).

FIGURE 3

order to fit the data on the basis of this assignment it is necessary to assume that the resonance is excited through only one channel spin, and further that the s-wave potential phase-shift vanishes for the same value of channel spin. In either case the s-wave potential scattering is spin-dependent.

Figure 4 is a cosine plot of the results on resonance.

The solid points are those of Willard² et. al., who previously noticed that spin-dependence of the potential scattering was indicated in the vicinity of this resonance.

Thus far we have obtained no definite results from a corresponding analysis of the differential scattering in the neighborhood of the 7.54-Mev level in Be^{10} .

S^{32} , Si^{28} , F^{19} :

Scattering measurements in the neighborhoods of the 110, 375 and 585-kev resonances in S^{32} , the 190-kev resonance in Si^{28} , and the 100-kev resonance in F^{19} have been made but the AVIDAC analysis of the data is not yet complete.

2. H. B. Willard, J. K. Bair and J. D. Kington, Phys. Rev. 98, 669 (1955).

FIGURE 4

20-11

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

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

The investigation of states having isotopic spin $T = 0$ in P^{30} by means of the $S^{32}(d, \alpha)P^{30}$ reaction has been continued. Alpha particle groups have been observed at 63° and 90° to the incident beam by magnetic analysis over a range of incident deuteron energies from 1.62 to 2.90 Mev. A ground state Q value of 4.831 ± 0.013 Mev has been measured and states have been observed at 0.693, 1.440, and 1.97 Mev excitation in P^{30} . These results are in good agreement with level schemes determined from other reactions. Our observation of the 0.693-Mev state in the $S^{32}(d, \alpha)P^{30}$ reaction indicates that, if T may be considered a good quantum number, this level is $T = 0$ rather than $T = 1$ as reported in studies of the $Si^{29}(p, \gamma)P^{30}$ reaction.¹

No state of lower excitation, which would be the analogue of the $T = 1$ Si^{30} ground state, is observed in our study.

-
1. Endt, Kluyver, and Van der Leun, Phys. Rev. 95, 580 (1954)
Broude, Greene, Singh and Willmott, Phys. Rev. 101, 1052 (1956).

22-2

Scattering of Charged Particles

(5220)

Jan Yntema

The design work on the major portions of the 60-inch scattering chamber has been completed.

Design work on the target assembly and the detector system is in progress.

24-2

The Decay of Sn^{123} (125-day)

(5220)

S. Bradley Burson and Robert C. Doerner
Reported by Robert C. Doerner

Because of the large number of relatively abundant isotopes of tin there is a good deal of confusion in the literature on the decay schemes of the various radioactive species of these isotopes. The purpose of this investigation is to study the decay properties of the 125-day and the 40-minute states of Sn^{123} .

Livingood and Seaborg¹ were the first to observe the 40-minute period and many subsequent investigations² have led to the decay scheme proposed by Duffield and Langer³ in which a 1.26 ± 0.01 -Mev

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1. J. J. Livingood and G. T. Seaborg, Phys. Rev. 55, 414 (1939).
 2. C. M. Nelson, B. H. Ketelle and G. E. Boyde, ORNL-828 (Nov., 1950).
D. L. Mock, R. C. Waddel, L. W. Fagg and R. A. Tobin, Phys. Rev. 74, 1536 (1948).
A. S. Newton and W. R. McDonell, UCRL-395 (July, 1949).
J. C. Lee and M. L. Pool, Phys. Rev. 76, 606 (1949).
 3. R. P. Duffield and L. M. Langer, Phys. Rev. 76, 1272 (1949).

beta having an allowed shape ($\Delta I = 1$, no) is followed in less than 5×10^{-8} second⁴ by a 0.153 ± 0.005 -Mev M1- type transition to the ground state of Sb^{123} with a total internal conversion coefficient of 0.12^3 .

The results of the present investigation add no new data concerning the 40-minute period of Sn^{123} .

The 125-day period was probably first observed by Leader⁵ as a fission product but he could not definitely identify the parent. The presently accepted decay scheme⁶ consists merely of a first forbidden 1.42 ± 0.01 Mev beta-transition ($\Delta I = 2$, yes) to the ground state of Sb^{123} . No gamma rays reported by one investigator have been confirmed by another, so that any gamma radiation present is expected to be less than 0.1% of the beta intensity.

Our earlier report of the investigation indicated 11 gamma rays in the 125-day activity of Sn^{123} between 0.16 and 2.6 Mev. Subsequent studies with the Argonne 256-channel scintillation spectrometer showed that six of these gamma rays were due to contaminants in the sample, principally Sb^{124} .

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4. F. K. McGowan, ORNL-952 (March, 1951).
 5. G. R. Leader, RADIOCHEMICAL STUDIES: THE FISSION PRODUCTS, Book 2, National Nuclear Energy Series, Division IV, Plutonium Project Record Volume 9, Paper 130, pp. 919-927, McGraw-Hill Book Co., New York, (1951).
 6. W. E. Grummitt and G. Wilkinson, National Research Council of Canada, Atomic Energy Project, Research Division, CRC-470, (March, 1951).
- J. M. Cork, A. E. Stoddard, E. E. Branyan, W. L. Childs,
D. W. Martin and J. M. LeBlanc, Phys. Rev. 84, 596 (1951).
B. H. Ketelle, C. M. Nelson and G. E. Boyde, Phys. Rev. 79, 242 (1950).
A. S. Newton and W. R. McDonell, UCRL-395, (July, 1949).
J. C. Lee and M. L. Pool, Phys. Rev. 76, 606 (1949).
J. W. Mihelich and R. D. Hill, Phys. Rev. 77, 743 (1950).

A new sample of SnO_3 enriched in Sn^{122} was irradiated for a period of 3 months in CP-5. Six weeks following irradiation, chemical purification was performed by E. P. Steinberg and K. F. Flynn of the Argonne Chemistry Division and the following gamma rays were observed in the pulse-height distribution: 0.026, 0.252, 0.395, 0.600 and 1.08 Mev. The 0.395-Mev gamma ray, by far the most prominent one in the spectrum, is due to the 112-day Sn^{113} . The 0.026-Mev peak is attributed to internal conversion of the 0.395-Mev transition.

Gardner and Hopkins⁷ have recently reported a weak ($12 \pm 2\%$ of the 0.395-Mev gamma ray) 0.258-Mev gamma ray having a lifetime of 130 days in a Sn^{113} source. We have looked for this gamma ray in the source derived from enriched Sn^{122} . The pulse-spectrum of the single 0.411-Mev gamma ray of Au^{198} was used to obtain an approximation to the spectrum of the 0.395-Mev gamma ray. By lowering the gain of the photomultiplier, the 0.411-Mev photopeak was caused to coincide in channel number with the 0.395-Mev peak. A properly normalized spectrum thus obtained was subtracted point-by-point from the composite Sn spectrum. The difference showed a peak corresponding to a 0.252-Mev gamma ray with an intensity of about 7% that of the 0.395-Mev transition. It has not yet been determined with what isotope this gamma ray is associated.

The 0.60 and 1.08-Mev gamma rays have intensities of 0.24% and 0.39% relative to the 0.395-Mev gamma. Their half-lives have not as yet been determined.

7. G. Gardner and H. I. Hopkins, Phys. Rev. 101, 999 (1956).

25-2 Decay of Ba¹³⁹ (85-min)

(5220)

S. Bradley Burson and Robert C. Doerner
Reported by Robert C. Doerner

Investigation of the Ba¹³⁹ spectrum has been continued and is now complete. The last progress report indicated the presence of the two known gamma rays at 0.163 and 1.43 Mev in addition to two new weak gamma rays at about 0.84 and 2.2 Mev. (See previous progress report, I-25-1). The decay of these latter two gamma rays was measured to have a half-life of 2.6 hours indicating a possible Mn⁵⁶ contaminant. A new sample of Ba was prepared and chemically purified. The results of the scintillation spectrometer studies show the decay scheme of Mitchell and Hebb¹ to be correct with no new additions.

The Mn⁵⁶ spectrum was briefly looked at and the 0.84- and 2.2-Mev gamma rays observed in the Ba were confirmed as being due to a Mn contaminant.

1. A. C. G. Mitchell and E. Hebb, Phys. Rev. 95, 727 (1954).

26-2 Decay of Ca^{49} (8.9-min) and Sc^{49} (57-min) (5220)

S. Bradley Burson, James M. Cork (University
of Michigan) and David W. Martin
Reported by David W. Martin

The previous results have been submitted to the
Physical Review and are scheduled for publication in the issue of
April 15, 1956 (Vol. 102, No. 2).

No further reports will be made on this program.

29-4 (Decay of Nd^{151} (12-min) and Pm^{151} (27-hr)) (5220)

S. Bradley Burson, James M. Cork (University
of Michigan), and David W. Martin
Reported by David W. Martin

No further results have been obtained in this quarter.
It is anticipated that the study will eventually be resumed, but no
further reports will be issued until such time as there are further
results.

30-1 Decay of Mo^{101} (15-min) and Tc^{101} (14-min) (5220)

S. Bradley Burson, James M. Cork (University of Michigan), and David W. Martin
Reported by David W. Martin

The decay chain $\text{Mo}^{101} - \text{Tc}^{101}$ was apparently first observed by Sagane and co-workers. On irradiation of Mo with slow and fast neutrons, they observed a beta activity that was assigned to Mo^{101} and was at first reported¹ to have a half-life of 24 minutes. They later observed that this activity was really a genetic chain and reported² it to show a 9-minute Tc^{101} daughter growing in from a 19-minute Mo^{101} parent. Meanwhile, Hahn and Strassman had observed an 18-minute Mo period among the fission products, but believed it not to be identical with the 24-minute period and assigned it to higher mass number.³ Maurer and Ramm reproduced and extended the growth-decay curve of Sagane et. al. and showed⁴ that it could be resolved into approximately equal lifetimes of 14.6 and 14.0 minutes for Mo^{101} and Tc^{101} , respectively. Hahn and Strassman then reported⁵ that the fission-product activity could be resolved into this genetic chain and another short-lived Mo activity. The assignments have been

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1. Sagane, Kojima, Miyamoto, and Ikawa, Phys. Rev. 54, 543 (1938).
 2. Sagane, Kojima, Miyamoto, and Ikawa, Phys. Rev. 57, 750 (1940); 57, 1179 (1940).
 3. O. Hahn and F. Strassman, Naturwiss. 28, 543 (1940).
 4. W. Maurer and W. Ramm, Naturwiss. 29, 368 (1941); Z. Physik 119, 339 (1942).
 5. O. Hahn and F. Strassman, Naturwiss. 29, 369 (1941); Z. Physik 117, 789 (1941).

confirmed⁶⁻⁹. Reports of the half-lives have varied somewhat, but seem to cluster around 14.6 and 14.3 minutes for Mo^{101} and Tc^{101} , respectively.

Mo^{101} is reported^{4,8,9} to emit two principal beta-components of 1.2 and 2.2 Mev representing about 70% and 30% of the decays, respectively. The conversion lines of a strong low-energy gamma transition have been measured in magnetic spectrographs⁸, giving a transition energy of 0.1912 Mev. The K/L ratio was measured to be 6.0 ± 2.5 with the L-shell conversion predominantly L_I , giving a probable M1 interpretation. A second gamma ray has been reported at 0.96 Mev from scintillation studies^{8,9}. It is further reported that there appear to be coincidences between high-energy betas and low-energy gammas⁸, which has been interpreted to mean coincidence of the 2.2-Mev beta with the 0.191-Mev gamma. A level scheme has been proposed^{8,9} for the Tc^{101} nucleus in which the two beta components proceed to excited levels

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6. L. Seren, H. N. Friedlander, and S. H. Turkel, Phys. Rev. 72, 888 (1947); E. E. Motta and G. E. Boyd, Phys. Rev. 73, 1470 (1948); M. L. Perlman and G. Friedlander, Phys. Rev. 74, 442 (1948); D. Mock, R. Waddel, L. Fagg, and R. Tobin, Phys. Rev. 74, 1536 (1948); L. S. Edwards and F. A. MacMillan, Phys. Rev. 87, 377 (1952).
 7. E. der Mateosian, Phys. Rev. 83, 223 A (1951).
 8. W. C. Rutledge, J. M. Cork, and S. B. Furson, Phys. Rev. 86, 775 (1952).
 9. D. R. Wiles, Phys. Rev. 93, 181 (1954).

at 0.191 and 1.12 Mev. Assignments of $g_{9/2}$, $7/2^+$, and $5/2^+$ have been proposed for the ground and first and second excited states respectively.⁹ Systematics and the shell model predict a $p_{1/2}$ level in Tc^{101} . Such a state would be an M4 isomer of half-life around 20 days if it were the first excited state about 200 kev above a $g_{9/2}$ ground state. Since a careful search for the isomeric activity detected none with a lifetime greater than about 2 minutes⁹, it was concluded that the $p_{1/2}$ level must lie above the $7/2^+$ level, to which it could decay by an E3 transition. For a transition energy of the order of 100 kev, the lifetime of the E3 transition would be a few seconds, and would not have been seen.

Tc^{101} is reported¹⁰ to emit a beta ray of 1.20 ± 0.05 Mev energy of intensity representing more than 95% of the decays. It is in coincidence with a gamma ray whose energy, as measured from its conversion lines in a magnetic spectrograph⁸, is 0.3069 Mev. Other weak gamma rays of 0.556, 0.734, and possibly 0.856 Mev have been observed with a scintillation spectrometer¹⁰. The K/L ratio of the 0.306-Mev transition was given by the spectrograph measurement as 6.3 ± 3.0 , with the L-shell conversion predominantly L_1 and a probable M1 interpretation.

The ground state of Ru^{101} has a spin measured¹¹ to be $5/2$. It is reported¹² to have excited levels at 0.127, 0.307, and 0.522 Mev

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10. G. E. Boyd and B. H. Ketelle, Phys. Rev 83, 216A (1951); also verbal report.
 11. J. H. E. Griffiths and J. Owen, Proc. Phys. Soc. 65A, 951 (1952).
 12. G. M. Temmer and N. P. Heydenburg, Phys. Rev. 100, 961 A (1955); also private communication reported in Nuc. Sci. Abstracts 9, No. 24B, 69 (1955).

from Coulomb excitation experiments using 7-Mev alpha particles. A 0.180-Mev gamma transition between the first two of these levels was observed in these experiments.

Study of these activities has been initiated using our 256-channel scintillation spectrometer. Enriched Mo^{100} has been obtained in the form of an oxide.

NaI (Tl) pulse-height spectra taken with "good" geometry (using our 4-inch tapered Pb collimator) display a number of previously unreported gamma rays. Besides the very strong 0.191-Mev peak, fairly strong peaks at 0.51, 0.59, 1.02, and 2.09 Mev, and lesser peaks at 0.40, 0.70, 0.90, 1.19, and 1.55 Mev are all seen to decay with a single period of about 15 minutes. Other peaks at 0.126, 0.307, and about 0.54 Mev grow in at first, and eventually decay with about a 15-minute half-life, and may be associated with the Tc^{101} daughter. All of the peaks mentioned, with the possible exception of the very weak one at 0.40 Mev, appear quite certainly to represent gamma rays.

Preliminary gamma-gamma coincidence studies have been carried out using the "summing" technique, pending the completion of modifications of the regular coincidence circuits of the analyser. In this technique, two identical NaI counters are placed in contact with the source between them. Their gains are adjusted to be precisely equal. Their outputs are added electronically and the resulting pulse spectrum compared with that obtained from either crystal alone. Two peaks that

are in coincidence will be depleted in the "sum" spectrum, while a new peak will appear at the pulse height corresponding to the sum of their energies. If the crossover transition is actually present itself, its peak will be augmented in the "sum" spectrum.

The results of these experiments have sufficed to provide only a few facts about the decay scheme. No sum pulses were observed at pulse heights greater than that of the 2.09-Mev gamma ray; thus there are no decay cascades of total energy exceeding this value. The 2.09-Mev peak itself was substantially augmented. Most of the rest of the spectrum appeared little different from the single-crystal spectrum, except for a small diminution of the 0.51-Mev peak.

The conversion-electron spectrum has been examined in the magnetic spectrographs. Accumulated half-hour exposures from about 20 successive irradiations brought out the known K and L lines of the 0.191 and 0.307-Mev transitions, and one new line interpreted as the K line of a 0.126-Mev transition. Successive iterated exposures designed to distinguish between lines of the parent Mo and the daughter Tc did not prove to be very practical. The scintillation spectra are fully consistent with the observed conversion lines, and can distinguish the two activities very readily.

A full series of ordinary gamma-gamma and beta-gamma coincidence experiments is planned for further study of these activities. Since several reported lines of Tc¹⁰¹ are not seen in the composite spectrum, chemical separation of Tc will be used to observe it in detail.

The parent Mo^{101} will have to be studied in the presence of its daughter, however, since the growth time is rather short compared to the times involved in the separation.

31-2 (Decay of Yb^{177} (1.9-hr)) (5220)

S. Bradley Burson, J. M. Cork (University of Michigan)
and David W. Martin
Reported by David W. Martin

No further work has been done on this activity. The results indicated in the previous report have been published¹ together with work done at the University of Michigan on the other activities of Yb.

32-1 The Decay of Ni_{28}^{65} (2.56 hours) (5220)

S. Bradley Burson

According to the more recent reports in the literature², the 2.56-hour activity of Ni^{65} may be summarized as follows: the photon spectrum is comprised principally of three gamma rays having energies of 0.37, 1.12, and 1.49 Mev; the charged radiations consist of three beta-components with energies and intensities of 0.6 (29%), 1.01 (14%), and 2.1 (57%) Mev. These beta-ray branches are assigned ft values of 6×10^4 , 8.4×10^5 , and 6.8×10^5 , respectively. The 0.6-Mev branch is interpreted as "allowed" and the other two components "first forbidden". Angular correlation measurements between the 0.37 and

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1. J. M. Cork, M. K. Brice, D. W. Martin, L. C. Schmid, and R. G. Helmer, Phys. Rev. 101, 1042 (1956).
 2. K. Siegbahn and A. Ghosh, Arkiv for Matematik, Astronomi OCH Fysik, Vol 36, paper No. 19 (1949).

1. 12-Mev gamma rays³ indicate that the cascade is of dipole-quadrupole nature.

Preliminary studies with the scintillation spectrometer verify the presence of the three reported gamma rays. We also conclusively observe coincidences between the 0.37 and 1.12-Mev radiations, which is consistent with the published decay scheme.

Analysis of the beta rays was attempted with the 180° spectrometer, but difficulties with the G-M counter during this experiment rendered the results unreliable. Since this experiment will be redone, the results will not be reported here.

49-4 The Decay of $_{50}\text{Sn}^{125}$ (9.7-day and 9.4-min.) (5220)

S. Bradley Burson, Robert C. Doerner and David W. Martin
Reported by S. Bradley Burson

The final draft of this paper is now complete and will be submitted for publication in the immediate future.

51-11 (Characteristics of a Scintillation Spectrometer) (5220)

Bernard Hamermesh and Carroll C. Trail
Reported by Carroll C. Trail

No changes have been made on the scintillation spectrometer this quarter.

Reports on this topic will be discontinued.

3. T. Wiedling and A. Carlsson, Phys. Rev. 83, 181 (1951).

52-11

Neutron Capture Gamma Ray Spectra Using the
Scintillation Spectrometer (5220)

Bernard Hamermesh, Charles M. Huddleston
and Carroll C. Trail
Reported by Carroll C. Trail

Further studies on the capture gamma-ray spectrum from Hg using two scintillation counters in coincidence have yielded no additional information on the cascade scheme. The spectrum is too complicated for analysis with a NaI (Tl) spectrometer. Adyasevich, Groshev and Demidov¹ report forty gamma rays from neutron capture in Hg.

Preliminary studies of the gamma-ray spectrum from neutron-induced fission of U²³⁵ have begun. Those gamma rays in coincidence with fission are analyzed with the NaI (Tl) spectrometer. Fission events are detected with a gaseous scintillation counter.²

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1. Adyasevich, Groshev and Demidov, Conference of the Academy of Sciences of the U.S.S.R. on the Peaceful uses of Atomic Energy, July, 1955.
 2. C. Eggler and C. M. Huddleston, Nucleonics, April, 1956.

55-3

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

Bernard Hamermesh, Sol Raboy, G. R. Ringo
and Carroll C. Trail
Reported by Carroll C. Trail

The gamma-ray spectra will be studied with a NaI (Tl) crystal 2-1/2 inches in diameter and six inches long. To reduce the complication in the spectrum resulting from Compton scattering and annihilation escape peaks the cylinder is coaxial with a NaI (Tl) counter 12 inches long with walls 2-1/2 inches thick. Pulses from the outer crystal are placed in anti-coincidence with pulses from the inner cylinder. Both crystals have been ordered.

A collimator which rests on the arm of the crystal monochromator has been designed and submitted to the shops for construction. This collimator consists of ten lead plates 0.040 inch thick, one meter long. The plates are separated by 0.114 inch. This design preserves the twenty minute collimation of the neutron beam.

56-2

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

Richard S. Preston

Three basic types of Compton spectrometer have now been considered for use with the CP-5 reactor. All require the counting of coincidences between electrons ejected forward from the Compton radiator and the corresponding back-scattered photons. The electron

energy, however, may be determined by 90° , 180° or 270° deflection in a magnetic field. 90° and 270° focussing permit the use of a Compton radiator of large area with a relatively small magnet, although there are special advantages in the use of 180° focussing¹. Similarly, 270° focussing, which is being used by Groshev, et al,² gives better resolution than 90° focussing

Prior to deciding on the type of magnetic analyser, a temporary 90° spectrometer will be set up using some existing equipment, such as collimators and magnets. It is expected that experimentation with this equipment will determine the final choice of magnetic analyser and also aid in its design

Preliminary measurements have shown that it is possible to get a good capture gamma-ray beam from a source inside the reactor, and that it can be collimated well enough that a 2-1/2" cube of sodium iodide scintillator located within an inch of the edge of the beam can still distinguish between background and back-scattered photons coming from a Compton radiator.

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1. Henry T. Motz , Proposal for the Construction of a Compton Spectrometer, Brookhaven National Laboratory, October 5, 1955.
 2. Groshev, Adyasevich and Demidov, International Conference on the Peaceful Uses of Atomic Energy, A/Conf. 8/P/ 651. USSR, July 5, 1955.

57-1

Lifetime Measurements from Recoil Studies (5220)

Stanley S. Hanna

A program has been initiated for measuring the lifetimes of nuclear states in the range from about 10^{-6} to 10^{-11} sec. The method makes use of the recoil motion imparted to a radiating nucleus by a previous radiation or by an impinging particle initiating the reactions, or by both. The recoiling nuclei are allowed to travel in vacuum and a measurement is made of the distance traversed before emission of radiation. From a knowledge of the velocity of the recoils the lifetime is easily obtained.

Recoil studies of this type have been used by a number of investigators for some thirty years to obtain lifetimes of nuclear states. In all these investigations the distance travelled by an excited nucleus was determined by using some form of collimated detector which could receive radiation coming from only a limited volume of space.

The method in use in the current program was devised²

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1. J. C. Jacobsen, Phil. Mag. 47, 23 (1924).
A. W. Barton, Phil. Mag. 2, 1273 (1926).
Devons Hereward and Lindsey, Nature 164, 586 (1949).
J. Thirion and V. L. Telegdi, Phys. Rev. 92, 1253 (1953).
 2. J. C. Severiens and S. S. Hanna, Phys. Rev. 100, 1254 (1955).

in order to obtain greater intensity than that afforded by the use of a collimator, and also to provide a beam of recoils of practically constant and known velocity. In a typical reaction $N_1(d,p)N_2^*(\gamma)N_2$, gamma rays from forward-moving recoils only are observed by registering only gamma photons that are coincident with protons emitted (approximately) anti-parallel to the deuteron beam. The gamma counter is at 0° to the beam, at a distance approximately $2d$, where d is the distance travelled by a recoil during its mean life. A recoil "stopper" is placed between target and counter and the coincidence yield measured as a function of stopper position. In effect, one measures the change in solid angle produced by mechanically controlling the range of the recoils. The method provides a beam of excited nuclei produced in a unique manner and with a known spatial distribution and velocity. Since fairly large solid angles can be used without affecting the accuracy of the results, very satisfactory counting rates can be obtained with this technique.

A target chamber for use in these experiments has been designed and constructed by the shop. It has been assembled and tested and numerous improvements in it are currently being made. Specifications for a fast ($\sim 10^{-8}$ sec) coincidence circuit incorporating energy discrimination have been worked out and the circuit is presently being developed and constructed by the Electronics Division.

The principal feature of the design provides for gating all the "slow" parts of the circuit by the fast coincidence output. It is anticipated that with this feature the relatively high background rates inherent in Van de Graaff experimentation can be tolerated.

Preliminary experiments have been performed with the Van de Graaff generator using coincidence equipment, on loan from Krohn and Raboy. The $\text{Al}^{27}(\text{d},\text{p})\text{Al}^{28*}(\gamma)\text{Al}^{28}$ and $\text{Na}^{23}(\text{d},\text{p})\text{Na}^{24*}(\gamma)\text{Na}^{24}$ reactions have been used to test the target chamber, counters, etc. It is hoped that with the latter reaction the lifetimes of the first two excited states in Na^{24} can be measured. The preliminary observations have indicated modifications in the equipment, but the measurement appears feasible.

58-1

Energy of Delayed Neutrons from Fission (5220)

Gilbert J. Perlow and Andrew Stehney (Radiological
Physics Division)
Reported by Gilbert J. Perlow

An attempt is to be made to isolate delayed neutron emitters by chemical methods and measure the energy of the emitted neutrons by means of the neutron spectrometer reported in this and previous reports by one of us (G. J. P.). The experiment is in a preliminary stage at this time.

60-11

7.7-Meter Bent Crystal Spectrometer

(5220)

Bernard Hamermesh and David Rose
Reported by David Rose

Since the last progress report, the spectrometer has been placed in successful operation and a number of preliminary results obtained. A gold foil 10 cm high, 2 mm deep, and 0.001" wide was placed in CP5 at the approximate focal position of the bent crystal. The 411.8-keV γ -ray line in Hg^{198} was then used to check the accuracy of focus of the bent quartz crystal. All parts of the crystal were found to focus within a region 0.06 mm wide. The full width at half maximum for this 411.8-keV γ ray was found to be 13 seconds of arc or about 15 milliangstroms. This corresponds to a resolution at this energy of about 0.5%. A rough measurement of the reflectivity for this line has been found to be approximately 0.015.

A larger sample (0.010" wide x 10 cm high x 2.5 cm deep) has been used to search for neutron capture γ rays in Au^{198} . Values of the energy for those capture γ rays observed in a preliminary and limited search are as follows, in keV: 439, 411.8*, 384*, 372*, 353*, 347*, 331*, 319*, 314*, 309*, 293, 278, 273, 263. The values marked (*) correspond to lines that have been observed in both positive and negative first order. All these energy values are known (except for the 411.8-keV line) to an accuracy of ± 2 keV. This work was only recently begun and the survey needs to be carried out over the full range of the instrument in both positive and negative first order with a more accurate

determination of energies and of relative intensities.

The upper energy limit of this spectrometer depends in addition to relative intensities on how well the channeled collimator which separates the diffracted from the undiffracted beam has been constructed. The nominal design was for an upper limit of 5 Mev, but it is now known that an upper limit of 6.9 Mev is feasible.

The preliminary performance of the instrument has proven quite satisfactory. It now remains to complete some remaining constructional details so that its operation shall be completely automatic. Also a new full size (12" x 12") quartz crystal should be received in the near future. Its use should increase the intensity of the diffracted beam by about a factor of six.

70-11 Measurements of Nuclear Moments by Angular Correlation
(5220)

Victor E. Krohn and Sol Raboy
Reported by Sol Raboy

A) Am^{241} (Collaboration with T. B. Novey, Chemistry)

The attenuation studies of the α - γ angular correlation in the decay of Am^{241} in liquids will be described in an article which is being prepared for publication in The Physical Review.

B) The decay scheme of Pb^{204} has been clarified. An article has been accepted for publication by the Physical Review.

C. The instrumentation was improved in order to extend this technique to decay schemes with intermediate half-lives of 10^{-8}

sec and shorter. A coincidence circuit with a resolving time of 15×10^{-9} sec was put into operation. A study of the Ta^{181} decay is under way in order to improve our previous measurement of the gyromagnetic ratio for the 10^{-8} -sec state (Phys Rev. 95, 1689 (1954)).

The angular correlation function of the Ta^{181} decay scheme has a large A_2 and relatively large A_4 , where A_2 and A_4 are the coefficients of $P_2(\cos \theta)$ and $P_4(\cos \theta)$. It is planned to measure A_2 and A_4 as a function of delay in liquid media. If attenuation is observed then the ratio of λ_2/λ_4 uniquely determines the spin of the intermediate state, provided the theory of Abragam and Pound (Phys. Rev. 92, 943 (1953)) for the attenuation of the angular correlation in liquids obtains. λ_2 and λ_4 are the inverse time constants for the attenuation of the A_2 and A_4 coefficients, respectively.

$$\frac{\lambda_2}{\lambda_4} = \frac{3}{10} \left[\frac{4 I (I + 1) - 7}{4 I (I + 1) - 21} \right]$$

This ratio becomes 0.6 for $I = 5/2$ and 0.4 for $I = 7/2$. It is hoped to measure this ratio well enough to decide on the spin assignment of the intermediate state. Measurements have been made in Hydrofluoric acid media with delays of about 4×10^{-9} sec and 20×10^{-9} sec. This is the medium used for previous gyromagnetic ratio measurements and was selected because there was very little attenuation observed in it by McGowan (Phys. Rev. 93, 471, (1954)).

TABLE I

<u>Measurements of Ta¹⁸¹ in HF</u>		<u>Results of Angular Correlations.</u>
delay	4×10^{-9} sec	20×10^{-9} sec
A ₂	$-.263 \pm .003$	$-.267 \pm .002$
A ₄	$-.075 \pm .003$	$-.073 \pm .003$

Our results shown in Table I confirm this result.

An HCl medium was selected for attenuation studies.

There is pronounced attenuation and precision measurements are currently under way.

80-11 Molecular Beam Studies (5220)

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

Because of the confusion introduced by the presence of multiple quantum transitions in the studies of the atomic $P_{1/2}$ state of indium isotopes, the magnitude of the nuclear magnetic moments of both the 50-d. In^{114m} and 54-m. In^{116m} are somewhat in doubt although the signs of the moments and the spins are well determined.

In order to resolve this difficulty and to proceed to measure quadropole moments of these isotopes, studies of the atomic $P_{3/2}$ state of indium isotopes have been started.

A resonance has been observed for radioactive In^{116m} at 17.32 ± 0.02 Mc/s at a magnetic field corresponding to a value

of $x = 0.3$ for the field parameter for In^{115} . This particular resonance ($F = \frac{13}{2}$, $\Delta F = 0$, $m_F = -\frac{11}{2} \longleftrightarrow m_F = -\frac{9}{2}$) and field was chosen because it is rather insensitive to the value of the nuclear magnetic moment and has good though moderate sensitivity to the value of the nuclear electric quadrupole moment.

The frequency of the resonance observed indicates that the quadrupole moment of $\text{In}^{116\text{m}}$ is equal to the quadrupole moment of normal In^{115} within the precision of the experiment. The exact precision is difficult to estimate without considerable further AVIDAC computation. It is not necessary that it be known before proceeding to higher fields and frequencies.

90-11

Cross Sections for 14-Mev Neutrons

(5220)

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

1. General Remarks .

The two major problems in the maintenance of the accelerator have been the periodic deterioration of the operation of the R. F. ion source and the build-up of carbon on the Zr-T target. About once every six weeks it becomes necessary to replace the tip of the ion bottle and to clean the bottle with hydrofluoric acid or to replace it. About once every three weeks the Zr-T target is removed from the accelerator and the carbon surface layer removed by abrasion while the

target is immersed in alcohol. This process removes a negligibly small amount of the tritium of the target and has permitted us to use the same target for more than seven months.

A new ion bottle assembly, in which the bottle is not cemented to its flange, but held against it to make an O-ring seal, will be installed in the near future.

A tritium line has been constructed, and an induction heating system is in the process of assembly to enable us to fill our own Zr targets with tritium.

To achieve greater stability the millimicrosecond coincidence circuit and associated electronics used in our 14-Mev neutron measurements have been modified. Replacing the 165-ohm cables leading from the preamplifiers to the Hewlett-Packard amplifiers with 185-ohm cables has resulted in an increase by about a factor of 2 in the size of pulses arriving at the coincidence circuit.

A new coincidence circuit, to be used in conjunction with the old circuit, was constructed in order to permit continuous monitoring of the accidental coincidence rate.

A variable delay was constructed permitting cable delays from 1 to 63 millimicroseconds to be inserted conveniently in either the neutron or alpha channels.

2. Angular Distribution of Elastically Scattered 14-Mev Neutrons

The differential elastic scattering cross section of lead has been measured between 7° and 40° in steps of about 5° (in the

laboratory coordinate system). Further measurements are now in progress.

3. Total Cross Sections for 14-Mev Neutrons.

In February, 1956, transmission experiments were performed on palladium, cadmium, neodymium, samarium, hafnium and tantalum by the method described in previous quarterly reports of this group. The results are summarized in the table below:

TABLE II

Element	Transmission	Tentative Cross Section (barns)	Cross Section Reported in the literature
Palladium	0.362	4.30	
Cadmium	0.370	4.37	4.44 ± 0.09 (1)
Neodymium ⁽³⁾	0.368	5.08	
Samarium ⁽³⁾	0.373	5.12	
Hafnium	0.299	5.44	
Tantalum	0.352	4.96	5.24 ± 0.10 (1) 5.14 ± 0.10 (2)

1. J. H. Coon, E. R. Graves and H. H. Barschall, Phys. Rev. 88, 562 (1952).
2. W. I. McGany, J. O. Elliott and W. R. Faust, NRL Report No. 4666 (1955).
3. The neodymium and samarium samples were made available to us through the courtesy of Dr. Frank H. Spedding, Iowa State College, Ames, Iowa

Each value of the transmission above is the average of four consecutive measurements. Each of these measurements was made to a statistical accuracy of 1 to 1.5 percent. However, the deviation of these measurements from each other exceeds this and is about two percent. The cross-section values are listed in the table as tentative pending some possible small correction of the order of one percent.

The cadmium cross section may be seen to be in agreement with previously reported values. The tantalum cross section seems to be somewhat low. Work is in progress to attempt to determine the cause of the discrepancy.

These measurements have been reported⁴ at the 1956 Washington, D. C., Meeting of the American Physical Society.

4. Inelastic Scattering of 14-Mev Neutrons.

Additional measurements on the inelastic scattering of 14-Mev neutrons by carbon by the time-of-flight method described in the last quarterly report have been made. The results have been reported⁵ at the 1956 New York Meeting of the American Physical Society.

Low counting rates, too large a resolving time and instability of the present fast coincidence circuit make it advisable to use a time-of-flight to pulse height converter in conjunction with a multi-

4. Bull. Am. Phys. Soc. 1, 187 (1956).

5. Bull. Am. Phys. Soc. 1, 56 (1956).

channel pulse height analyzer for future inelastic scattering measurements. The development of such a system is in progress.

91-11 Neutron Transport Cross Sections; Angular Distribution
of Scattered Neutrons (5220)

Alexander S. Langsdorf, Jr , and James E. Monahan
Reported by James E. Monahan

The data described in previous reports under this title have been corrected for multiple scattering. An indication of the nature of these corrections can be obtained from Figure 5. The dashed curve gives the experimental cross sections for five thicknesses of carbon scatterer at a neutron energy of 394 kev. The circles indicate the corresponding cross sections corrected for multiple scattering. The point at thickness 0.085 is taken from independent transmission measurements as a standard for the total cross-section ordinate. In this survey the target thicknesses seldom exceed 0.10 mean free path.¹

98-10 Neutron Cross Sections in the Kev Region (5220)

Carl T. Hibdon

1. Improvement of Counting Equipment

The collimator of the neutron counter (elephant) has been converted to accept slit type insert defining slits 1-1/4" high and 1/8", 1/4" or 3/8" wide. This conversion results in better angular resolution and increase in the counting rate by factors of 1.3, 2.6 and 3.8, respectively.

1. The report covering all work done to date on this project will be published in ANL-5567 early in August, 1956.

FIGURE 5

An insert having a 1/2" diameter circular aperture can also be used.

These inserts can be readily interchanged.

2. Transmission Measurements

The transmission cross sections of Cr and Fe have been measured from 80 to 409 kev by the same methods and using the same samples as before (see ANL-5498) with a resolution of about 700 ev.

The cross section of Be was measured from 550 to 830 kev. The 1/4" insert was used up to about 250 kev and the 3/8" one at higher energies.

a) Chromium

Variations in the cross section of chromium show the presence of 10 prominent resonances of Cr^{52} and many others attributable to less abundant isotopes. The results are summarized in Table III where all of the widths of the resonances except the one at 98 kev have been estimated from the curve obtained by the formula $E_{\text{max}} - E_{\text{min}}$

$$= - \frac{\pi}{2} \left\{ \tan \phi_e + \cot \phi_e \right\}.$$

For the resonances of Cr^{52} an average value of the strength function in the region up to 409 kev was found to be $\frac{\overline{f_n^0}}{\overline{D}} = 2 \times 10^{-4} \text{ ev}^{-1/2}$. It is expected to be correct to better than a factor of 2.

b) Iron

The variations in the cross section of iron show 12 resonances attributable to Fe^{56} and many others attributable to Fe^{54} and Fe^{57} . The results are shown in Table IV where the widths of the resonances quoted were mostly obtained by finding values of the parameters for best fit to the curves. The theoretical peak heights are those for

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TABLE III

Resonances of Chromium					
E_0 , kev	Γ , ev	σ_{max} (measured)	σ_{max} (100% isotope) (theoretical)	σ_{min} (measured)	Comments
98	3200±200	17 barns	27.6	0.83	Cr ⁵² , clearly S-wave
102	-	-	-	-	Cr ⁵⁰ , or Cr ⁵⁴
106	-	-	-	-	Apparently Cr ⁵³
111	-	-	-	-	Cr ⁵⁰ or Cr ⁵⁴
120.5	< 1000	9	22.4	2	Cr ⁵² , clearly S-wave
127.5	-	-	-	-	Cr ⁵⁰ or Cr ⁵⁴
138.5	< 3500	11	19.5	1.5	Cr ⁵² , clearly S-wave
142	< 2500	11	19	-	Cr ⁵²
147	< 1500	10.7	18.4	-	Cr ⁵²
152.5	< 1000	9	17.7	-	Cr ⁵²
157	-	-	-	-	Cr ⁵⁰ or Cr ⁵⁴
160.5	-	-	-	-	Cr ⁵⁰ or Cr ⁵⁴
163.5	-	6	-	3.5	Apparently Cr ⁵³
167	-	-	-	-	Cr ⁵⁰ or Cr ⁵⁴

TABLE III (Continued)

Resonances of Chromium					
E_o kev	Γ ev	σ_{max} (measured)	σ_{max} (100% isotope) (theoretical)	σ_{min} (measured)	Comments
171	-	-	-	-	Cr^{50} or Cr^{54}
178	-	-	-	-	Cr^{50} or Cr^{54}
188	-	-	-	-	Cr^{50} or Cr^{54}
220	-	-	-	-	Cr^{50} or Cr^{54}
233	-	-	-	-	Apparently Cr^{53}
243	<2300	5	11.1	2.2	Cr^{52} , S-wave
252	-	-	-	-	Cr^{50} or Cr^{54}
278	-	-	-	-	Cr^{50} or Cr^{54}
325	<3000	6	8.3	1.5	Cr^{52} , S-wave
330	-	-	-	-	Cr^{50} or Cr^{54}
336	-	-	-	-	Cr^{50} or Cr^{54}
342	-	-	-	-	Cr^{50} or Cr^{54}
362	-	3.5	-	-	Possibly Cr^{53}
366	<4400	4.5	7.4	1.4	Cr^{52} , S-wave

TABLE III (continued)

Resonances of Chromium					
E_o kev	Γ ev	σ_{max} (measured)	σ_{max} (100% isotope) (theoretical)	σ_{min} (measured)	Comments
396	<2000	3.5	-	-	Apparently Cr ⁵³ Possibly Cr ⁵²
406	<10,000	5.7	6.7	1.1	Cr ⁵² , S-wave

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TABLE IV

Resonances of Iron

E_o kev	Γ ev	σ_{max} (measured)	σ_{max} (100 % isotope) (Theoretical)	σ_{min} (measured)	Comments
85.5	975 $\pm$ 50	11.5	31.6	0.9	Fe ⁵⁶ , S-wave
90	-	-	-	-	Fe ⁵⁴ , Possibly Fe ⁵⁷
92	-	-	-	-	Apparently Fe ⁵⁴
127.7	575 $\pm$ 50	6	21.1	1.3	Fe ⁵⁶ , S-wave
138	825 $\pm$ 50	9.1	19.6	0.8	Fe ⁵⁶ , S-wave
143	-	-	-	-	Apparently Fe ⁵⁷
145	<1000	8	18.6	-	Fe ⁵⁶ , Apparently S-wave
149	-	-	-	-	Apparently Fe ⁵⁷
153	-	-	-	-	Fe ⁵⁴
162	875 $\pm$ 100	5.7	16.7	1.2	Fe ⁵⁶ , S-wave
180	-	2.5	-	-	Apparently Fe ⁵⁴
188	950 $\pm$ 50	9.5	14.4	0.8	Fe ⁵⁶ , S-wave

TABLE IV (continued)

Resonances of Iron					
E_0 keV	Γ eV	σ_{max} (measured)	σ_{max} (100% isotope) (theoretical)	σ_{min} (measured)	Comments
219	550 $\pm$ 50	5.6	12.3	1.2	Fe ⁵⁶ , S-wave
240	-	4.3	-	-	Narrow resonance
272	2275 $\pm$ 200	5.5	9.9	0.9	Apparently Fe ⁵⁶ Fe ⁵⁶ , S-wave
316	3500 $\pm$ 500	5.3	8.5	0.9	Fe ⁵⁶ , S-wave
334	-	-	-	-	Apparently Fe ⁵⁴
360	4000 $\pm$ 500	5.0	7.5	1.2	Fe ⁵⁶ , S-wave
376	-	-	-	-	Apparently Fe ⁵⁴
388	$\approx$ 8000	5.8	6.3	1.5	Fe ⁵⁶ , S-wave
396	-	-	-	-	Apparently Fe ⁵⁴
401	-	-	-	-	Apparently Fe ⁵⁴
406	$\approx$ 5000	5.3	6.1	-	Fe ⁵⁶

isolated S-wave type resonances.

The strength function has been computed for all resonances of Fe^{56} up to 409 kev. Its average value, $\frac{\overline{\Gamma}_n^0}{\overline{D}} = 1.7 \times 10^{-4} \text{ev}^{-1/2}$, is expected to be correct to within 25% of the true value.

c) Beryllium

Metal samples were used for these measurements. Two resonances were observed, one at 622 kev with an apparent width of 16 kev and another at 809 kev having an apparent width of 7.6 kev. These resonances are apparently due to p-wave neutron interactions. No minimum was observed on the low energy side of either resonance. The observed potential scattering cross section is 3.4 ± 0.2 barns and is higher than 2.1 barns given by $\sum_l (2l + 1) 4\pi \lambda^2 \sin^2 \delta_l$.

d) Strength Function

The values of $\overline{\Gamma}_n^0 / \overline{D}$ found for both $_{24}\text{Cr}^{52}$ and $_{26}\text{Fe}^{56}$ are small compared to the value for $_{24}\text{Cr}^{53}$ (See ANL-5498, p. 55), to numerous values found for nuclei of odd Z and odd A in the same region of masses (See ANL-5420, I-3-8, pp. 12-15), and to predictions of the "cloudy crystal ball" theory.

102-8

(Neutron Cross-Section Measurements by the Self-Detection Technique) (5220)

James E. Monahan

This title will be discontinued until the detectors described in another section of this report under the title "A New Neutron-Counting

System'' are completed.

108-5 An He³ Neutron Spectrometer (5220)

Frank J. Lynch

Another solenoid-operated circulating pump has been constructed using stainless steel instead of brass. The copper purifier has been replaced by an uranium purifier. A Toepler pump has been added to transfer the He³ from the container to the purification system, and from thence to the counter.

The 2-inch diameter stainless steel counter for use in a reactor assembly has been assembled. The insulator assembly consisting of center wire, guard tube, and field tube was assembled using thermal-cure epoxy resin. The ends of the counter have been sealed with polyvinyl acetate. Difficulty with leaks in these seals has delayed the filling operation. A tight seal has been obtained by replacing the vinyl acetate with epoxy resin.

Plans for a counter utilizing brazed ceramic seals are in the machine shop. The counter will have field tube, but no guard tube. The alumina ceramic parts which were due last January are expected.

A large heating element for the vacuum furnace has been wound and special heavy copper leads have been installed. High current transformers to power the heating element have been received. The counter will use a gold gasket. It may be baked out at 600° C.

109-1

A 10-Kv Regulated D. C. Supply

(5220)

Frank J. Lynch and James E. Baumgardner
Reported by Frank J. Lynch

For use with the high pressure proportional counter a highly regulated high voltage supply was constructed. Figure 6 is a schematic diagram. It consists of an R. F. oscillator, V_4 , and an air core transformer, T_4 . A D.C. amplifier, V_9 , V_7 and V_2 amplifies the voltage difference between the RK-75 reference tube and the high voltage bleeder tap, and controls the screen voltage of the oscillator V_4 . The supply delivers a maximum voltage of 10kv at 1 ma. Five output ranges are provided from taps on the wire wound bleeder: 5-10 kv, 4-8 kv, 3-6 kv, 2-4 kv and 1-2 kv.

The output voltage changes less than 0.01% for a line voltage change of 30 v. The short term variation from the average voltage is less than 0.005%. The long term variation is less than 0.015%.

The design is flexible and may be used for other voltages by choice of a suitable R. F. transformer and number of stages of rectification. The only special tubes required are the high voltage rectifiers.

FIGURE 6

10 kilovolt regulated high voltage supply.

114-11

Development of a Recoil-Type Neutron Spectrometer
(5220)

Gilbert J. Perlow

The development is essentially complete and a descriptive paper has been submitted to "The Review of Scientific Instruments". When monoergic neutrons of 800 kev are used, a resolution of 7% is obtained (full width at half maximum). The line shape at that energy is determined by the angular acceptance function of the collimator apertures, widened by fluctuations which are characterized by a Gaussian of $\sim 3\%$ full width at half-maximum. The latter arises from the intrinsic ionization fluctuations of particles stopping in a gas plus a miscellany of smaller effects associated with the constructional details of the equipment.

Satisfactory spectra of monoergic neutrons at various energies between 50 and 1100 kev have been obtained. This must be considered the proper range of the instrument. The lower limit is determined by the small value of the efficiency at low energies and the upper by the onset of multiple scattering in the counter gas. Over this range the efficiency varies from approximately 5×10^{-6} to 6×10^{-5} roughly linearly and is 10^{-5} at 180 kev.

No further reports will be made on this topic.

133-11

Design Study for a Multi-Bev Proton Accelerator
(5240)

The principal activities of the accelerator group are indicated under various topics below. The Reports referred to

have been distributed to those known to be working in the general field.
Additional copies of some of them are still available.

"General Theory of Particle Accelerators"

Lee C. Teng
Reports No. 1, 2, 3, 5, 7, 9, 17

These reports develop a general approximation method which is an extension of the so-called "smooth approximation" and enables one to continue the analysis to arbitrarily high power of $1/N^2$ (where N is the number of sectors in a general accelerator with a guiding magnetic field). The accuracy of the various orders of approximation is examined. The formulas for AGS and for FFAG are derived as special cases.

"The Smooth Approximation to the Hill Equation"

Lee C. Teng
Published as ANL -5517

Several conceptual mistakes made by Symon in his smooth approximation are corrected. After the correction, the approximation for the linear Hill equation has been extended and the "smoothed" oscillation frequency evaluated to the third order. The result is then checked in a special case against the exact solution obtained by the matrix method.

"Constant Frequency Multi-Bev FFAG Accelerator"

Lee C. Teng
Bulletin of the American Physical Society, Series II,
Vol. 1, No. 4, page 178, April 26, 1956

This shows that with specific choice of the radial

dependence of field flutter, the $1/N^2$ term in the expression for $\dot{\gamma}_x^2$ (where $\dot{\gamma}_x$ is the number of radial betatron oscillations per turn) can be made of such sign that a constant-frequency cyclotron can be designed for energies much higher than one rest-mass energy, without crossing the $\dot{\gamma}_x = 2$ resonance, and that constant-frequency FFAG ring accelerators with fixed values of $\dot{\gamma}_x$ and $\dot{\gamma}_z$ can be built for a wide energy span, up to 100 Bev.

"Design Considerations for a Zero-Gradient, Edge-Focussing Ring Magnet"

Lee C. Teng
Report Nos. 8 and 11

These develop the equation of betatron wavelength, the ratio of lengths of magnet and straight section, momentum compaction, angle of magnet edges, etc., to a high order of accuracy, for a ring magnet in which all vertical focussing forces are obtained from the "lenses" which exist at properly oriented ends of magnets.

"Space Charge Effects in the 12.5-Bev Ring"

Melvin Ferentz
Report No. 10

Discusses the effect of space charge on the betatron wavelength for the zero-gradient ring accelerator.

"Gas Scattering in the 12.5-Bev Ring"

Melvin Ferentz
Report No. 12

Derives the equation for gas scattering for the 12.5-Bev zero-gradient ring, and indicates that there will be negligible loss of

beam from this cause, for an injection energy of 50 Mev.

"Effects of Errors in Construction and Alignment on
the Amplitude of Betatron Wavelength and on the Position
of the Operating Point in the Zero-Gradient Accelerator"

Edwin A. Crosbie
Report No. 13

Calculations are given for the effects of

Vertical Displacement of magnet sections

Errors in gap size

Tilt of magnet sections

Rotation of magnetic sections

Errors in magnet section lengths

"Consideration for Determining the Size of the Ring
Vacuum Donut"

Morton Hamermesh
Report No. 15

Calculations are made on the amplitude of the betatron oscillations which will exist in the zero-gradient 12.5-Bev accelerator if injection is carried out in such a way that ions will not strike the injector plates. The minimum rate of rise of magnetic field is given. The amplitude of radial motion, due to phase oscillation, is computed. The necessary width of donut is given for various values of the number of injected turns.

"Preliminary Parameters for a Zero-Gradient, Pulsed
Ring Proton Accelerator for 12.5 Bev"

John J. Livingood
Report No. 16

Stability in both the vertical and radial directions can be

attained using a magnetic guide field with zero gradient, provided the ratio of magnet lengths to straight section length is properly chosen and if the edges of the magnets make an appropriate angle with the mean orbit. Tentative parameters are given below:

Injector 50-Mev Thomas-like cyclotron

Weight	150 tons
Average final field	15 kilogauss
Oscillator frequency	22.8 mc/sec
Circulating current, at final energy	10 m amp
Pulse length	200 micro sec.
Peak Oscillator Load, including losses	900 K watts
Peak Power-Supply Load	1500 K watts
Repetition Period	4 sec

Ring Accelerator

No. of Magnets and No. of Straight Sections	8
Length of 1 magnet section	57.5 ft.
Average length of 1 straight section	16.4 ft.
Machine circumference, at orbit	591.0 ft.
Machine radius, at orbit	94.2 ft.
Mass of Iron (1/2-inch laminations)	3500 tons
Mass of copper	120 tons
Inside dimensions of vacuum donut	6 in. x 24 in.
Orbit radius of curvature	73 ft.
Injection field	466 gauss

Final field	20 000 gauss
Final energy	12.5 Bev
Rise time of field	1 sec.
Fall time of field	1 sec.
Repetition period	4 sec.
Peak stored energy in magnet	33×10^6 Joules
Dissipated Energy per pulse in magnet	7×10^6 Joules
Average Magnet Power	1750 K watts
Rating of Generator	72 000 KVA
Energy gained per turn	7.8 kev
No. of accelerating stations	1 or 2
No. of radial betatron oscillations per turn $\nu_x =$	0.75
No. of vertical betatron oscillations per turn $\nu_z =$	0.85
Field index inside magnets	$n = 0$
Azimuthal average field index	$k = -0.4375$
Momentum Compaction	$\alpha = 0.5625$
Angle between magnet faces	0.339 radian
Injection revolution frequency	0.521 mc/sec
Final revolution frequency	1.66 mc/sec
Injection Oscillator frequency (9th harmonic)	4.7 mc/sec
Final Oscillator frequency (9th harmonic)	14.9 mc/sec
Oscillator frequency ratio	3.18: 1
Circulating beam in injector, at 50 Mev	10 m amp
Beam deflected out of injector	2.5 m amp

Beam deflected into Ring with proper divergence	0.03 → 0.3 m amp
Beam accepted in phase stable orbits	0.01 → 0.1 m amp
No. turns injected per pulse	100
12.5-Bev ions per pulse	$10^{10} \rightarrow 10^{11}$

Radio Frequency Studies for the 12.5-Bev Accelerator"

John H. Martin

Most of the design features for the 50-Mev constant-frequency pulsed cyclotron are proceeding along conventional lines. The RF system will need to supply about 1.5 megawatts for a total pulse duration of about 500 microseconds to accelerate the rather large beam of particles. Vacuum tubes under investigation to do this are Machlett Type ML-5682 and RCA Type 5831. A delay line technique is under investigation for the energy storage needed in this system.

The necessary range of frequency variation for the accelerator in the ring magnet is 3.18. To keep in step with the pulsed magnetic guide field the gap potential (per turn) should be about 16 000 volts. Calculations and model tests so far indicate that this frequency variation range can be covered by moving a capacity coupled end section in the accelerating cavity without introducing serious losses.

Use of a frequency which is a low harmonic (say the 9th) of the revolution frequency will involve a large cavity or an excessive amount of ferrite, resulting in a low value for Q. A higher harmonic, say the 44th, will make the injector and ring R.F. frequencies equal at transfer time; a smaller resonant cavity can be used, tuned grossly by mechanical means and trimmed to the exactly required frequency by a modest amount

of ferrite.

134-3

Atomic Excitation Following β^- -Decay of Tritium
(5230)

Sol Wexler

Efforts have been directed toward finding experimental conditions which will produce a high steady-state concentration of atomic tritium in the gas exposure cell. Hydrogen served as a stand-in for the radioactive isotope.

1. A high frequency and an AC high voltage discharge were tested.
2. In order to minimize recombination of the atomic species on the pyrex walls of the discharge tube and gas cell, several wall "poisons" were tried in turn:- 1% H_2O in the hydrogen, water vapor from a sulfuric acid bath, meta phosphoric acid, 7% H_3PO_4 and syrupy phosphoric acid.
3. Four Hg-pumps were tested as circulating pumps in the closed system: - a van Hespén two-stage pump, a small and a large Brewer pump, and a mercury ejector. The last-named was made from a standard Princeton pump by introducing a large nozzle as a single stage and by altering the boiler.

Five to ten percent atomic hydrogen is the highest found thus far in the 0.5 mm. H_2 used. This amount was obtained when the wall poison was syrupy phosphoric acid and the gas was circulated by the mercury ejector pump. Tungsten-filament calorimeters introduced into the gas cell measured the partial pressure of the atomic hydrogen. The Wrede molecular flow gauges used previously were found to give erroneously high readings for the concentration of the atomic species.

Construction of a large cold trap to house the multiplier phototube detector and cool it by liquid nitrogen was completed, and the best available 1 P 28 tube was installed. More than a dozen multipliers were tested to select the one with the lowest dark current and the highest spectral sensitivity at 2500 Å and in the visible. Numerous pulse height analyses of the dark current and of a very weak light signal were taken of the best tube to determine the best operating conditions.

A vacuum line for purification of tritium was finished.

135-10

Electron-Neutron Interaction

(5220)

Marshall F. Crouch, (Case Institute of Technology)
Victor E. Krohn and G. R. Ringo
Reported by Victor E. Krohn

The measurement of the coherent scattering amplitudes of krypton and xenon has been completed and the results have been accepted for publication in the Physical Review.

New apparatus is being constructed for another measurement of the anisotropy in the scattering of thermal neutrons by gaseous krypton and xenon. Also, a new measurement of the total scattering cross sections of xenon and krypton will be made.

All three of the above measurements are needed for a substantial improvement in the accuracy of our result for the electron-neutron interaction.

139-3

Liquid Scintillators

(5230)

Robert K. Swank and Warren L. Buck

Using the apparatus mentioned in ANL-5498, I-139-2, a study has been made of the effects of changing the concentration of the solute and of dissolved gases on the output of scintillation light from various organic liquid solutions. This report includes a description of the apparatus used and a discussion of the results.

Apparatus.

Figure 7 shows a somewhat simplified diagram of the apparatus used in this study. It can be used to saturate a sample of liquid solution with a desired gas and to measure the output of scintillation light resulting from excitation of the liquid with beta particles. This measurement may be repeated for the same liquid sample with different gases without removing the sample from the apparatus. Alternately, the concentration of a constituent of the solution may be reduced in successive steps, by a total factor of about 200, making measurements of light output at each concentration and maintaining equilibrium between the solution and the desired gas.

The apparatus is constructed of Pyrex glass and consists of a reservoir B-1, a metering bulb B-2, a mixing bulb B-3, and a measuring cell C-1, all interconnected by tubing and stopcocks as shown. The desired gas, supplied at a pressure slightly above atmospheric, can be bubbled through the liquid in various parts of the system; or the gas can be used to push liquid from one part of the apparatus to another

LIQUID SCINTILLATOR APPARATUS

FIGURE 7

or to expel liquid from the apparatus through stopcock S-11. Only when leaving the apparatus does the liquid pass through a stopcock. Before it is supplied to the system the gas is bubbled through a trap (not shown) containing the same solvent as the solution being studied; this "washes" the gas and minimizes loss of solvent from the liquid scintillator.

The measuring cell is cylindrical in shape with its axis horizontal. A 1-millicurie Sr^{90} - Y^{90} beta source contained in an Al needle is inserted into a glass thimble extending into the cell along its axis, so that the source is placed near the center of the cell. The walls of the needle and thimble are very thin, and the dimensions of the cell are such that essentially all of the energy of the beta rays is dissipated in the liquid filling the cell. Light from the resulting scintillations is detected by an RCA-6342 photomultiplier (S-9 response), connected as a photodiode, which views the interior of the cell through the rear face. MgO is packed around the cell as a reflector, and the cell and phototube are enclosed in a light-tight housing. The d. c. output from the phototube, measured by a vacuum-tube electrometer, is taken as a measure of the light output from the scintillator.

To illustrate the functioning of the apparatus, suppose it is desired to determine the variation of light output with concentration for argon-saturated solutions of p-terphenyl in toluene. A solution of the highest desired concentration is introduced via J-2 to fill the measuring cell to the level b--b. Excess solution is drained through S-11,

leaving a calibrated volume (~ 20 ml) of the solution. The reservoir is filled with pure toluene to be used for dilution of the solution.

Argon introduced through S-8, 9, 10 forces the solution from the measuring cell into the mixing bulb and bubbles up through the solution. The toluene in the reservoir may be bubbled at the same time. After a period of bubbling the solution is returned to the measuring cell and the light output determined. When additional bubbling of the solution produces no further change in light output, the solution is diluted by a known amount with toluene from the reservoir.

The first step in making a dilution is to fill the metering bulb to the level a--a with toluene from the reservoir. Opening S-1, with S-2, 3 closed and S-4,5 open causes toluene to move up from the reservoir into the metering bulb. When the level a--a is exceeded S-2 is opened and S-1 closed, causing excess solvent to drain back into the reservoir and leaving the metering bulb filled to the level a--a. Closing S-2 and S-4 and opening S-3 then pushes this toluene over into the mixing bulb. The original solution is thus diluted by a factor determined to be approximately 2.15.

After further bubbling of the diluted solution in the mixing bulb, it is returned to the measuring cell with excess solution being drained off in such a way as to leave a sample having the original volume (b--b). Light output of the diluted solution is then determined, after which still further dilutions can be made. After completion of a series of such dilutions, the remaining liquid is forced out through S-11,

the apparatus is rinsed with a suitable solvent, and is then dried by allowing gas to flow through the system.

When it is desired to study the effect of varying the concentration of only one solute in a solution containing two or more solutes, the reservoir is filled with a similar solution lacking the solute whose concentration is to be varied.

Successive measurements of light output from a given liquid scintillator during the course of a day are usually found to vary less than 1 %. A slow decrease in sensitivity over longer periods has been noted and has been taken into account by periodic redeterminations of light output from a standard solution. The dilution factor is believed to be accurately known to within about 1/2%, but owing to the cumulative effect of successive dilutions of the same sample the solution is usually discarded after seven dilutions.

Summary of Results

The apparatus described has been used to study the effects of variation of the concentration of solute and of dissolved gases on the output of scintillation light from various solutions, using toluene as the solvent. Results of these measurements are summarized in Table V, which lists the name of the solute (and its abbreviation), the gas with which the solution was saturated, the maximum light output measured and the concentration at which this light output was obtained. Figure 8 shows some typical curves of light output vs concentration for argon-saturated solutions.

FIGURE 8

TABLE V

Relative Scintillation Light Outputs from Toluene Solutions with Beta-Particle Excitation

<u>Name of Solute</u>	<u>Abbrevi- ation</u>	<u>Gas</u>	<u>Optimum Conc. ^(a) g/liter</u>	<u>Relative Light ^(b) output</u>
1,4-di- [2,5-phenyloxazolyl) - benzene]	POPOP	argon	1.5*	0.67
		air	"	0.44
		oxygen	"	0.17
2-phenyl-5-(4-biphenyl)-1,3,4- oxadiazole	PBD	argon	8	0.63
		air	10	0.51
		oxygen	15	0.31
2-(1-naphthyl)-5-phenyloxazole	α NPO	argon	3	0.63
		air	5	0.46
7-diethylamino-4-methylcoumarin [†]	DEAMC	argon	1.2	0.59
		air	1.8	0.32
2,5-diphenyloxazole	PPO	argon	4	0.54
		air	5	0.40
		oxygen	8	0.21
<u>p</u> -terphenyl	<u>p</u> -TP	argon	9*	0.48
		air	"	0.36
		oxygen	"	0.19

* Solubility limit. Corresponding light output measured at solubility limit.

+ Material suspected to be impure.

TABLE V (Cont'd)

<u>Name of Solute</u>	<u>Abbrevi- ation</u>	<u>Gas</u>	<u>Optimum Conc. (a) g/liter</u>	<u>Relative Light (b) output</u>
1,6-diphenylhexatriene	DPH	argon	0.7	0.47
		air	1.3	0.26
		oxygen	2.5	0.09
<u>m</u> -terphenyl	<u>m</u> -TP	argon	>100	>>0.37
		air	"	>0.21
naphthalene	N L	argon	335*	0.18
		air	"	0.03
		oxygen	"	0.01
fluorene ⁺	—	argon	10	0.15
		air	5	0.05
1,4-diphenylbutadiene	D PB	argon	1.4	0.14
		oxygen	5	0.06
2-methylnaphthalene	2-MNL	argon	1.2	0.12
		air	2.5	0.03
anthracene	AC	argon	0.7	0.11
		oxygen	3.5	0.03

* Solubility limit. Corresponding light output measured at solubility limit.

+ Material suspected to be impure.

TABLE V (Cont'd)

<u>Name of Solute</u>	<u>Abbrevi ation</u>	<u>Gas</u>	<u>Optimum Conc. (a) g/liter</u>	<u>Relative Light (b) Output</u>
biphenyl	BP	argon	450*	0.06
		air	"	0.03
trans-stilbene	SB	argon	2	0.03
		air	-	-
(none)	-	argon	-	0.01
		air	-	< 0.01
		oxygen	-	"

(a) Grams of solute per liter of solution for maximum light output.

(b) With MgO reflector and RCA-6342 (S-9 response).
Normalized to 0.40 for air-saturated toluene containing
5 g/liter PPO. Excitation by beta particles from Sr^{90}
-Y⁹⁰.

* Solubility limit. Corresponding light output measured at solubility limit.

In this report the relative values of light output obtained with the various solutions are normalized in such a way that an air-saturated solution of 2, 5-diphenyloxazole (5 g/liter) in toluene gives light output equal to 0.40. On the same scale an anthracene crystal would give a relative light output in the neighborhood of 1.0. It should be mentioned that the particular photo-multiplier used for these measurements is believed to have an S-9 type of spectral response, tending to favor those scintillators which emit at the longer wavelengths.

In addition to the solutions listed in Table V, some others containing more than one solute have been studied. These may be divided into two classes:

- (a) Solutions containing two different fluorescent solutes.
- (b) Solutions containing a compound of a heavy element.

Results of tests on such solutions will be discussed later in this report, but it may be noted here that argon-saturated toluene containing PBD (10 g/liter) and POPOP (0.2g/liter) gave a light output of 0.77, the largest value we have obtained from any scintillating liquid solution.

The toluene used in these solutions was prepared by purifying stock of reagent grade by distillation to meet pre-determined spectrophotometric standards. The solutes were obtained commercially and were purified additionally except in those cases where "Scintillator-Grade" purity was specified.

Oxygen Quenching

Quenching of the fluorescence of organic solutions by dissolved oxygen was reported by Bowen and Norton¹. The importance of this effect in liquid scintillators was pointed out by Pringle, et al.², and the magnitude of its effect on several well-known scintillator formulations was given by Ott, et al.³. At the time this study was initiated, no data were available on the effect of dissolved oxygen (or air) on the curves of light output versus concentration of activator. Such information would be very useful in determining practical scintillator formulas and also in understanding more fully the nature of the effect. The need for this information was an important factor in deciding to build the apparatus described above. Since beginning this work, it has come to our attention that such studies were being pursued by Prof. H. Kallmann's group⁴ and also by Seliger, et al.⁵ However, there seems to be only a small duplication of effort in the work so far reported. Much more work needs to be done, since the great majority of the data on liquid scintillators reported up to now have been obtained using systems of unknown oxygen content. It is not safe to assume that solutions standing in the laboratory are saturated with air since experience so far has shown that such solutions have not always come to equilibrium with the atmosphere. Furthermore, some materials are quenched by oxygen to a much greater degree than others, so that materials previously

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1. Bowen, E. J. and Norton, A., Trans. Far. Soc. 35, 44 (1939).
 2. Pringle, Black, Funt and Sobering, Phys. Rev. 92, 1582 (1953).
 3. Ott, Hayes, Hammel, and Kephart, Nucleonics 13, No. 5, 62 (1955).
 4. H. Kallmann, Progress Report No. 6, U. S. Signal Corps, Contract No. DA-36-039-SC 42626, New York University (1955).
 5. H. H. Seliger, C. A. Ziegler and I. Jaffe, Phys. Rev. 101, 998 (1956).

rejected as unusable may prove to be useful in oxygen-free solutions.

Further investigation of the effect of oxygen- or air- quenching on liquid scintillators has been one of the principal activities during the period covered by this report. Figure 9 shows the light output of solutions of PPO in toluene. The quenching effect of oxygen is quite apparent. The curves shown have been fitted to the data using the formula developed by Kallman and Furst⁶:

$$L = L_{\infty} \left(\frac{c}{Q + c} \right) \left(\frac{R}{R + c} \right). \quad (1)$$

We have taken the liberty of writing L_{∞} for P/R . When written in this way, the physical processes represented by the formula are easily explained. The first factor, L_{∞} , is made up of three subfactors: (1) the total number of solvent molecules excited per unit time by the high energy radiation, (2) the fluorescence quantum yield of the solute at very small concentration, and (3) the instrument factor. The second factor, $c / (Q + c)$, is the fraction of the solvent excitations which are transferred to the solute. The third factor, $R / (R + c)$, is a correction to the fluorescence quantum yield of the solute necessary to account for the effects of self-quenching. In the Kallmann-Furst theory these factors are derived on the basis of competition between the processes of emission, quenching and energy transfer.

6. Kallmann, H. and Furst, M., Phys. Rev. 79, 857 (1950); 81, 853 (1951); Furst, M. and Kallmann, H., Phys. Rev. 85, 816 (1952).

FIGURE 9

The addition of a quencher, such as oxygen, will alter the parameters in this equation. The process of quenching consists of introducing a new path by which an excited molecule may reach the ground state without the emission of light. This new process will then compete with all the processes normally taking place. If the quenching action is against the solvent molecules, its effect will be to increase Q to a new value $Q' = Q (1 + a c_q)$, where c_q is the concentration of the quencher and a an appropriate constant. Quenching of the solvent will have no effect on L_∞ or R . On the other hand, quenching action against the solute will have the following influence:

$$\begin{aligned} L_\infty &\longrightarrow L'_\infty = L_\infty / (1 + b c_q) \\ R &\longrightarrow R' = R (1 + b c_q) \\ Q &\longrightarrow \text{unchanged} \end{aligned}$$

From the above considerations it is evident that the influence of the quencher on the parameters of the equation offers some insight into the nature of the quenching process. Using the values for Q and L_∞ from Table VI one obtains for air saturated solutions

$$\begin{aligned} a c_q &= 1.40 \\ b c_q &= 0.20 \quad ; \\ \therefore a/b &= 7 \quad , \end{aligned}$$

showing the solvent to be quenched seven times more readily than the solute. For oxygen saturation, the value of a/b is calculated to be 6.25, in fair agreement, considering the limits of accuracy of the experimental method. However, if one calculates $b c_q$ from the change in R ,

the result is negative! This seems to be in contradiction to the theory. At the present time, however, no great significance is attached to this result for two reasons: (1) The value of R is much larger than the concentrations used in these experiments, and therefore cannot be determined accurately; (2) the apparent decline in L at high concentrations may be partly due to losses resulting from self-absorption of the fluorescent light by the solute. No attempt was made to correct the results for self-absorption. In these calculations, R must be regarded mainly as an empirical parameter used to fit the experimental data. Since its effect on the curve is small, it is believed that the error introduced into the other parameters will be unimportant.

TABLE VI

Scintillation parameters for PPO in toluene (atmospheric pressure)

parameter	argon	air	oxygen	$\frac{\text{air}}{\text{argon}}$	RATIO
$L_{\infty} = (P/R)$	58.8	48.7	30.7	0.83	
Q	0.247	0.595	1.67	2.40	
R	105.	54	35.	1.95	
L_m^*	53.5	40.0	20.8	0.75	
c_m^*	5.10	5.68	7.65	—	

* L_m and c_m are values of light output and concentration at the peak of the curve.

Many of the well-known scintillators produce curves very similar to Figure 9. The lowest oxygen quenching is exhibited by PBD (Figure 10), but the quenching is similar for most of the polyphenyls and phenyloxazoles. However, some solutes produce very much greater oxygen quenching. The most striking example is naphthalene. The curves for naphthalene are shown in Figure 11.

Energy Transfer

The air quenching factor for PPO in toluene was found to be 0.75. The value for POPOP was approximately the same. It is common practice to add very small quantities of POPOP to solutions of PPO in toluene to "shift" the wavelength to larger values for practical reasons. It has been assumed that this shift was accomplished as a result of the fact that the fluorescence radiation emitted by the PPO is subsequently reabsorbed by the POPOP and re-emitted as characteristic POPOP fluorescence. (This is in contrast to the mechanism by which the energy is transmitted from the solvent to the primary solute, where a non-radiative mechanism is believed to be involved.) However, if the process of reabsorption and re-emission takes place, then the air quenching factor for PPO plus POPOP should be approximately equal to the product of the individual values for each solute taken alone. This is not the case. In fact, the quenching factor for both solutes is almost identical to that for either one alone. A possible explanation of this unexpected result is that the energy is not transferred from PPO to POPOP by radiation at all, but is transferred by a non-radiative

FIGURE 10

FIGURE 11

mechanism. If this is true, then the transfer takes place at about tenfold lower concentration than the transfer between solvent and solute. Since the lifetimes involved in these transitions are not known, it is not possible to say at this time whether this behavior is consistent with the current theory of liquid scintillators.

Heavy Elements in Liquid Scintillators

Preliminary results were reported in the previous progress report concerning the loading of liquid scintillators with compounds of heavy elements. All such compounds so far investigated are severe quenchers. However, the usefulness of heavy elements in gamma-ray detectors makes it desirable to investigate this quenching in greater detail and to search for methods of minimizing the quenching. Considerable success was reported by Kallmann⁷ through the use of naphthalene as an auxiliary "solvent". During the period covered by this report, experiments were performed with diphenylmercury in liquid scintillators. Some results of these experiments are shown in Figure 12. The severe quenching by the mercury compound is apparent. It is somewhat interesting to note that although naphthalene when used alone is greatly quenched by mercury, its presence in the PPO solution reduces the quenching of that solution.

7. Kallmann, H. , Progress Report No. 5, U.S. Signal Corps contract No. DA-36-039 SC 42626, New York University, October, 1954.

FIGURE 12

140-7 A Gaseous Scintillation Counter (5230)

Charles Egglar and Charles M. Huddleston
Reported by Charles Egglar

Further investigation of the response of a PbS photo-conductor to the light emitted by charged particles in a gas indicate that in addition to perhaps a true photo-response there is a definite contribution to the pulse observed from electron collection on the charged photoconductor. Suppression of this contribution by the use of a metal grid at the same or higher potential than the photoconductor reduced the pulse observed to a point that it was next to impossible to resolve the pulse from the thermal noise of the semi-conductor. The search is still continuing for a detector which will have a higher efficiency for the wide-spread spectral emission of the gases employed than does the photomultiplier tubes now available.

142-5 Electron Accelerator (5230)

H. B. Phillips and Robert K. Swank
Reported by Robert K. Swank

The construction of apparatus essential to the operation of this instrument is completed.

Preliminary tests of its performance have been made. Although a vacuum pressure of approximately 10^{-5} mm Hg was obtained, the useful life of a cathode after activation was only a few minutes (with heater power off). A large liquid nitrogen trap and a water-cooled

baffle were installed. With this modification, the life of a freshly activated cathode is about 24 hours. Although the pressure in the system is still 10^{-5} mm., the pressure of condensible vapors is probably much lower than it was before the installation of the trap. The beam has been observed visually in a plastic scintillator outside the vacuum window.

Although the life of the cathode activation is short, it is probably usable. A given cathode can be re-activated at least five times, although the output current diminishes somewhat with each new activation. The system will have to be observed under fast pulse conditions before the lower limit of cathode activation can be determined. Such observations are about to begin.

143-5 Plastic Scintillators (5230)

Louis J. Basile

In the hope of developing a more efficient plastic scintillator, studies have been carried out using phenylbiphenyl-oxadiazole (PBD), and POPOP as fluor additives to vinyl toluene.

A plastic containing POPOP acts as a fairly good scintillator. The maximum light output was 36% relative to our standard anthracene crystal. As a wavelength shifter it proved to be much more efficient. Addition of small amounts of POPOP to p-terphenyl solutions in polyvinyltoluene results in a scintillator having a maximum response of 48-49%. This is as efficient as any plastic scintillator previously developed.

PBD in polyvinyltoluene also acts as a fairly good scintillator. 1-3% solutions of PBD in the plastic give a light output response of 41%. Addition of small amounts of POPOP to this mixture did not improve the light output much. The maximum response obtained was 47% of anthracene.

It should be emphasized that the purity of the compounds used is very important. Only slight amounts of impurities can act as light quenchers that seriously deteriorate the quality of the scintillators.

Plastic Scintillators Loaded with Heavy Elements.

During the past quarter a more detailed study has been carried out on the effects on the light output of plastic scintillators of the addition of diphenylmercury. It was previously reported, ANL-5498, that diphenylmercury acts as a quencher and that varying the concentration of terphenyl produces little change in light output.

In an attempt to increase the scintillation efficiencies (as measured by light output relative to our standard anthracene crystal) of these mercury-loaded plastics, 1,1,4,4 tetraphenylbutadiene (TPB) and POPOP were used as wavelength shifters.

Typical curves obtained in this study are shown in Figure 13. These curves represent the maximum light output obtained for the particular additives. All of the curves show a definite characteristic quenching effect on the light output. The concentration of p-terphenyl in the samples was 3%. Addition of a small amount of TPB significantly increases the light output. The optimum concentration of TPB for

FIGURE 13

maximum light output was found to be 0.1 %.

A mixture of POPOP plus p-terphenyl in polyvinyltoluene was found to be a very good scintillator. Addition of diphenylmercury to this system again results in a sharp quenching effect. The resulting curve lies intermediate between the p-terphenyl curve and the p-terphenyl plus TPB curve. Thus, in this system POPOP is not as efficient a wavelength shifter as TPB.

Plastic Scintillators Loaded with Boron.

In an attempt to develop a boron-loaded polymer, diborane (B_2H_6) was allowed to react with 2 and 4-vinylpyridine. It was hoped that borine (BH_3) would coordinate to the nitrogen of the pyridine ring in a typical acid-base reaction. We then would have a boron vinylpyridine compound with the vinyl group still available for polymerization.

Reaction between the two substances takes place immediately. A small amount of hydrogen is produced, probably by decomposition of diborane. The product formed was viscous, indicating that polymerization had taken place. The color turned to a deep reddish brown and thus we could not use it for its intended purposes.

Decaborane was also added to some vinylpyridine and again a rapid reaction took place. It was accompanied by a similar color change. The matter was not investigated further.

144-5

Scintillation Counter Techniques

(5230)

John S. Moenich and Robert K. Swank
Reported by Robert K. Swank

This program has covered principally the work done on photomultipliers and the canning of sodium iodide crystals and associated techniques. As of 2-17-56, this program was transferred to the Electronics Division. Up to this time the routine canning and testing was carried out as usual. The last official act was the canning of the largest sodium iodide crystal so far obtained at this Laboratory. It is 8" in diameter and 4" thick. It will be used by the Radiological Physics Division.

This is the final report for this program.

148-5

Electrical Conduction in Dielectrics

(5230)

Raymond J. Munick

Because of improvements in the apparatus and techniques, it was possible to extend the range of the temperature measurements from 25 -75° to 21-90° C and to obtain greater consistency in the data. Primarily, measurements were made of the conduction currents from Plexiglas as a function of temperature and voltage. Secondly, the polarization currents that occurred when voltages were applied and removed were observed.

The most interesting feature of the new current-temperature data was that they could be represented by the sum of two exponentials, as shown in Figure 14. The data have not been converted into terms of conductivity because of uncertainty about the linear coefficient of thermal

expansion over this range of temperature, particularly since Plexiglas is reported to undergo a change in structure in the temperature range of 70-110° C.¹ However, if the equation that represents the curve of Figure 14 be expressed in terms of conductivity using dimensions at room temperature it becomes

$$\sigma = \sigma_1 \exp(-W_1/kT) + \sigma_2 \exp(-W_2/kT),$$

where $\sigma_1 = (2.9 \pm 1.3) \times 10^5$ mhos/cm,

$$W_1 = 1.451 \pm 0.012 \text{ ev},$$

$$\sigma_2 = (3 \pm 12) \times 10^{27} \text{ mhos/cm},$$

and $W_2 = 3.00 \pm 0.10 \text{ ev}.$

The values of σ_1 and W_1 agree very well with the corresponding values of $(3.2 \pm 0.9) \times 10^5$ mhos/cm and 1.452 ± 0.008 ev, which were reported in ANL 5498 for the same specimen, Plexiglas M3. Thus, the previously reported results are for the lower temperature part of the curve. More remarkable is the apparent constancy of the conductivity of this specimen over a period of almost nine months between the first and second sets of measurements. On the other hand, the conductivity of Plexiglas M2, which also reveals the superposition of the two exponentials, appears to be smaller than it formerly was by a factor of 2/3. This sample of Plexiglas M2, however, had undergone one month of beta-irradiation prior to the current-temperature measurements.

The conduction current from Plexiglas M3 was measured at 51.5° C for eight voltages from 6.236 to 631.5 volts and obeyed Ohm's

1. E. H. Riddle, Monomeric Acrylic Esters (Reinhold Publishing Corp., New York, 1954), p. 59.

FIGURE 14

Logarithm conduction current from Plexiglas M3 (for constant voltage of 313 volts) versus reciprocal absolute temperature (26.0-89.5°C). Voltage was applied on 12-16-55 at 29.8°C and removed on 1-20-56 at the same temperature. Circles represent experimental points taken in mixed order from 12-21-55 to 1-17-56. Solid line represents the equation:

$$I = 1.91 \times 10^{10} \exp(-16.84 \times 10^3/T) + 1.8 \times 10^{32} \exp(-34.8 \times 10^3/T),$$

where the current I is in amperes. Dashed lines represent the individual exponentials.

law very well. These voltages correspond to electric intensities of 58.1 to 5.88×10^3 volts/cm, which are below the region of nonlinear conduction reported in ANL-5498.

Polarization currents were observed incidentally in the course of applying and removing voltages from the specimens. An example is shown in Figure 15.

An article entitled "Transient Electric Currents from Plastic Insulators" has been submitted to the editor of the Journal of Applied Physics. This is concerned with the polarization currents from Lucite, Fluorothene, polyethylene, polystyrene, and Teflon.

A paper entitled "Electrical Conduction in Plexiglas" was presented at the Chicago meeting of the American Physical Society on November 26, 1955.

A paper entitled "Temperature Dependence of Conduction Current from Plexiglas" is to be presented at the meeting of the American Physical Society in New Haven in June, 1956.

149-3 A Dynamic-Condenser Magnetometer (5220)

S. Bradley Burson, Robert C. Doerner, and
David W. Martin
Reported by S. Bradley Burson

The electronic components of the instrument were designed in collaboration with and constructed by the Argonne Electronics Division. The voltage for the sections of the condenser stator is provided by an electronically regulated power supply which is isolated from ground.

PHG-1059
6-15-56
B S.

FIGURE 15

Logarithm current from Plexiglas M2 (at 90.0°C) versus logarithm time elapsed from voltage change of 313 volts. O = positive current for application of voltage on 2-14-56, when background current was 1.9×10^{-14} ampere. + = positive current less conduction current of 2.30×10^{-10} ampere, which was measured on 3-23-56. □ = negative current when voltage was removed on 3-23-56. Oscillation of charging current (+) about discharging current (□) is thought to be due to slight rise in temperature observed 10 minutes after voltage was applied.

The load consists of a "bleeder" string of precision resistors selected so that corresponding points are balanced above and below ground. A decade switch provides coarse control while fine adjustment is obtained by means of a dual ten-turn "helipot" equipped with a five-inch 1000-division dial. Each dial division represents approximately 0.1 gauss.

The error signal is picked up by means of a cathode-follower mounted on the dynamic-condenser housing. The signal is then transmitted by cable to the circuit chassis. Between the cathode follower and the main amplifier are a system of twin-"T" filter networks designed to suppress the bothersome harmonics present in the error signal. The signal from the output transformer is returned to a commutator mounted on the condenser shaft. By appropriately orienting the commutator on the shaft so that it is phased with the condenser, the output meter, which is of the "center-scale zero" type, indicated directly whether a null is obtained and if not, in which sense the field is in error.

As yet, the magnetometer has not been calibrated against any known magnetic standard. Before this is done, a new coupling between the rotating search coil and condenser must be designed. Since the instrument is sensitive to axial orientation in the field, the search coil must be carefully phased with the condenser. The coupling now being used has no provision for making fine adjustments.

A mechanical suspension was designed and constructed for mounting the magnetometer over the 180° beta-ray spectrometer. The suspension is designed so that the magnetometer can be swung out of the field to permit work on the vacuum chamber, or the installation of

sources, while accurately preserving the "in-field" position.

The DC condenser supply is provided with sampling resistors so that the current through the divider string can be checked periodically with a precision potentiometer. As yet, no provision has been made for checking the line frequency, which constitutes the only other parameter which might introduce error. The long-range frequency stability is evidently quite good; during tests of several hours duration no tendency to drift was observed.

The performance of the instrument has been checked under actual operating conditions. The dial setting corresponding to the maximum of the 624-kev K-shell internal-conversion line of Cs^{137} was found to reproduce even after extreme excursions of the magnetic field. This reproducibility extended over a period of several days, during which the magnetometer had been swung in and out of the field on its mounting several times, and the source had been removed from the vacuum chamber and later replaced. Although quantitative evaluation of the over-all precision of the device has not yet been made, it appears that it will amply satisfy the design expectations.

152-2

Radiation Damage to Dielectrics

(5230)

Raymond J. Munick

The primary objective of this investigation is to study the effects of radiation upon the electrical properties of insulating dielectrics. The two types of experiments that were performed represent different

approaches to this problem: in the one an attempt was made to measure the conduction current in Plexiglas while the specimen was undergoing irradiation; in the other the conduction current was measured before and after, but not during, irradiation.

In the first type of experiment the measurements were made while Plexiglas M2 was exposed to the Strontium-90 source described in ANL-5498. Control of temperature and relative humidity and careful electrical shielding contributed to eliminate difficulties that were mentioned in ANL-5498, such as large fluctuations in current. The current due to the beta particles being projected into the region between the electrodes was $0.14 \mu\text{a}$, which is consistent with a maximum possible current of $0.34 \mu\text{a}$ from the 110-microcurie source. The voltage drop produced across a 10^{11} -ohm resistor by the beta current was balanced out by an adjustable voltage, which was monitored with a Rubicon No. 2730 portable potentiometer, and then the current produced by a battery of 3.13 volts was measured at four temperatures from 35 to 50°C. The pattern of the results is not clear. Some of the polarization currents were the same as those prior to irradiation; others were definitely larger. The conduction current was less after radiation than before but in later post-irradiation measurements it was still lower. Thus, for example, the conduction current at 49.7°C during irradiation was $0.31 \mu\text{a}$ compared to $0.38 \mu\text{a}$ about eight months previously; but two months later the post-irradiation current was down to $0.22 \mu\text{a}$. In any event, the expected increase in conduction current was not observed.

The above results influenced the subsequent experimentation on Plexiglas M3. To better specify the pre-irradiation condition of the specimen, current-temperature and current-voltage measurements were taken before subjecting the specimen to any radiation. Also, since the above-mentioned effects were smaller than expected, it was decided to increase either the intensity or the dosage of the irradiation. Furthermore, the problem of determining the dosage and distribution of the irradiation in Plexiglas M2 suggested that it would be better to use a more penetrating radiation, which would give a homogeneous dose of known amount. These considerations suggested the use of the Gamma Irradiation Facility or of reactor CP-5. The work of Charlesby¹ at Harwell on the effects produced by radiation on the chemical, mechanical, and thermal properties of plastics showed that permanent chemical and structural changes are produced and encouraged attempting a simple before-and-after experiment. Consequently, Plexiglas M3 has been subjected to three irradiations in the Gamma Irradiation Facility, which employs used fuel rods from the MTR reactor as a source.

Plexiglas M3 received successive doses of 1.00×10^6 , 2.00×10^6 , and 7×10^6 r, for an accumulated dose of 1.00×10^7 r. There was no visible change in the specimen. The pre-irradiation conduction current at 51.62°C with 316.0 volts across the specimen was 0.541 μa . The respective values after the first, second, and third irradiations were 0.469, 0.470, and 0.588 μa with an estimated error of $\pm 0.001 \mu\text{a}$.

1. A. Charlesby, Nucleonics 12, No. 6, 18-25 (1954).

Before final conclusions are drawn, the thermistor that measures the temperature of the specimen must be recalibrated, as its calibration in the vicinity of 51.6°C is out of line with the other thermistor calibrations. The others indicate a lower temperature for the same bridge setting. This thermistor, after a hasty calibration around 51°C , had been substituted for the one that had been used just prior to the irradiation because the latter was broken when the specimen was being replaced in its holder after the first irradiation. The results do suggest that the conduction current is increased by the gamma irradiation. If this is true, a practical application might be to use this effect for high level radiation dosimetry.

II. MASS SPECTROSCOPY

1-10 (Mass Spectrometric Techniques) (5230)

Mark G. Inghram

Reporting on this topic will be discontinued until there are new techniques to discuss.

3-1 Rebuilding of MA-15 (5230)

William A. Chupka

The rebuilding of MA-15 has been completed. The mass spectrometer has been put into operation and is fully up to expectations. The resolution is approximately equal to the theoretically expected value. Without baking, the source and analyser sections have pumped down to a pressure less than 10^{-8} mm. A new triple differential pumping source enclosure operates successfully.

Some parts of the instrument still remain to be completed or revised but these will be finished while research is in progress.

10-11 (A Search for Rare Naturally Occurring Isotopes) (5220)

David C. Hess

Reporting on this program will be discontinued until it again becomes active.

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Measurement of Top Gas for Borax III (5220)

David C. Hess and Mark G. Inghram
Reported by David C. Hess

At the request of the Borax group, samples of gas recovered from the condenser of Borax III were analysed to determine the approximate abundances of Argon, Krypton, and Xenon for correlation with certain counting data.

The results were that, within the accuracy of the measurement, the isotopic and elemental abundances were those of air.

Further measurements may be made on samples which have had hydrocarbon and other background gases removed, if desired by the Borax group.

Gaseous Species in Equilibrium with Metal-Metal Oxide Systems

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

The mass spectrometric technique described in previous reports has been applied to the study of TiO_2 and Ti_2O_3 . Preliminary results show that the major species evaporating from TiO is TiO(g) and that from TiO_2 is $\text{TiO}_2(\text{g})$. Ti_2O_3 evaporates as a mixture of Ti(g) , TiO(g) and $\text{TiO}_2(\text{g})$. The study of this system has been deferred temporarily while awaiting some necessary materials.

The molecular species evaporating from a crucible containing solid MoO_3 were studied. Interpretation of the mass spectrum of the vapor

indicated that the major molecular species present were Mo_3O_9 , Mo_4O_{12} , and Mo_5O_{15} in the approximate ratios 1:0.3:0.015 at 850°K . The values of the heat of vaporization $\Delta H(850^\circ\text{K})$ of these species at this temperature are 80, 93, and 103 kcal/mole respectively. Other species were not detected and were shown to be less than 1% of the Mo_3O_9 . This work will be reported at the April, 1956 American Physical Society meeting in Washington, D. C. and an abstract is published in the Bull. Am. Phys. Soc. Series II, vol. 1, No. 4, p. 202.

A study was made of the vapor effusing from tantalum Knudsen cells containing ZrO_2 and Zr-ZrO_2 mixtures. In both cases, the major gaseous species was the ZrO molecule. Copious amounts of TaO vapor were also found in both cases as were minor amounts of ZrO_2 and Zr . Thermodynamic treatment of the data on Zr , ZrO and ZrO_2 vapor yielded the following heats of reaction:

$$\Delta H(2000^\circ\text{K}) = -17 \pm 5 \text{ kcal/mole for the reaction } \text{Zr(g)} + \text{ZrO}_2(\text{g}) \rightarrow 2\text{ZrO(g)}.$$

$$\Delta H(2300^\circ\text{K}) = 155 \pm 8 \text{ kcal/mole for the reaction } 1/2 \text{ Zr(s)} + \\ + 1/2 \text{ ZrO}_2(\text{s}) \rightarrow \text{ZrO(g)}.$$

The dissociation energy of ZrO is then calculated to be 184 kcal/mole or 8.0 ev. This work will also be reported at the April 1956 American Physical Society meeting in Washington, D. C. and an abstract is published in the Bull. Am. Phys. Soc. Series II, vol. 1, No. 4, p. 202.

A study of the molecular species evaporating from solid V_2O_5 has been started. The preliminary results indicate that V_4O_{10} is the major gaseous species present. Work on this system is continuing.

A preliminary study of the species evaporating from solid ThO_2 indicates that both ThO and ThO_2 molecules are present in the vapor. This study is continuing.

34-9 A⁴⁰-K⁴⁰ Dating of Meteorites (5220)

Johanness Geiss (Fermi Institute) and David C. Hess
Reported by David C. Hess
(Formerly entitled Argon Age Determinations. The
last report, II-34-8, appeared in ANL 5420).

The now widely used argon-potassium method of dating will be applied to a number of meteorites to attempt to find samples of different ages. The work done previously in this laboratory ^{1,2} indicated only ages in excess of 4.5×10^9 years. Other experimenters report some younger samples. ³

Some modification is being made in the techniques previously used. The samples are heated in a nickel crucible by R.F. induction. This allows sample processing to proceed at a temperature of 1200°C or higher. Thus some measurements can be made by high temperature outgassing without the use of a flux.

Preliminary results on the Holbrooke meteorite give an age in agreement with that reported by Wasserburg, Hayden and Jenkins ².

35-7 (Study of Negative Field Emission) (5220)

Mark G. Inghram

This project has been discontinued.

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1. G. J. Wasserburg, R. J. Hayden, Phys. Rev. 97, 86-87 (1955).
 2. G. J. Wasserburg, R. J. Hayden, K. Jensen, private communication
 3. E. K. Gerling, K. G. Rik, Doklady. Akad. Nauk. SSSR, 101, 433-35 (1955).

36-7 Field Emission Studies (5230)

Mark G. Inghram and R. Gomer (U. of Chicago)
Reported by Mark G. Inghram

The equipment being used for field emission studies is being rebuilt in order to allow operation of the "tip" at any temperature at or above that of liquid helium. With this versatility we should be able to obtain quantitative data on chemisorption.

37-3 Ion Bombardment of a Solid Target (5220)

Henry Stanton

The work on the yield of ions from a solid target under bombardment by various types of projectile ions has continued with the installation of a solid beryllium target in mass spectrometer MA-17.

The target was provided with a small heater and a second resistive element to give a rough idea of its temperature. Observations were made using various gases in the auxiliary ion source which supplied the bombarding projectile and with the target at various temperatures between room temperature and approximately 240° C. Intensities of mass peaks were observed from mass 9 (the atomic weight of the target) through mass 18, thereby including the water group and hydrocarbons of lower atomic weights.

The machine was also provided with an extra filament so arranged that ions could be produced in the target chamber close to the target to permit analysis of the background gases. This source of ions will be

referred to as the "gas source". For the beryllium target at room temperature, Figure 16 shows the differences in the yields of different ionic species when the bombardment source is used and when the gas source is used. The two typical mass spectra shown cannot be directly compared for the different sources, since the yield from the gas source is generally two orders of magnitude greater than the maximum possible yields under bombardment conditions. The curves have been normalized for convenience.

One notes, however, that there are no spurious mass peaks at masses 9, 10, 11 in the machine background. Mass position 11 has no peak under any of the conditions used in the study, but the production of appreciable quantities of ions of mass 9 and 10 under bombardment is evident. The first is attributed to Be^+ being driven out of the target under ion bombardment and the second to BeH^+ whose origin has not yet been determined. Although no great accuracy is claimed for the relative peak heights under a given set of experimental conditions, it appears likely that under ion bombardment there is considerable preferential discrimination against the "water ions" of masses 16, 17 and 18 in comparison with the hydrocarbon ions of masses 12 to 15, inclusive.

It is, however, evident from Figure 16 that in some instances background peaks are larger than the Be peak. This would lead to difficulties (as noted in previous reports) in using the method to analyze for materials in the midst of a hydrocarbon background.

In the hope of reducing the sizes of these peaks relative to

FIGURE 16

the beryllium peak, the target was heated with the auxiliary heater mentioned earlier. As the temperature increased, runs were made using only ion bombardment. As the temperature was raised from room temperature to about 125° C the BeH^+ peak decreased by a factor of 5 or more, the hydrocarbon peaks remained the same (or occasionally diminished somewhat).

Much of this background may have come from gases occluded in the target, because after 3 days of target heating at about 130° C all the background peaks examined had decreased by about two orders of magnitude so that the Be^+ peak was almost 5 times as great as any of the others. The target temperature was then increased to 240° C and this effected a marked additional decrease in the hydrocarbon peaks relative to the Be^+ peak. This is shown in Figure 17. One notes that the peaks at masses 16 and 17 were reduced also in going to the higher temperature, whereas the peak at mass 18 increased. (One may suspect that hydrocarbon components at masses 16 and 17 partially explain this result since CH_5^+ is known to exist.)

Effects of the Mass of the Bombarding Ion.

The yield of Be^+ ions was determined as a function of the mass of the bombarding ions. The gases used were the chemically inactive noble gases (except neon) and the two reactive gases, air and CO.

For the lighter gases, the yield of ions from the target per unit of bombarding current increased with pressure at low pressures, passed through a maximum at about 6×10^{-7} m m Hg, and then decreased

TARGET TEMP.

133°C

240°C

RELATIVE PEAK HEIGHT

FIGURE 17

slowly at higher pressures. For the heavy gases Kr and Xe, no maximum appeared probably because the background pressure in the machine ($\sim 10^{-7}$ m m Hg) was too high. The energy of the bombarding ions was maintained throughout these experiments at the constant value of 540 ev.

At a fixed gas pressure (as measured in an ion gauge), the yield of Be^+ ions was measured for each gas used. This is shown in Figure 18, where the atomic or molecular weight of the ion is used as abscissa. The two curves correspond to two different pressures in the region of the source.

The yield of Be^+ appears to be higher for bombarding ions of lower mass (such as He and air) and falls off smoothly with increasing mass number. This apparent dependence in mass number in the case of Be is different from the results of earlier experiments on the emission from Pb under ion bombardment, in which little if any dependence on ionic mass was found.

38-1

Mass Spectrometric Study of Charged Atomic and Molecular
Products of Nuclear Transformations

(5230)

David C. Hess and Sol Wexler
Reported by Sol Wexler

A study of the charged atomic and molecular species formed in various nuclear decay reactions is being planned. The experiment will involve charge and mass analysis of the products from the decay of radioactive gases at low pressure in the source volume of a modified 60° wedge

FIGURE 18

mass spectrometer. The results of measurements on monatomic gases will provide interesting experimental checks on theoretical predictions with respect to relative probabilities of formation of ions of various charges in β^- , β^+ and α -emission, isomeric transition by internal conversion, and K-electron capture. Studies on the molecular fragments formed in the decay of active atoms incorporated in molecules will indicate modes of molecular disruption and may give an insight into the process of internal charge transfer.

The mass analyser planned is a 60° wedge direction-focussing spectrometer. Among its distinguishing features will be a strong differential pumping system. Four stages of pumping are called for to minimize the background of the detector due to radioactive decay of atoms which have found their way into the electron multiplier. In addition, the repeller, extraction and focussing electrodes will be designed to maximize the transmission to the detector of ions formed in the source volume. The active gas will be circulated through the apparatus.

During this period the frame, tube and differential pumping system of the spectrometer were designed and constructed. Drawings of the large cold traps were made and shop work on these is nearly finished. Modifications of the electron multiplier and detector focussing system salvaged from MA-15 were made. Details of the clamps for the tube and pumps were decided upon, and these are almost done. The magnet and its carriage are under construction. Two 450 ℓ / sec metal Hg-diffusion pumps were received and altered to fit gold gaskets.

An electric analogue was set up to study various ion optic lens

systems, the purpose being to select an electric field which will transmit the largest fraction of ions through the spectrometer.

V. THEORETICAL PHYSICS, GENERAL

1-11 (The Interpretation of the Energy States of Light Nuclei)
(5220)

David R. Inglis

There is nothing to report on this program.

2-11 Excited States of Light Nuclei (5220)

Dieter Kurath

The probabilities for radiative transitions by magnetic dipole and electric quadrupole radiation are being computed on the AVIDAC for nuclei in the 1p-shell. A model involving spin-orbit coupling of intermediate strength is used to obtain the nuclear wave functions. Results have been obtained for transitions in Be^8 , C^{12} and B^{11} that have been observed experimentally.

In comparing the Be^8 results with the transition width observed in the $\text{Li}^7(p, \gamma) \text{Be}^{8*}$ reaction, agreement for the total width is reached at a somewhat higher value of the spin-orbit coupling parameter, a/K , than is obtained from matching observed and calculated energy level schemes. A further comparison can be obtained by using the somewhat doubtful experimental branching ratio for the two gamma rays involved. Here the 17.6-Mev M1 transition to the ground state gives a value of a/K which is nearly the same as that determined from the comparison of level schemes. However, the mixed M1 and E2 transition to the first excited state is computed to be too slow, as is shown in

Figure 19.

In C^{12} a similar mixed M1 and E2 transition is again too slow, this time by an order of magnitude, but here the experimental evidence is much poorer. The computed value of the E2 transition from the first excited state at 4.4 Mev is of the right order of magnitude, but is too slow by a factor of two and does not vary much with the parameter a/K . Calculation of E2 transition probabilities is much less reliable than for M1 because they depend on the quantity, $\langle r^2 \rangle$, which can be estimated only approximately. They are also likely to be strongly influenced by small cooperative effects of the Bohr-Mottelson type which were not computed.

In B^{11} , comparison with the $Li^7(\alpha, \gamma) B^{11*}$ resonances enables one to pick out one of the three resonances as a $5/2^-$ state and suggests possible spin assignments for the levels as shown in Figure 20.

3-1 Dynamics of Nuclear Collective Motion (5220)

David R. Inglis

The model known as the "cranked model", in which the potential defining the nucleon wave functions of a deformed nucleus is constrained to rotate, gives the interesting result that the moment of inertia has the rigid-rotation value for a deformation caused by a few open-shell nucleons, and the irrotational flow result of the droplet model for an imposed distortion of closed shells.¹ These earlier results depend on the use of harmonic oscillator wave functions with their characteristic

1. D. R. Inglis, Phys. Rev. 96, 1059 (1954); 97, 701, (1955); A. Bohr and B. Mottelson, Kgl. Danske Videnskab. Selskab. 30, Nr. 1 (1955).

GAMMA TRANSITION WIDTHS FOR $\text{Li}^7(p,\gamma)\text{Be}^{8*}$ RESONANCE

FIGURE 19

GAMMA TRANSITIONS IN B^{11}
 FROM $Li^7(\alpha, \gamma)$ RESONANCES
 (From AJZENBERG & LAURITSEN)

FIGURE 20

PHG-994
 4-10-56
 B.G.

9400

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states of spin 2, which correspond to surface vibrations of the nucleus. It is perhaps doubtful if the first excited state of carbon is in fact a surface vibration. However, if it can be described by this model, this mathematical analysis of the scattering can be made.

So far, the theory has only been done in the Born approximation. It turns out that indeed the polarization of the inelastically scattered protons is very different from those scattered elastically. At angles at which the elastically scattered protons have minimum cross-section, the inelastically scattered protons have maximum cross-section.

A more careful calculation, expanding the proton beams in spherical harmonics, is very complicated for inelastic scattering in even this simple model. The calculation has been deferred at present until the effect has been definitely established experimentally.

8-1 Double K-Capture (5220)

Maria Goeppert Mayer

Madansky at Johns Hopkins intends to try to measure double K-capture from Cd^{106} to Pd^{106} . In this case, the intermediate nucleus Ag^{106} decays both by β^+ and β^- emission. Both transitions are allowed and have a low ft value. There are, then, enough empirical data available to make a numerical calculation. If the neutrino is a Dirac particle, the lifetime of Cd^{106} is of the order of 10^{23} years,

which is probably much too long to be measurable. If the neutrino is a Majorana particle--which most people do not believe--double K-capture would not occur, but instead one electron would be captured and a positron would be emitted with the entire energy available in the transformation.

10-7 The Effect of Inelastic Scattering in the Analysis of
Scattering Resonances (5220)

James E. Monahan, F. Paul Mooring and Sol Raboy
 Reported by James E. Monahan

A measurement of the relative γ -ray yield from $\text{Na}(n, n'\gamma) \text{Na}$ at angles of 40° and 90° has been carried out for a range of neutron energies from 440 kev to 880 kev. There is definite anisotropy in the neighborhood of 650 kev and an indication of anisotropy in the region from 750 kev to 800 kev. This definitely rules out the assignment $1/2$ for the spin of the 470-kev level of Na^{23} .

The contribution of slow neutrons to the yield of γ rays from the $\text{B}^{10}(n, \alpha) \text{Li}^{7*}$ reaction was determined by two independent experiments: one giving a lower limit of 10%, the other an upper limit of 25% of the total yield from this reaction. Since an error of 50% was ascribed previously to the cross section for the $\text{B}^{10}(n, \alpha) \text{Li}^{7*}$ reaction, used as a standard, this additional error has very little effect on the results previously quoted.

12-4

Investigation of Neutron Scattering under the Feshbach-
Porter-Weisskopf Model of the Nucleus

Morton Hamermesh and Jack Sokoloff
Reported by Jack Sokoloff

Both the square well code and the harmonic oscillator code have been completely debugged. A survey has been made of the square well for the 42-Mev potential mentioned in the last quarterly report; and during the past quarter the survey has been extended to 20-Mev and 30-Mev well depths with the parameters $\zeta = 0.03, 0.07, 0.1, 0.3$ in the neutron energy range from $E = 0.06$ -1.5 Mev. The theoretical curves have been compared with the preliminary neutron angular distribution data of Langsdorf and Lane. The agreement between theoretical and experimental curves does not seem good enough to determine a "best fit".

A study was undertaken to determine the effect of ζ , the so-called absorption parameter, in the FPW formalism. It was ascertained, among other things, that there does not appear to be a natural bound on ζ and that very large values of ζ yielded hard-sphere scattering rather than black-nucleus scattering. Plots of σ_t and σ_c for fixed nuclei, potential depth, and energy vs. $\ln \zeta$, where ζ ranged from 0.001 to 10, did not yield a "best fit" for ζ . However, they did illustrate very clearly the hard-sphere limit for large ζ , i.e., $\lim_{\zeta \rightarrow \infty} \sigma_c = 0$. The curves were plotted for both square well and harmonic oscillator potentials.

Attention was then fixed on the data of Walt and Barschall¹ at 1 Mev, since their data are for elastic scattering and are therefore more adaptable to comparison with the FPW formalism than the data of Langsdorf and Lane, which give the angular distribution of both elastically and inelastically scattered neutrons. The results, again, are not conclusive enough to establish a "best fit".

We have now taken a new tack. We are going to try to fit the coefficients in the Legendre Polynomial expansion of the differential cross sections. These have already been calculated from the experimental data of Langsdorf and Lane. The code for the calculation of the theoretical expansion coefficients is in the final debugging stage.

Going outside the FPW formalism, we have carried through a variational calculation which gives the phase shifts, of all orders, in closed form. This calculation will be included in the final report.

14-1

Analysis of the (d,p) Reactions*

(5220)

B. James Raz and J. Bruce French (University of Rochester)

Reported by B. James Raz

By examining the results of the (d,p) reaction in the calcium isotopes, we are able to compute certain amplitudes in the nuclear wave functions. These computations indicate that the Ca isotopes have a coupling scheme very close to the jj limit with only small con-

1. M. Walt and H. H. Barschall, Phys. Rev. 93, 1062 (1954).

* This is the continuation of work started at the University of Rochester.

A paper entitled "Analysis of (d,p) Reactions in Calcium Isotopes" will be given at the Washington Meeting of the Physical Society and a full report of the work will be submitted shortly for publication.

Norbert Rosenzweig

$$R(N, Q) = \frac{e^{\pi \sqrt{(2/3)Q} \rho(\epsilon_0)}}{\sqrt{48} Q} \quad (1)$$

1. H. A. Bethe, *Phys. Rev.* 50, 332 (1936).

2. C. Van Lier and G. E. Uhlenbeck, *Physica* **4**, 531 (1937).

* $\rho(\epsilon_0)$ is the individual particle level density at the Fermi level ϵ_0 .

has also been given by C. Bloch³. The assumptions underlying the last two derivations are that (a) the Darwin-Fowler integral can be evaluated with sufficient accuracy by the saddle point method, (b) the individual particle levels may be represented by a continuous density function such that the sums over the discrete levels may be replaced by integrals, (c) for degenerate systems the integrals may be approximated by the first two terms of Sommerfeld's asymptotic expansion and (d) the saddle point is assumed to lie "sufficiently close to the location it would have for the ground state of the system" so that certain quantities which arise in the course of the derivation may be treated as negligibly small.

The assumptions (a), (c) and (d) are not unrelated, and it is therefore desirable to know the conditions under which they are simultaneously valid. For example, (a) and (d) may be incompatible if the system is too close to its ground state. Another question which requires clarification is whether assumption (d) is a consequence of (c) or whether (d) is an approximation which requires still higher degeneracy. During the last few months we have attempted to answer the above and related questions by studying the individual-particle level-density functions which obey a power law:

$$\rho_n(\epsilon) = k^n \epsilon^{n-1} \quad (2)$$

That class of functions is chosen because the calculations can be carried

3. C. Bloch, Phys. Rev. 93, 1094 (1954).

out for all values of the degeneration parameter α .

The main conclusions and results to date are these: (A)

For high degeneracies the level density may be expressed as a series of inverse powers of α^2 of which Formula (1) is the constant term. It is shown that the quantities which are neglected under assumption (d) are of order $1/\alpha^2$ and higher. However, it is also shown that, as a rule, three terms must be retained in the Sommerfeld asymptotic series in order to get a result which is correct to $1/\alpha^2$. Therefore, (d) is generally not a separate assumption but is implied by (c). (B) The exceptional case arises if the entire Sommerfeld series consists of only two terms, for example if $n = 1, 2$. The level-density formula will then have an unusual range of validity. (C) The series expansion for the level-density formula has been worked out explicitly to order $1/\alpha^2$ for any n . Thus, a formula for intermediate degeneracy is given and a criterion for the validity of the simple Formula (1) is established. (D) The conditions for the compatibility of assumptions (a) and (c) have also been derived.

34-11

(Quantized Space Time)

(5230)

Robert H. Bryan and Katsumi Tanaka
Reported by Robert H. Bryan

Reporting on this program will be discontinued until such time as there is significant progress to report.

43-7 The S-Matrix (5230)

Hans Ekstein and Katsumi Tanaka
Reported by Katsumi Tanaka

An abstract entitled "Insensitivity of the Scattering Matrix" has been presented at the 1956 Annual Meeting of the American Physical Society in New York City.

44-4 The Tamm-Dancoff Method (5210)

James C. Swihart and Katsumi Tanaka
Reported by James C. Swihart

A new approach to pion-nucleon scattering using the non-linear integral equation given by Ekstein has been studied. For a suitable approximation to the physical nucleon state that is needed to solve the integral equation, we do not use the customary perturbation or Tamm-Dancoff method but rather a modified particle representation related to the New Tamm-Dancoff method. The outstanding difference is that the particles are superimposed on the real vacuum and not on the bare vacuum.

In the fixed source limit and after renormalization, we find in the lowest approximation the modified Born approximation term of Chew and Low.

A paper on this work entitled, "Pion-Nucleon Scattering in a Modified Particle Representation" was given at the Midwest Conference on Theoretical Physics at Iowa City.

Y. Nambu (University of Chicago) and Katsumi Tanaka
Reported by Katsumi Tanaka

We have used the method given by Castillejo, Dalitz and Dyson (Phys. Rev. 101, 453, (1956)) in order to solve the Low equation for the Lee Model and meson pair theory. They have solved the Low equation for the neutral scalar and charged scalar meson theories and found an infinite number of solutions. We also found an infinite number of solutions for the cases above, as expected.

While solving the Low equation, we further found that the Lee model violates the condition of causality. This may be one reason why a ghost state appeared in the Lee model.

The additional pole pointed out by G. Feldman [Proc. Roy. Soc. A 223, 112, (1954)] that may appear in the modified propagator of the nucleon due to iteration of self-energy diagrams, is identical to the root that gave rise to the ghost state. That is

$$S'_{F1} = \frac{1}{Z_2} \quad S'_F = \frac{1}{Z_2} \quad \frac{1}{p_0 - m - \Sigma(p_0) + Sm} = \frac{1}{h(p_0 - m)} \quad , \quad (1)$$

where

$$h(p_0 - m) = (p_0 - m) \left[1 + g^2 \sum_k \frac{(p_0 - m) f^2(k)}{2\Omega\omega^3 (\omega - p_0 + m)} \right] \quad (2)$$

S'_{F1}	=	finite part of the modified propagator
Z_2	=	renormalization constant
g	=	renormalized coupling constant
$f(k)$	=	cut-off function

If $g^2 < g_{\text{crit}}^2 = \left[\sum_k \frac{f^2(k)}{2\Omega\omega^3} \right]^{-1}$, then equation (2) has exactly two

roots, namely $p_0 - m = 0$ and an extra root for $(p_0 - m) < \mu$, the latter giving the ghost state. The existence of this additional pole in S'_{F1} , makes it clear that the Lee model violates the condition of causality.

For the meson pair theory, we found a different kind of singularity which is due to the ambiguity in defining the renormalized coupling constant.

46-1 Scattering of Pions by Complex Nuclei (5210)

Melvin Ferentz and Morton Hamermesh
Reported by Melvin Ferentz

In a recent paper, Mitin and Grigorev¹ reported on measurements of the distributions in energy and angle of 300-Mev negative pions scattered by complex nuclei in emulsions. The angular distribution shows sharp peaking in both the forward and backward directions while the energy spectrum is peaked at 75 Mev. In an attempt to explain these results we are doing a calculation on the AVIDAC.

1. N. A. Mitin and E. L. Grigorev, Dokl. Akad. Nauk SSSR, 103, 219 (1955).

We assume the mechanism of energy loss is elastic scattering of the pions by individual nucleons inside the nucleus. The nucleons are taken to be a degenerate Fermi gas and the scattering cross sections used are those given by Gell-Mann and Watson² for a single resonance fit to the pion-proton scattering data.

Having calculated the scattering of 3952 pions on the AVIDAC, we find that the fit to experiment is poor, there being too much energy loss, no forward peaking and too little backward peaking. It seems as if the calculations would fit the experiment if for some reason the cross sections inside the nucleus were significantly lower than those for free nucleons. The Pauli principle's reduction of the cross section, which is included in our calculations, is not nearly large enough to account for the discrepancy.

2. M. Gell-Mann and K. M. Watson, Annual Reviews of Nuclear Science 4, 219 (1954).

VII. ELECTRONIC DIGITAL COMPUTERS

2-11

The AVIDAC

Joseph M. Cook, Donald A. Flanders, Burton S. Garbow,
Herbert L. Gray, Willard S. Greenhow, Jean F. Hall,
Charles Harrison Jr., Howard E. House, Loretta I. Kassel,
Richard F. King, Eleanore M. McNulty, William F. Miller,
Diana P. Satkus, William J. Schnoebelen, Anthony J. Strecok
Reported by Jean F. Hall

Computations continued on many of the programs mentioned in previous reports.

A new program for the analysis of neutron-chopper data was developed. The input to the AVIDAC comes in the form of punched paper tape prepared directly by recording equipment associated with the chopper. The tape can be read directly by the AVIDAC. It is proposed that later modifications of this program of data analysis should enable the AVIDAC to detect and reject input data which indicate malfunction of the recording equipment.

A table approximating the efficiency of gamma ray detection by sodium iodide crystals of various configurations was computed.

A computation of the efficiency of alpha-particle detection in a certain gaseous scintillation chamber was done by a direct Monte Carlo model of the physical situation. Expressed analytically, the computation would have required the evaluation of an integral over five dimensions and would have consumed huge amounts of machine time. Two distributions of alpha emitters within the chamber were considered.

A least-squares calculation of thermal conductivities was done for the metallurgists.

Another least-squares analysis concerned the diffusion of smoke in a plume. The data giving the boundaries of plumes with respect to the distance from the source are taken from photographs. It appears that the functional form assumed for the least-squares analysis required more accuracy in the measurements than is available.

A table of transformations of elastic-scattering data from the Laboratory System to the Center of Mass System was calculated. This was done for about twelve different elements.

Computations were started on a table concerned with bubbles at the tip of a capillary tube. The surface tension of the bubble is tabulated as a function of radius, density of the medium, and the pressure required to blow the bubble. This computation is expected to require several hundred hours on the AVIDAC.

A new program for the analysis of Borax data was developed.

VIII. APPLIED MATHEMATICS AND COMPUTATION,
GENERAL

13-6 REAC Problems

Nye F. Morehouse

The solution of problems of fast-reactor kinetics on the REAC has been made possible with the use of a fast integrator constructed by the Electronics Division. Currently, a variety of pile-kinetics problems are being run for the Reactor Engineering Division.