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FOREWORD

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

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

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

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

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

I. EXPERIMENTAL NUCLEAR PHYSICS

1-14 The Argonne Fast Neutron Velocity Selector (5220)

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

The two uranium sections of the new rotor have been finished and considerable progress has been made on the slits in the monel piece which will enclose the uranium. In order to maintain the required accuracy and to keep the cutting speed as high as possible, a special electrode support was made so that the slits could be cut from the inside as well as from the outside. Using this and the standard support, the slits have been roughed out to a depth of about 1/2" from each side.

Many of the other parts which can be machined by standard techniques have been finished.

Weather conditions have hampered the completion of the flight tube to the detector station 120 meters from the chopper. The supports are all in place and all parts of the tube are completed and awaiting final assembly. The detector station at 120 m has been completed except for some final electrical work and the installation of the air conditioner.

2-14 Neutron Detectors (5220)

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

The investigation of the neutron-detection characteristics of silver-activated zinc sulfide in fused anhydrous boric oxide has produced no re-

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heart of the experiment is shown in Fig. 1. A current I of neutrons from the fast chopper (turning slowly) impinges on a metallic foil of the fission-

Fig. 1. Detection system for an absolute measurement of the fission cross section. To reduce the loss of neutrons through scattering, the air has been replaced by an argon atmosphere in the flight path between the fission chamber and the γ -ray counting system.

able material being studied. The foil should be thin enough to transmit most of the incident neutrons and yet thick enough to be easily weighed. The rate of occurrence of fission R_f is then $n\sigma_f I$, where n is the sample thickness in atoms per unit area. Thus a measurement of R_f and I as a function of neutron energy gives an absolute value of σ_f as a function of energy.

The rate R_f is measured by detecting fission neutrons in the pair of large liquid scintillators shown in the figure. It has been

shown in previous experiments that a fission event is detected with high efficiency and that the background rate is small if coincident pulses from the two counters are required. The conventional fission chamber which is directly in front of the foil being studied is used to determine the probability of obtaining this coincidence when a fission occurs. This measurement is made by observing the fraction of counts in the fission chamber which are coincident with a count from the liquid system.

The current of neutrons that passes through the foil, and hence the current incident on the foil, is measured in a similar way by the set of detectors about 120 cm behind the fissile foil. The neutron beam passes through a thin B^{10} foil in an ionization chamber and into a thick slab of B^{10} . Here essentially all of them are absorbed in the reaction $B^{10}(n, \alpha)Li^7$ and the rate of absorption is measured by detecting the resulting 481-keV γ -ray with a NaI scintillator. The efficiency of the NaI counter for detecting the capture of a neutron is again determined by a coincidence method; it consists of measuring the fraction of those neutrons giving a count in the ionization chamber which also cause a count in the NaI detector.

To avoid errors due to instrumental instability, the six counting rates required to determine the fission cross section were recorded simultaneously. The rates from the fission neutron detection system and from the NaI detector were recorded as functions of flight time in the 1024-channel analyser. For the other rates, only the total counts received were recorded.

This new method was used to measure the fission cross section of U^{235} . The experiment consisted of a series of runs for three different sets of experimental conditions. The laborious calculations required to obtain a final value for the cross sections are now in progress. Preliminary results are somewhat higher than the generally accepted value of 582 barns. It is believed that the error for our final value will be about 0.5% as compared to a 2% uncertainty in previous measurements.

b) MEASUREMENT OF η/ν FOR U^{235}

The methods for measuring η/ν which were described previously in connection with experiments on Pu^{239} have now been used with U^{235} . The measurements cover the range of energy from 0.01 ev to about 50 ev. For the upper part of this range, the resolution of the system was about 0.1μ sec/meter. The data obtained are now being analysed.

4-2 Mass Distribution in Fission (5220)

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

The problem of making a large plastic foil coated with uranium has been solved. Uranium metal is evaporated upon the plastic film, the latter being mounted on a glass plate. After the evaporation process the film is loosened from the glass and mounted upon the collimator.¹ The very pure U^{235} metal for this purpose will be prepared in Los Alamos. Use of this very pure U^{235} in the film for the large counter is necessary to avoid the high background of alpha particles from the 1% of U^{238} which is present in ordinary U^{235} .

In the meantime another approach to the problem was made. By means of adequate filters in the neutron beam, attempts are made to isolate the various resonances in the material being studied. A counter, to be described later, gives two pulses, v_1 and v_2 . The ratio $v_1 / (v_1 + v_2)$ is converted into a time, which is fed into the time analyzer.

The counter used in this experiment has been constructed at the Physical Laboratory of the University of Amsterdam. This again, is a double, back-to-back Frisch-grid ionization chamber. The grid consists

¹ P. Barreau, et al., J. Phys. et Radium 15, 4A

of copper wires of 0.013-cm diameter, spaced 0.188 cm apart. The distances from the collector and the source to this grid are 1 cm and 7.5 cm, respectively.

Another counter will be used for the U^{233} measurements. This one was constructed in this laboratory and has a grid consisting of 2-mil diameter wire spaced at 0.080 in. The distance between collector and grid is 1 in. and that between grid and source is 2 in.

With the first counter, a collimator was used consisting of two Al plates 1 mm thick with 1 mm holes. The foil is mounted between the two plates. The uranium film was $115 \mu\text{g}/\text{cm}^2$. This collimator had the disadvantage that 10% of the pulses emerging from it were distorted because of fission fragments passing through the edges of the holes.

This number has been greatly reduced by using two brass collimators $1/32$ in thick with holes of $1/8$ in diameter. The foil used with this collimator has a thickness of $12.5 \mu\text{g}/\text{cm}$.

A study will be undertaken of the dependence of properties of these counters on foil thicknesses, collimator dimensions, voltages and pressure.

6-13 Spiral Velocity Selector for Slow Neutrons (5220)

Rauf Nasuhoglu and Roy Ringo
Reported by Roy Ringo

The helical velocity selector for neutrons has been used in a series of cross-section measurements on hydrogenous liquids in the neutron wavelength range of 10 to 30 Å. The results are not yet analyzed.

Other preliminary results indicate that the selector will be useful for measurements of small-angle scattering.

8-2 Fission Yield at Different Neutron Absorption Resonances (5220)

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

The measurement of the fission yield of U^{235} at different resonances was undertaken by irradiating samples of U^{235} with monoergic neutrons from the crystal spectrometer. The energies used corresponded to the 1.1, 3.2, 3.6, and 9-ev. resonances. The chemical analysis is not completed as yet.

There was sufficient neutron intensity, however, to allow analysis of Cd activities in the minimum of the fission-yield curve.

11-14 Installation and Operation of the Van de Graaff Generator (5220)

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

This report covers the operation of the Van de Graaff Generator in D-203 for the period January 2, 1957 to March 28, 1957.

The generator was used to accelerate protons, deuterons and alpha particles.

The following time distribution shows both the division of time and the types of experiments being performed with the Van de Graaff generator by the group. No effort has been made to show any efficiency factor for the time allotted to the various experimenters. These are actual running times of the generator for the different experiments. For details of results of each experiment see the individual reports of the experimenters.

1. Neutron Spectra by Time of Flight	Holland	157.4 hours
2. Studies of Angular Correlation	Hanna, Lee Schiffer	13.3
3. Measurements of Proton Strength Functions	Lee,	
Angular Distribution of Protons	Schiffer	212.0

4. Total Neutron Cross Sections	Hibdon	70.7
5. Proportional Counter	Perlow	4.9
6. Calibration of Counter	Smith	3.9
7. Angular Distribution of γ -rays	Hanna, Meyer	223.1
8. Photo-Fission Cross Sections of the Heavy Elements	Clark	90.2
9. Tests of Beam Squeezer	Lane	8.0
10. Alignment of 90° Analyzer		6.6
		<hr/>
		790.1 hours
Time available		1122.0
Start-up and daily maintenance		43.0
Machine repairs and changes		200.0
Experimental setup time		88.9

The new electronic control circuit for the analyzing magnet has been delivered and installed. No data on its operation are available as yet.

During this quarter, the two major losses of time on the Van de Graaff Generator were for work on (1) the Belt Tightener, and (2) the Focus Supply of the Ion Source.

The other sources of trouble and loss of time were minor such as changes in the ion source, changes of gas in the ion source, broken wires in the corona system, and disconnected hoops.

Much effort has gone into improving the target assemblies and their mountings so as to cut the time required to set up a facility for the different experiments being performed with the Van de Graaff Generator.

Additional space has been requested for experimental equipment. If it is obtained, it should enable the experimenters to use their limited machine time more efficiently.

13-1 Instrumentation for Time-of-Flight Neutron Spectrometer
(5220)

Robert Holland and Frank J. Lynch
Reported by Frank J. Lynch

This instrument must measure the time between a burst of charged particles striking a thin target and the scintillation which a neutron from the target produces in a plastic scintillator at a measured distance from the target.

A. TIME-TO-PULSE-HEIGHT CONVERTER

A second time-to-pulse-height converter of the Los Alamos type¹ has been built. It was modified somewhat to improve the linearity, and an output amplifier was added to feed directly into the 256-channel analyser. In an effort to reduce the dependence of the time delay of the "start integration" pulse upon the height of the input pulse, the "long-tailed-pair" preceding the start-pulse generator was replaced, first by a fast univibrator, second by a cathode follower which served as a limiter, and third by a high-gain pentode which limited the output when operated at low plate voltage. These changes did not reduce the time jitter.

B. TIME-INTERVAL VERNIER

Work has been started on a time-interval vernier^{2, 3} which should be superior to the above instrument in regard to time jitter, linearity,

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

² Lefevre and Russell, Nuclear Physics Quarterly Report, Hanford Laboratories Operation, Richland, Wash., July, Aug., Sept., 1956.

³ Millman and Taub, Pulse and Digital Circuits, (McGraw Hill, New York, 1956), pp. 509-513.

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and stability. In this device, the pulse from the neutron detector is stored and circulated in a coaxial loop driven by an EFP-60 univibrator, until a coincidence occurs with a repetitive timing pulse. The time required for the stored pulse to make one transit around the coaxial loop is shorter than the period of the timing pulses by one part in 256. Each transit of the stored pulse around the loop delivers one pulse to the address scaler of the 256-channel analyser, and advances it one channel. So far, we have produced stored pulses with amplitudes of about 50 volts in a load of 60 ohms. Their rise time was about 2 mμsec and their duration was about 6 mμsec. The coincidence and gate circuits have not been developed.

14-13

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

Robert E. Holland

Additional data have been taken on the neutron groups from ^{55}Mn (p,n) ^{55}Fe by the method described in the last quarterly report. In this case, an effort was made to increase the accuracy of the measurements by more careful calibration of the converter circuit and by accurate measurements of the distance.

After subtraction of background, the spectrum in Fig. 2 was obtained with a proton energy of 3.26 Mev and a detector distance of

112cm. Five neutron groups are evident in this data, corresponding to excited states of ^{55}Fe .

Neutron groups D and E have not been resolved previously,¹ but the existence of the doublet has been inferred from resonance transmission data.² Preliminary

results of measurements of Q for these groups are given in Table I,

together with data obtained by other methods. The values given under "Time of Flight" are averages of several measurements at several

Fig. 2. Spectrum of neutrons from $^{55}\text{Mn}(p,n)^{55}\text{Fe}$.

Table I. States of ^{55}Fe

$^{55}\text{Mn}(p,n)^{55}\text{Fe}$	^{55}Fe	$^{54}\text{Fe}(d,p)^{55}\text{Fe}$	^{55}Co β -decay
Time of Flight	Mooring and Lee ²	Sperduto and Buechner ³	Caird and Mitchell ⁴
A ground state	ground state	ground state	ground state
B 390 ± 50	436	413	-
C 890 ± 40	927	932	935
D 1280 ± 40	1314	1302	-
E 1360 ± 40	1406	(?)	1410

¹ Stelson and Preston, Phys. Rev. 82, 655 (1951).

² F. P. Mooring and L. L. Lee, Jr., ANL-5609 and ANL-5667.

³ A. Sperduto and W. W. Buechner, Bull. Am. Phys. Soc. Series II, 1, 223 (1956).

⁴ Caird and Mitchell, Phys. Rev. 94, 412 (1954).

bombarding energies, and the errors are the rms deviations of these measurements from the means. It is interesting that data from the β -decay of Co^{55} do not show either the 420-kev state or the 1310-kev state, both of which are seen in $\text{Mn}^{55}(\text{p},\text{n})\text{Fe}^{55}$ and in $\text{Fe}^{54}(\text{d},\text{p})\text{Fe}^{55}$. The report by Sperduto and Buechner does not state whether they observed the upper state of the doublet or not. Angular distributions were taken on the neutrons from transitions to these states at a bombarding energy of 3.07 Mev. Although these data have not been analyzed, there is no indication of a strong forward peak which would be indicative of direct interaction.

15-10 Stopping Cross Sections of Gases for Heavy Ions (5230)

Merle T. Burgy

Work on the project was stopped early in the past quarter to engage in another experiment. It is hoped that time can be found in the succeeding quarter to prepare a final report on this project.

18-5 Differential Cross Sections for Neutron Resonance Scattering
(5220)

Raymond O. Lane

The new revisions and additions to the apparatus to measure the angular distribution of the resonance scattering of neutrons have been completed. Tests show that the second bending magnet as well as the strong-focusing magnetic lens will give better experimental flexibility with considerably higher usable proton currents. Several new scattering samples have been canned in preparation for experiments on the spin-dependence of potential scattering.

The Monte Carlo calculation of multiple scattering near resonances is being programmed for the AVIDAC.

20-14 Energy States of Light Nuclei from Charged Particle Reactions
(5220)

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

Design work is continuing on an improved track and a new angular-distribution chamber for use with the magnetic spectrometer.

21-3 Study of Gamma Rays in Nuclear Reactions (5220)

Stanley S. Hanna and Luise Meyer-Schützmeister
Reported by Stanley S. Hanna and Luise Meyer-Schützmeister

The study of gamma rays produced in the radiative capture of alpha particles by nuclei has been continued. Work has been concentrated on the ${}^6\text{Li}(\alpha, \gamma){}^{10}\text{B}$ capture in order to obtain information on the energy levels in the interesting ${}^{10}\text{B}$ nucleus. A careful search was made for resonances in this reaction, between $E_\alpha = 0.7$ and 3.8 Mev, corresponding to states in ${}^{10}\text{B}$ between $E_{\text{ex}} = 4.9$ and 6.7 Mev. At each observed resonance the spectrum of the radiation was examined in detail, making use of the 256-channel analyzer which is now available to the Van de Graaff group.

Table II gives a summary of the resonances and the gamma rays observed in this experiment. A thin-target yield curve showing the region above $E_\alpha = 1.17$ Mev is reproduced in Fig. 3. Spectra obtained at the

prominent resonance at $E_\alpha = 1.18$ Mev are given in Fig. 4.

Table II

Resonances and Gamma Rays Observed in Radiative Capture of
Alpha Particles by Li^6

All energies are in Mev. The parentheses (w) and (s) denote weak and strong, respectively.

Resonances		Radiation	
E_α	E_{ex} in B^{10}	Primary	Secondary
0.50 *	4.77 *	4.77 (w) 4.05 (s)	0.72
1.085	5.105	5.105 (s) 4.39 (w)	0.72
1.175	5.16	5.16 (w) 4.44 (s) 3.01 (s)	0.72 2.15 1.43, 0.72 0.41, 1.02, 0.72
2.43	5.91	5.91	
2.605	6.02	6.02	

* These values are taken from the literature.

Fig. 3. Thin-target yield curve in the reaction $\text{Li}^6(\alpha, \gamma)\text{B}^{10}$.

Fig. 4. Spectra obtained with the 256-channel analyzer at the resonance at $E_\alpha = 1.18$ Mev in the reaction $\text{Li}^6(\alpha, \gamma)\text{B}^{10}$.

At each resonance, angular distributions were measured for each primary gamma ray. A theoretical study of these data is now in progress.

22-5

Scattering of Charged Particles

(5220)

Jan Yntema

The scattering chamber has been placed for use with the external beam of the 60-inch cyclotron. In the initial experiments the deuteron beam current was as high as $0.3 \mu\text{a}$. A better alignment of the scattering chamber with the focussed external beam is in progress and currents of well over $1 \mu\text{a}$ are expected.

Initial experimental work has been done on the elastic scattering of 21.6-Mev deuterons by gold, silver and magnesium. In all of these cases an absolute differential cross section was readily obtainable with an accuracy of better than 5%. Preliminary data on the angular distribution of the 1.37-Mev group in Mg^{24} were obtained. The energy spread

in the measurement of the elastic peak was about 3%. No background due to protons was observed under any of the deuteron groups being investigated. The neutron and γ -ray backgrounds were completely negligible.

An attempt was made to observe the protons emitted at 90° from the (d,p) reaction on Au^{197} . A very weak proton group was found.

Preliminary work has been started on an analyzing magnet to be operated inside the scattering chamber.

23-3 Resonant Detection of Neutron Energy Groups (5220)

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

A paper is being written on this subject. Further experimental work will be postponed until more ideal experimental equipment can be designed and built. Until such time, no further report will be issued on this project.

24-5 The Decay of Sn^{123} (125 days) (5220)

Bradley Burson and Loren C. Schmid
Reported by Bradley Burson

Efforts have been made to continue following the decay of the three gamma rays previously reported in the tin samples, although the intensity of the radiations has grown so weak that reliable data are difficult to obtain.

The gamma ray with an energy of 1.08 Mev continues to decay with a period of about 130 days. This result continues to encourage further investigation of Sn^{123} for which no gamma rays have been reported in the literature.

The assignment of the 0.60-Mev gamma ray is somewhat more doubtful. Since the general character of the spectrum in this region seems to have changed, some doubt is cast upon the reliability of the analysis for

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both the recent and the earlier data. The peak is so weak that the intensity measurements are extremely sensitive to the amount of background subtracted. The more recent data indicate that the half-life of the decay of this peak may be somewhat longer than that of the 1.08-Mev gamma ray.

The 252-kev gamma ray appears to decay with about the same lifetime as the 0.395-Mev gamma ray of Sn^{113} . This decay is being followed in samples of normal tin as well as in the source enriched in Sn^{122} . In view of the discussion set forth in earlier reports¹ this result seems anomalous.

In an effort to clarify these questions, new samples of enriched tin isotopes have been ordered. They are to be prepared in the metallic form in order to simplify the problem of chemical purification after irradiation.

¹ ANL-5609, Project I-24-3, page 24.

25-2

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

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

Excitation functions for the $\text{Ca}^{40}(\text{d}, \text{p})\text{Ca}^{41}$ (ground state) reaction have been studied at 45° , 90° and 135° with bombarding energies ranging from 1.50 to 4.22 Mev using a Ca target with a thickness of 30 kev. The total cross section ranges from 0.05 to 12 millibarns over this energy range. At least 30 resonances in the excitation function were observed with widths approximately equal to or less than the target thickness. The intensities of the resonances indicate that compound-nucleus formation accounts for at least 20% of the reaction. Angular distributions were measured at 7.5° intervals between 0° and 157.5° in the laboratory system. Although these show strong fluctuations over resonances, a general forward peaking is apparent throughout the energy region studied.

26-2 Measurement of Proton Strength Functions (5220)

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

Experiments on proton strength functions have been extended to yields from (p,n) reactions. Preliminary results on 28 elements indicate a maximum in the strength function at $A \sim 75$. This work will be reported at the Washington Meeting of the American Physical Society.¹

¹ J. P. Schiffer and L. L. Lee, Jr., Bull. Am. Phys. Soc. 2, 177 (April, 1957).

33-1 The Decay of ${}_{26}\text{Fe}^{52}$ (8 hours) (5220)

Bradley Burson and Loren C. Schmid
Reported by Bradley Burson

Fe^{52} is reported to decay by K-electron capture and positron emission to Mn^{52} . The latter has an isomeric state with a lifetime of 21 minutes. The ground state of Mn^{52} , in turn, decays to Cr^{52} with a period of 5.7 days. No attempt will be made at this time to summarize the previous work on this activity because of the preliminary nature of our own results.

The source was produced by the $\text{Cr}^{50}(\alpha, 2n)\text{Fe}^{52}$ reaction when chromium was irradiated with alpha particles in the Argonne Laboratory's cyclotron. The iron was then chemically extracted. The other iron isotopes which are produced are distinguished readily from Fe^{52} on the basis of very different half lives.

The radiations were seen to decay with two periods, 9 hours and 3.5 days. Although the Fe^{52} is reported to decay to the 21-min isomeric state in Mn^{52} , no evidence of this period was observed.

Five gamma rays, ranging in energy from 1.44 Mev to 4.69 Mev, were observed to decay with the 9-hr period. The energies were found to correspond to those associated with 9-hour Ga^{68} . These radiations were attributed to a gallium impurity in the source. Thus no clear evidence for the decay of Fe^{52} can be reported.

The five peaks in the photo spectrum which decayed with the 3.5-day period were found to correspond very closely to gamma rays of similar energy reported in the spectrum of Ga^{67} whose half-life is reported as 3.3 days.

The results thus far are totally negative. However, a mechanical failure during the bombardment makes the time of irradiation very uncertain so a definite conclusion is impossible until the work is repeated. This work is being conducted in collaboration with Dr. John Huizenga of the Argonne Chemistry Division.

35-2

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

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

Further investigation with the coincidence scintillation spectrometer showed that secondary effects of gamma rays caused the peaks which previously were thought to be gamma rays with energies of 0.33, 0.55 and 0.62 Mev and to be associated with the β -decay. In addition, the existence of a 0.7-Mev gamma ray was confirmed. Its energy was found to be 0.704 ± 0.005 Mev, as compared to 0.725 Mev reported by Grodzins and Kendall.¹

The photographic magnetic spectrographs were calibrated using samples of Ir^{192} . An attempt will be made to observe conversion-electron

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

lines for the gamma rays of the 9-hour europium.

A survey of several short-lived isotopes was made. However the investigation has not progressed far enough for the results to be reported at this time.

52-14 Gamma Rays from Fission Induced by Thermal Neutrons
(5220)

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

A third NaI counter has been installed at CP-5 to study further the angular distribution of gamma rays from fission of U^{235} . The shielding of the counter is similar to that of the other counters: the crystal is first surrounded by one inch of LiF, then come four inches of bismuth, 1/4 inch of Boral and four inches of lead.

The new counter, which is operated in coincidence with the fission chamber, detects gamma rays emitted through the fission chamber along the normal to the source foil.

For details of the experimental arrangement, refer to Physics Division Summary Report, ANL-5667, Project I-52-13.

55-6 Capture Gamma-Ray Spectra for Neutrons with Energies
from 0.1 to 10 ev. (5220)

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

Facilities for handling the big shield should be available soon. A large dry box for packing the NaI crystals is nearing completion. It is expected that the crystals will be ready for testing in a few weeks.

56-5 Compton-Electron Magnetic Spectrometer for Neutron-Capture
Gamma Rays (5220)

Richard S. Preston

The design of a 270° magnetic Compton-electron spectrometer, based on the studies described in previous reports, has been started in Central Shops.

57-4 Lifetime Measurements from Recoil Studies (5220)

Stanley S. Hanna

Some Doppler-shift measurements have been carried out in the $\text{Li}^6(\alpha, \gamma)\text{B}^{10}$ reaction. These results, however, will be included in the report on that reaction. (See Report I-21-3.)

58-4 Energy of Delayed Neutrons from Fission (5220)

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

DELAYED NEUTRONS FROM I^{138} AND OTHER HALOGEN FISSION PRODUCTS

Following previous work¹ in which 15.5-sec Br^{88} was found to be a delayed-neutron precursor, it was decided to make a search for other halogen precursors which may have escaped detection in experiments without chemical separation. We are using a gas-flow system in which halogen fission products are chemically separated during irradiation of samples of U^{235} with slow neutrons.

¹ G. J. Perlow and A. F. Stehney, Bull. Am. Phys. Soc. 2, 16 (1957).
ANL-5667, I-58-3, page 30.
ANL-5609, I-58-2, page 44.

In order to isolate iodine activities for counting of neutrons, 2 g of U^{235} in 15 ml of a solution which was 0.25 M in Fe^{+2} , 0.25 M in Fe^{+3} , and 0.5 M in H_2SO_4 were irradiated in the cell which had been used for the bromine experiments. Air containing iodine vapor as a carrier was drawn through the solution to sweep out radioactive iodine, and the decay of neutron activity from iodine absorbed in CCl_4 in a cell outside the reactor (CP-5) was measured after the flow of air had stopped. Runs were made both with and without a trap containing a solution of Fe^{+2} and Fe^{+3} to enhance removal of radioactive bromine; some runs were continued until the activity in the CCl_4 built up to equilibrium, and others were irradiated for shorter times to favor detection of short-lived iodine activities. In all cases, the decay was found to be that of a single period which was followed while the activity decreased by a factor of over 200. The average half-life found for 3 runs was 24.2 sec with an average deviation of 0.2 sec. This value may be compared with a value of 21.7 ± 0.8 sec recently obtained by Keepin and Wimett² in the neutron decay of unseparated samples of U^{235} and the value of 23.8 ± 0.7 sec obtained by Snell *et al.*³ for the neutron decay of an iodine fraction separated from U^{235} . Sugarman⁴ obtained a value of 19.3 ± 0.5 sec for the half-life of I^{137} by measurements of 3.8-min Xe^{137} grown into AgI precipitated at various times after neutron irradiation of U^{235} . However, his work also ruled out the possibility of assigning a 24-sec half-life to I^{138} , I^{139} or I^{140} , and it seems quite evident that the iodine activity measured in the present work was that of I^{137} .

In an attempt to detect shorter lived activities, a new gas-flow

² G. R. Keepin and T. F. Wimett, Geneva Conference Paper, No. p /831 (1955).

³ Snell, Levinger, Meiners, Sampson, and Wilkinson, Phys. Rev. 72, 545 (1947).

⁴ N. Sugarman, J. Chem. Phys. 17, 11 (1949).

system was constructed which would reduce the time interval between the formation of radioactive halogens in the solution being irradiated and their absorption in the CCl_4 where neutron activity is measured. This was accomplished with a smaller irradiation-cell, which permitted use of as little as 5 ml of solution, and smaller glass tubing and safety vessels in the rest of the system. In addition, an auxiliary shutter made of boron carbide and aluminum (boral) was used for some runs in order to obtain much shorter irradiations of controlled time duration (as small as 1 sec) than the slow-moving gate which shields the thermal column in CP-5 offers.

Figure 5 is a decay plot of neutrons from iodine isolated after an irradiation period of approximately 15 sec. Two periods of appreciable yield are obviously present; the 24-sec period has already been discussed, but iodine activity of 5.6-sec half-life has not previously been described as a delayed-neutron precursor. Since Sugarman⁴ obtained a value of 5.9 ± 0.4 sec for I^{138} , it is evident that the new precursor reported here is I^{138} , a nuclide of odd Z and odd N analogous to Br^{88} .

Two runs with irradiation times of only 4 sec provided decay curves similar to that of Fig. 5, but for each run a half-life of ≈ 4 sec was obtained for the shorter lived component when an attempt was made to include all of the points left after subtraction of the 24.2-sec component. When a line corresponding to a half-life of 5.9 sec was drawn through the lower points, a component of 2- to 3-sec half-life was left after subtraction

Fig. 5. Decay of the neutron activity of separated iodine following an irradiation period of approximately 15 sec. The zero of time is the instant at which the flow of air stopped.

of the 5.9-sec component. Thus, there was some indication that the 2.7-sec I^{139} , which Sugarman⁴ found in fission, is also a delayed-neutron precursor.

When bromine was separated after short irradiations of U^{235} , subtraction of the 54-sec and 15.5-sec components from the neutron decay points left a period of 3.9-sec half-life with an average deviation of 0.4 sec for 4 runs. Using a comparison with Br^{87} , Sugarman⁵ had earlier identified as bromine the 4.5-sec delayed-neutron activity reported by Hughes and coworkers⁶ in their work on unseparated samples; the present work provides a very direct confirmation of this bromine precursor, whose mass number is not yet known.

⁵ N. Sugarman, J. Chem. Phys. 15, 544 (1947).

⁶ Hughes, Dabbs, Cahn, and Hall, Phys. Rev. 73, 111 (1948).

60-14 7.7-Meter Bent-Crystal Spectrometer (5220)

Bernard Hamermesh and Robert K. Smither
Reported by Bernard Hamermesh

During the past quarter, the gamma-ray studies with the spectrometer were suspended temporarily while preparations were made for the bending of a new large quartz crystal. The new crystal is 12" x 12" by 4 mm in thickness. (These dimensions should be compared with the 6" x 4" by 6 mm dimensions of the small crystal.) The crystal was bent successfully to the required 7.7-meter radius. Figure 6 shows the two bent crystals in their clamps.

Following the successful attempt to bend the crystal, some necessary changes were made in the drive system of the crystal table. The large crystal was then put into place. The preliminary alignment was made relatively quickly and a diffracted beam of gamma rays has been obtained.

Fig. 6. Comparison of new bent quartz crystal with the smaller one used in the initial operation of the spectrometer.

A paper entitled "Argonne 7.7-Meter Bent-Crystal Gamma Ray Spectrometer" by B. Hamermesh, D. Rose and H. Ostrander has been accepted by Reviews of Scientific Instruments. A more detailed description is given in a topical report, ANL-5642, having the same title and authors.

70-14

Measurements of Nuclear Moments by Angular
Correlation (5220)

Victor Krohn and Sol Raboy
Reported by Victor Krohn

A paper entitled "Gyromagnetic Ratio of the 10^{-8} -sec State of Ta^{181} " has been submitted to the Physical Review and will be given at the Washington Meeting of the American Physical Society.

A paper entitled "Gyromagnetic Ratio of the 3.5×10^{-9} -sec State of Tc^{99} by Angular Correlation Technique" will be presented at the same meeting. The abstract is as follows:

A preliminary result of $+1.9 \pm 0.5$ nuclear units has been obtained for the gyromagnetic ratio of the 181-keV state of Tc^{99} . The sources were prepared by neutron irradiation of natural molybdenum which was subsequently dissolved in nitric acid. Coincidences were observed between the 780- and 181-keV gamma rays following the beta decay of 67-hour Mo^{99} and their anisotropy was measured as a function of the magnetic field applied perpendicularly to the plane of the gamma rays. Information about the attenuation of the nuclear correlation by random

Fig. 7. Observed anisotropy as a function of magnetic field for the coincidences between the 780-keV and the 181-keV gamma rays of Tc^{99} .

fields in the liquid sources has not yet been obtained, but the short lifetime of the intermediate nuclear state suggests that the attenuation is probably negligible for the purposes of the present measurement.

A more accurate result, $g = +1.5 \pm 0.2$ nuclear units, has now been obtained for the Tc^{99} state. The data are shown in Fig. 7. This state has the shortest lifetime of any state for which the gyromagnetic ratio has been measured.

80-14

Molecular Beam Studies

(5220)

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

The present quarter began with an investigation of the 50-day isomeric state of In^{114} , produced by neutron capture in stable In^{113} . Due to the unexpectedly rapid depletion of the source, only preliminary data were obtained. Further work will be done on this isotope.

A freshly irradiated tin source was received, permitting a continuation of the investigation of In^{113}m . A comparison of the observed resonance frequency for the direct hyperfine transition with the values predicted from the most precise low field measurements permitted a determination of the sign of the nuclear magnetic moment. The hyperfine transition frequency was found to be 781.090 ± 0.010 mc/sec. Neglecting the hyperfine anomaly, this leads to a value for the magnetic moment of -0.210491 ± 0.000003 nuclear magnetons.

A considerable amount of time was devoted to important modifications of the Atomic Beam machine. The variable "B" magnet excited by a rotatable permanent Alnico magnet was completed, and a device for quickly changing a sample from the collecting to the counting position was installed. Some effort is being directed toward further improvements, particularly to techniques of reducing the background counting rate.

81-2 Review Paper on Deposition of Atomic Beams (5230)
Sol Wexler

The literature survey for this paper has been completed, and a first draft is nearly finished.

90-14 Cross Sections for 14-Mev Neutrons (5220)

H. Casson, L. S. Goodman, and L. A. Rayburn
Reported by H. Casson and L. A. Rayburn

Since the last report, a large percentage of the time was spent on maintenance of the equipment. The major sources of difficulty were the ion source and the millimicrosecond timing circuitry, with some service time required for the 256-channel pulse-height analyzer.

Modifications were made in the circuitry to improve the stability

and time resolution. Time resolutions (i. e., full width at half maximum) of 3 to 3.5 millimicroseconds have been obtained using d-T alpha particles and neutrons.

ANGULAR DISTRIBUTION OF ELASTICALLY SCATTERED 14-MEV NEUTRONS

Additional differential elastic-scattering cross-section measurements have been made since the last report. These values are shown in Table III.

Table III. Differential elastic-scattering cross sections.

Laboratory angle (degrees)	Angular resolution (degrees)	Differential elastic- scattering cross section (millibarns/steradian)	Estimated error(%)
<u>Lead scatterer</u>			
55	± 5	207	10
65	± 5	97	12
75	± 5	55	22
<u>Bismuth scatterer</u>			
10	± 3	7740	5
15	± 3	3980	5
20	± 3	1190	7
25	± 3	282	15
27.7	± 3	244	16
30	± 3	260	18
35	± 3	560	10
40	± 3	715	9
45	± 3	515	10
50	± 3	203	18
60	± 5	97	11

INELASTIC SCATTERING OF 14-MEV NEUTRONS

Investigation of the scattering of 14-Mev neutrons from polystyrene, water and the element carbon are being made, preparatory to the investigation of other elements. Elastic scattering from hydrogen through various angles provides a convenient range of neutron energies for calibrating and determining the efficiency of the detection system.

91-14 Neutron Transport Cross Sections; Angular Distribution of
Scattered Neutrons (5220)

Alexander S. Langsdorf, Jr.

A report on the experimental results has been submitted for publication. Reports on the equipment and techniques are being prepared now.

98-13 Total Neutron Cross Sections in the Kev Region (5220)

Carl T. Hibdon

REMOTE-CONTROL SAMPLE CHANGER

The equipment for changing transmission samples in front of the neutron counter (elephant) by remote control is completed. The additional wiring and some debugging have also been done. A mounting frame has been made and attached to the elephant. The numbering of the wheels and the installation of samples are nearly completed by the machine shop.

TRANSMISSION MEASUREMENTS

Measurements of the neutron transmission cross section of Al have been continued from 142 up to 415 kev by the same method as before and by use of the same samples. ¹

¹ ANL-5667, Report I-98-12, p. 42.

Variations in the cross section over the entire region from one up to 415 kev show the presence of at least 34 resonances having various values of J and l . Twenty-two of these resonances have not been reported previously. Detailed analysis of the results has not yet been completed.

This work on aluminum is to be reported at the Washington meeting of the American Physical Society under the title: "Neutron Total Cross Section of Aluminum in the Kev Region".

The paper on Cr and Fe under the title: "Total Neutron Cross Sections in the Kev Region: Cr and Fe" covering the region up to 410 kev has been submitted for publication. Preprints are available.

108-8 An He^3 Neutron Spectrometer (5220)

Frank J. Lynch

The ceramic parts for the brazed ceramic-to-metal insulator assemblies have been received. Test pieces of ceramic have been brazed using silver and BT solder with titanium and zirconium hydrides as fluxes in the new vacuum furnace. There is little visible difference in the effects of the two active metals. Experiments will be made with copper and gold in place of silver. The insulator assembly which includes a field tube will be made in two steps, the first with silver, gold or copper braze and the second with BT solder.

110-1 Storage of Pulse-Height Data on Magnetic Tape (5220)

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

In coincidence experiments which require analysis of pulse amplitudes from two or more detectors, much time can be saved by recording gated time-coincident pulses on magnetic tape.¹ A 256-channel analyser

¹ Cavanaugh and Boyce, Rev. Sci. Instr. 27, 1028 (1956).

and a single-channel analyser can then be used later to analyse the recorded data at a high tape speed. Experiments are planned to compare recording by direct, frequency modulated, serial, and binary digital systems. A surplus Ampex model 500 recorder in need of repair has been obtained for experimentation. It has now been placed in operation, but excessive amplitude modulation still remains.

117-3 Measurement of Neutron Half-Life Using a Diffusion
Cloud Chamber (5220)

H. Bryant, G. Caglioti, N. D'Angelo and Charles
M. Huddleston

Reported by G. Caglioti and N D'Angelo

Work has been done to operate the diffusion cloud chamber with gases other than air, at a total pressure of two atmospheres. The most satisfactory conditions have been reached with a mixture of about 5 psi of CO₂ and 25 psi of helium to give a total pressure of two atmospheres, always using a methyl alcohol vapor source. The temperature distribution along the side walls of the chamber has been adjusted, using an internal tape heater, so as to obtain a sensitive layer of the order of 6 cm thick.

A Beattie Varitron Model DR2 camera has been used with a repetition frequency of 2 frames/sec. The light for pictures comes from two linear flashes and the energy supplied is ~ 200 joules/frame.

In Fig. 8, we show a picture we got in the above conditions of operation using a Co⁶⁰ source.

Fig. 8. Photograph of electron tracks produced by gamma rays from a Co⁶⁰ source placed very near the diffusion cloud chamber.

121-1

Spin-Momentum Correlation in the Beta Decay of
Polarized Li^8 Nuclei (5220)

EXPERIMENTAL

M. T. Burgy, W. C. Davidon, T. B. Novey, G. J.
 Perlow, and G. R. Ringo

Reported by W. C. Davidon and T. B. Novey

Observations have been made which corroborate the experiments of Wu,¹ Garwin et al.,² and Telegdi³ on the failure of the beta-decay interactions to satisfy the previously assumed requirements of parity conservation. These effects have been observed in the beta decay of polarized Li^8 nuclei produced by the capture of polarized thermal neutrons by Li^7 in Li_2CO_3 and LiF . Preliminary data, obtained with a beam that was 26% polarized, gives an asymmetry $(n_+ - n_-)/(n_+ + n_-) = -0.04 \pm 0.01$, where n_+ and n_- are, respectively, the numbers of electrons emitted in and opposite to the direction of the neutron spin.

The neutrons were obtained from the Argonne CP-5 reactor and were polarized by the transmission method. Figure 9 shows the arrangement which was used. A collimated beam of neutrons from the

Fig. 9. Experimental arrangement for measuring asymmetry in the beta decay of polarized Li^8 nuclei.

reactor was polarized by passage through a magnetized block of steel.

¹ C. S. Wu, E. Ambler et al., Phys. Rev. 105, 1413 (1957).

² R. Garwin, L. Lederman, and M. Weinrich, Phys. Rev. 105, 1415 (1957).

³ J. P. Friedman and V. L. Telegdi, Phys. Rev. 105, 1681 (1957).

The intensity of the transmitted beam was measured with a fission counter. Depolarization of the neutron beam by the earth's field and stray magnetic fields was prevented by establishing a guide field over the path traversed by the neutrons. The Li^7 samples, both the carbonate and fluoride, were powders placed in an aluminum can. Plastic scintillation counters were used to detect the beta particles from the Li^8 decay. The high maximum energy of the betas (13 Mev) permitted the use of pulse-height discrimination which, with the shielding used, reduced the background sufficiently even though no coincidence techniques were used. To measure the amount of polarization, a second magnetized scatterer followed the Li^7 sample. The neutrons transmitted by the analyser were detected by a BF_3 counter.

The half-life of Li^8 is 0.84 seconds, and it is necessary for the nucleus to maintain its orientation for times at least of this order of magnitude in order to observe an effect. The spin-lattice relaxation time measured by nuclear resonance methods in Li_2CO_3 and LiF is considerably longer, but the relaxation time for a single nucleus is greatly reduced by spin-spin coupling to other nuclei. In this situation, the Li^8 nucleus subject to decay has a different g-factor than the neighboring Li^7 nuclei, and this will reduce the spin-exchange coupling between them by an amount proportional to the square of the ratio of external to internal field. Some of the effects of radiation on the crystal, such as the formation of F-centers, might be expected to reduce the relaxation time. The consequent reduction of the observed asymmetry with time has been observed. Heating of the sample partially restores the original asymmetry.

It should be possible to obtain improved statistics and resolve existing ambiguities by using a reflected beam of polarized neutrons instead of a transmitted one. This would provide an almost completely polarized beam, greatly reduce the background from gamma radiation and non-thermal neutrons, and provide a higher flux. An experiment in such a beam is

planned for the near future.

INTERPRETATION OF THE ASYMMETRY OBSERVED IN THE BETA DECAY OF POLARIZED Li^8

Dieter Kurath

In order to obtain asymmetry in the angular distribution of beta particles emitted by Li^8 , the ground state must have unequal probabilities of being in its sub-states of different magnetic quantum number, M_f .

That is, we need:

$$\langle M_f \rangle = \sum_{-I_f}^{I_f} M_f \omega(M_f) \neq 0$$

where $\omega(M_f)$ is the probability that the ground state of angular momentum I_f is in the substate M_f . This expectation value is calculated for the case when Li^8 is formed by capture of polarized neutrons in Li^7 .

Fig. 10. Angular momenta involved in the formation of Li^8 by neutron capture.

The process of formation is considered to be the capture of a neutron into an excited state of Li^8 with a subsequent gamma decay to the ground state of Li^8 . The total angular momentum and the magnetic quantum number are given in Fig.

10 for each step of the process.

The probability that the final ground state is formed with magnetic quantum number M_f if the neutron has magnetic quantum number S_z is:

$$\omega(M_f) = \left(\frac{2S+1}{2I_f+1} \right) \sum_{M_0, M_f, \mu} (I_0 \ S \ M_0 \ S_z | I \ M)^2 (I \ \lambda \ M \ \mu | I_f \ M_f)^2.$$

The summation of this product of vector-coupling coefficients can be carried out using Racah coefficients, $W(abcd;eg)$, to give:

$$\omega(M_f) = (2S+1)(2I+1) \sum_g W^2(I_0 \ S \ \lambda \ I_f; I_g) (S \ I_f \ S_z \ -M_f | g \ S_z - M_f)^2.$$

Since it is expected that the neutron is captured with zero orbital angular momentum, we have $S = 1/2$, and for $S_z = 1/2$ the formula simplifies to:

$$\omega(M_f) = \frac{1}{2I_f + 1} \left[1 \pm M_f \left(\frac{I_f(I_f + 1) + I(I + 1) - \lambda(\lambda + 1)}{I_f(I_f + 1)(2I_o + 1)} \right) \right]$$

where the $\pm$ sign is coherent with the sign in $I = I_o \pm 1/2$. For $S_z = -1/2$, the sign of the M_f term is changed.

In this experiment, $I_o = 3/2^-$ for Li^7 , $I_f = 2^+$ for Li^8 and the gamma transition is expected to be electric dipole, $\lambda = 1$. If we call p the fractional polarization of the incident neutrons, we can insert the known spins to obtain:

$$\omega(M_f) = \frac{1}{5} \left[1 + \frac{5p}{12} M_f \right] \quad \text{for } I = 2^-$$

$$\omega(M_f) = \frac{1}{5} \left[1 - \frac{p}{4} M_f \right] \quad \text{for } I = 1^-$$

These give the expectation value $\langle M_f \rangle$ needed for the angular distribution of the beta particles:

$$\langle M_f \rangle = +5p/6 \quad \text{for } I = 2^-$$

$$\langle M_f \rangle = -p/2 \quad \text{for } I = 1^-$$

The beta transition is an allowed one to the 2^+ state of Be^8 , which proceeds only by means of the Gamow-Teller interaction since the two states have different isotopic spins. The asymmetry coefficient in the angular distribution of the beta particles is:

$$a = \frac{\beta \langle M_f \rangle}{6}$$

$$I(\theta) \sim (1 + a \cos \theta)$$

An estimate of β is obtained from the experiment of Wu et al,¹ who find $\beta \approx -0.7$ for an electron velocity $v \approx 0.6 c$. In the present case, $v \sim c$ and the expression given by Yang and Lee shows that β is proportional to v/c . Hence, assuming a negligible amount of axial-vector interaction compared to the tensor contribution, $\beta \approx -1.1$ for the present experiment. This leads to an expected anisotropy coefficient:

$$a = -0.15 p \quad \text{for } I = 2^-$$

$$a = +0.09 p \quad \text{for } I = 1^-$$

These estimates assume no attenuation of the polarization by the crystalline fields, so they are upper limits to the magnitude of the asymmetry. The present experimental result, $a = -0.04$ for $p = 0.26$, indicates a strong preference for the $I = 2^-$ channel.

123-1 The Symmetry Properties of Neutron Decay (5220)

Merle T. Burgy, Victor E. Krohn, Theodore B. Novey (Chem. Div.) Sol Raboy, Roy Ringo and Valentine L. Telegdi (U. of Chicago).
Reported by Roy Ringo

Since the famous parity experiments of the Columbia University and Bureau of Standard workers, it has become of great interest to investigate the symmetry properties of the beta-decay of neutrons since this is one of the most fundamental, and presumably simple, beta-decays available for measurement. Two features of this decay appear of particular interest. The first is

the variation in intensity of β -emission with angle relative to the direction of the spin of a group of polarized neutrons (the neutron-parity experiment). The second is the dependence on spin direction of the intensity of beta emission in a direction normal to the spin direction and to the direction of the recoil proton involved in a given decay (the time-reversal experiment). The name of the second experiment comes from the fact that a change in the beta intensity mentioned, on reversal of the neutron-spin direction, would indicate the presence of a term in the fundamental particle interactions which is not invariant under reversal of all momenta. This reversal is commonly equated to time reversal.

Work is underway on the first of these experiments which it is proposed to attempt with a beam of thermal neutrons from a port in CP-5 having a height of 8" and a width of 1/4". This tall narrow beam has been reflected from a mirror of 95% Co - 5% Fe which is 50" long. This should produce fairly complete polarization when the mirror is magnetized. The polarized beam will be passed through a vacuum chamber in which the decay will be observed. The beta particles will be observed by a plastic scintillator and photomultiplier about 5" in diameter. To reduce background it is hoped to observe the proton recoils in delayed coincidence with the beta particles by means of an electron multiplier with a large (roughly 4" in diameter) cathode which the protons strike after acceleration to about 20 kev.

The apparatus for a first attempt at this experiment is now being assembled. It is hoped that this apparatus with relatively simple modifications can also be used for the time-reversal experiment.

138-3

Characteristics of Multiplier Phototubes (5230)

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

The investigation of the spectral response of multiplier phototubes is almost completed. The first part of this project, devoted to a survey of the spectral properties of some commercially produced phototubes, has been completed. The report on this part will be prepared by F. N. Hayes and D. G. Ott (Los Alamos Scientific Laboratory). The second part of the project, devoted to the use of liquid scintillators as reference standards, will be completed soon. When both parts are completed, joint publication with Hayes and Ott is planned.

In using a liquid scintillator as a reference standard, one compares the light output of an unknown scintillator with that of the standard liquid under specified conditions of excitation. Since the light output is determined by the response of a multiplier phototube, the wavelength range of the emission spectra of the two scintillators in relation to the sensitivity spectrum of the phototube is important. A brief analysis of the problem follows.

For the purposes of the present discussion, it is convenient to use the following relation for the number of photoelectrons liberated from the photocathode in response to a scintillation:

$$N = E \int_0^{\infty} \epsilon(\lambda) \tau(\lambda) \eta(\lambda) d\lambda \quad (1)$$

E is the energy which the high-energy particle dissipates in the scintillator, $\epsilon(\lambda)$ is the number of scintillation photons generated per unit wavelength interval and per unit absorbed energy, $\tau(\lambda)$ is the probability that an emitted photon (of wavelength λ) will terminate its existence in the photomultiplier, rather than being lost in the scintillator, cell, or reflector,

and $\eta(\lambda)$ is the quantum efficiency of the photocathode.

A few more comments are necessary to clarify the meaning of the quantities defined above. The quantity $\epsilon(\lambda)$ could be defined as the light output generated by the emitting molecules. However, the spectrum is strongly modified by reabsorption in the first millimeter of travel through the scintillator. After that, reabsorption is much smaller, since the shorter wavelengths have been largely eliminated. Therefore, it is more convenient to define $\epsilon(\lambda)$ as the light output viewed through some depth of scintillator. If this depth is greater than 1 mm, then reasonable variations (e. g. , a factor of two) in the actual path lengths of photons will not alter $\epsilon(\lambda)$ significantly. In these experiments $\epsilon(\lambda)$ is taken as the emission observed through 1 cm depth of solution. In all the observations to be reported, the scintillation light travels ~ 1 cm through the solution to reach the detector. In this way, effects due to absorption by the solution are already accounted for in the determination of $\epsilon(\lambda)$. Consequently, $\tau(\lambda)$ need represent only the probability that a photon is not absorbed in the reflector or cell. Its value depends upon the reflectivity of the reflector, the transparency of the cell, and to some degree upon the reflectivity of the photocathode. Absorption of light in the glass window of the phototube is taken care of in the definition of $\eta(\lambda)$, since this quantity is measured by illuminating the cathode through the window in the same manner in which the scintillation illuminates the cathode.

In the experiments to be described here, the absolute value of phototube response N is never measured, but rather the ratios of phototube responses for different scintillators, phototubes, cells, or reflectors. In comparative measurements such as these, it frequently is not important to know the absolute magnitude of quantities in Eq. (1), but it is always necessary to know the wavelength dependence. Therefore, it is convenient to separate each of the quantities in the integrand into two factors, one giving

the magnitude and the other a spectral shape factor. Let

$$\mathcal{E}(\lambda) \rightarrow S \cdot s(\lambda)$$

$$\tau(\lambda) \rightarrow T \cdot t(\lambda)$$

$$\eta(\lambda) \rightarrow P \cdot p(\lambda)$$

where

$$S = \int_0^\infty \mathcal{E}(\lambda) d\lambda$$

and

$$\int_0^\infty s(\lambda) d\lambda = 1.$$

T and P are simply the maximum values of $\tau(\lambda)$ and $\eta(\lambda)$, respectively, while $t(\lambda)$ and $p(\lambda)$ are normalized to unity at the peak. Equation (1) now becomes

$$N = E S T P m \quad (2)$$

where

$$m = \int_0^\infty s(\lambda) t(\lambda) p(\lambda) d(\lambda). \quad (3)$$

The parameter m is a spectral "matching factor", a dimensionless quantity having a maximum value of unity. It can have this maximum value if $t(\lambda) = p(\lambda) = 1$ at all wavelengths for which $s(\lambda) > 0$. This can happen if the emission spectrum $s(\lambda)$ is very narrow and is located at the peak of both $t(\lambda)$ and $p(\lambda)$, or if the maxima of both $t(\lambda)$ and $p(\lambda)$ are sufficiently broad and flat over the region occupied by $s(\lambda)$. In practice, neither of these conditions is achieved, so that m is always less than unity. The maximum value observed by the authors is $m = 0.87$.

When two scintillators are compared, using identical excitation and a common photomultiplier, cell, and reflector, the ratio of pulse heights

will be

$$N_1 / N_2 = (S_1 / S_2) (m_1 / m_2) \quad (4)$$

The ratio of pulse heights will equal the ratio of scintillator efficiencies S_1 / S_2 only if $m_1 = m_2$. The latter will be true in general if (a) the two scintillators have identical emission spectra, or (b) the photocathode and optical system have a "flat" response over the range of the two emission spectra. If neither of these conditions is satisfied, the relative values of "light output" obtained are actually relative values of $S m$ for the scintillators being compared. It is obvious from (3) that the results obtained depend upon the spectral characteristics of the reflector, cell, and phototube used for making the comparison. The first two of these three factors may readily be standardized. An evaporated aluminum reflector has an ideal spectral characteristic, being essentially independent of wavelength in the range 3000-5000 Å.¹ By making the test cell of highly pure fused silica, losses due to absorption in the cell are eliminated. By taking both these precautions one can make $t(\lambda) \approx 1$. However, the survey of phototube characteristics made in the first part of this investigation indicates that standardization of $p(\lambda)$ will be much more difficult. An alternative to the standardization of $p(\lambda)$ would be to satisfy condition (a) above, i. e., compare only scintillators having identical or very similar emission spectra. To do this would necessitate having a series of calibrated reference scintillators giving a graduated sequence of emission spectra. If such calibrated standards were available, it would only be necessary to determine which of the standards most closely matched the spectrum of the unknown sample. That standard would then be used for comparison. Selection of the proper standard could be done with any optical spectrometer, since high accuracy

¹ John Strong, Procedures in Experimental Physics, (Prentice-Hall, Inc., New York, 1947), p. 375.

would not be required. In addition, a method will be described later by which the selection may be made using ordinary scintillation counter equipment. Besides using the reference standards for direct comparisons of scintillators, they can be used to determine the approximate spectral response of a multiplier phototube.

Having decided that a series of calibrated scintillation standards would be desirable, we proceeded to select the appropriate liquid solutions having the desired properties. Six solutions were selected with mean emission wavelengths at approximately 300 Å intervals from 3360 Å to 4660 Å. In addition, three more alternate solutions were selected to add redundancy to the measurements. The nine solutions are listed in Table IV, together with the mean wavelengths of emission* and the abbreviations which will be used to represent the solutions.

Table IV. Nine solutions calibrated for standards. Numbers in parentheses indicate solute concentrations in grams per liter. Abbreviations of solutes: CPO = 2-cyclohexyl-5-phenyloxazole; TP = p -terphenyl; PPO = 2, 5-diphenyloxazole; PBD=2-phenyl-5-(4-biphenyl)-1, 3, 4-oxadiazole; BPO = 2-(4-biphenyl)-5-phenyloxazole; BBO = 2, 5-di-(4-biphenyl)-oxazole; POPOP = 1, 4-di-[2-(5-phenyloxazolyl)] -benzene; NOPON = 1, 4-di-[2-[5-(2-naphthyl)-oxazolyl]] -benzene; DPA = 9, 10-diphenylanthracene.

Solvent	First solute	Second solute	Abbreviation of solution	Mean wavelengths of emission, Å.
toluene	CPO (10)	none	CPO	3360
toluene	TP (5)	none	TP	3600
toluene	PPO (5)	none	PPO	3920
toluene	PBD (10)	none	PBD	3960
toluene	BPO (5)	none	BPO	4220
toluene	TP (5)	BBO (0.5)	BBO	~ 4400
toluene	TP (5)	POPOP (0.5)	POPOP	4440
toluene	TP (5)	NOPON (0.1)	NOPON	4660
toluene	TP (5)	DPA (0.5)	DPA	~ 4700

* The mean wavelength of emission is defined here as the wavelength which divides the plot of $s(\lambda)$ vs λ into two equal areas.

The toluene used in these experiments was purified by distillation and its purity was checked by measurements of optical absorption. The solutes were of the highest purity available but were not additionally purified. When materials were obtainable from more than one source, the sample which gave the highest light output was used.

Three methods were used to determine the light-output ratios of these solutions. The methods first will be described individually, and then the results of all three will be given.

In the first method a calibrated photomultiplier was used. The sensitivity spectrum of the tube was measured by Milton Adelman, Naval Material Laboratory, Brooklyn, New York. This was determined by illuminating the photocathode with collimated monochromatic light, and comparing the photocurrent at each wavelength with the response of a blackened thermocouple. A double-refracting monochromator was used to produce the monochromatic beam. This procedure resulted in the determination of $p(\lambda)$. Next, the emission spectrum of each solution was determined by Hayes and Ott on their spectrometer at Los Alamos. This was done by irradiating the solution in a rectangular fused-silica cell with 2537 Å ultraviolet. In every case, most of the ultraviolet was absorbed by the toluene, so that energy transfer to the solute occurred in much the same manner as in the scintillation process. The fluorescent light passed through a cell 1 cm thick and entered the entrance slit of a recording spectrometer. The intensity recorded at each wavelength was corrected by using data obtained from a tungsten filament lamp. The spectrum of the lamp can be calculated for the operating temperature used.² The corrected spectrum is then normalized to obtain $s(\lambda)$. Having determined $p(\lambda)$ and $s(\lambda)$ the relative pulse amplitudes were determined with the calibrated photomultiplier. The geometry of the setup is shown in Fig. 11. For this apparatus, $t(\lambda)$ is assumed to be unity. Putting these quantities into

² G. Kortum and B. Finckh, *Spectrochim. Acta* 2, 10-18 (1941).

Fig. 11. Schematic diagram of arrangement used for measuring scintillation pulse heights. The cell is 1 inch in diameter by 3/8 inch high.

Fig. 12. Sensitivity spectrum $p(\lambda)$ for a type 6292 photomultiplier, and emission spectra of six liquid scintillators. For a complete description of the scintillators see Table IV.

Eq. (3) one can determine the value of m for each solution. Figure 12 shows $p(\lambda)$ for the calibrated tube and $s(\lambda)$ for six of the nine solutions. The value of m for each solution is indicated. Once the value of m has been determined for each solution, relative pulse heights may be converted immediately into relative light outputs with the aid of Eq. (4). These results are given in Table V.

The second method is not completely independent of the first, but it is different in many ways. This method consists of making a comparison of the areas under the curves of emission spectra obtained with the spectrometer. Instead of arbitrarily normalizing the emission spectrum to get $s(\lambda)$, the samples are identically illuminated so the areas under the curve are proportional to S . This method leans more heavily upon the calibration of the spectrometer than does the first method, but does not depend upon the inde-

pendent calibration of a photomultiplier. It also measures the relative efficiency of excitation by ultraviolet of wavelength 2537 Å rather than by fast electrons. The results are given in Table V.

Table V. Relative scintillation output of nine liquid scintillators using three methods of measurement.

Abbreviation of solution [†]	Relative quantum output of scintillation [†]		
	Calibrated phototube	Calibrated spectrometer	Fluorescent converter
CPO	*	0.56	0.31
TP	1.15	0.96	1.02
PPO	0.85	0.91	0.85
PBD	1.03	1.01	1.04
BPO	0.98	1.10	0.95
BBO	1.01	*	1.00
POPOP	1.00	1.00	1.00
NOPON	0.90	0.99	0.88
DPA	0.78	*	0.75

[†] Relative numbers of photons normalized to unity for POPOP.

[‡] For complete composition of solutions see Table IV.

* No data taken.

The third method of determining the relative light outputs is completely independent of the other two methods. It is based on a remarkable property of fluorescent organic molecules: the quantum efficiency of fluorescence is independent of the wavelength of excitation. The property was first used by Bowen³ for obtaining a spectrally "flat" radiation detector. The property is first of all a consequence of the fact that the lifetimes of optical transitions in these molecules are several orders of magnitude longer

³ E. J. Bowen, Proc. Roy. Soc. 154 A, 349-53 (1936)

than the lifetimes of vibrational transitions. This means that thermal equilibrium is always established between electronic excitation and subsequent emission. When emission finally occurs, the molecule has completely "forgotten" which vibrational level was originally excited, and hence the emission spectrum and quantum efficiency are not correlated with the mode of excitation. A further, somewhat more unexpected, property of these molecules is that even when excited to a higher electronic state than the state from which the fluorescence occurs, they still emit from the lower state with the same quantum efficiency as when that state is excited directly. Apparently, at least the next few higher states are internally converted into the lower state with unit quantum efficiency. This latter property must be considered as an experimental observation

only and it cannot be assumed that all such molecules will exhibit this behavior.

Fig. 13. Simple arrangement for obtaining a detector whose response is proportional to the number of incident quanta. The phototube sees only the secondary radiation from the fluorescent converter. The primary radiation is totally absorbed in the converter.

A simple way of using this principle to obtain a spectrally "flat" radiation detector is shown in Fig. 13. However, this method may be subject to significant errors arising from the fact that the fraction of the emitted fluorescence which reaches the phototubes may vary with the depth of penetration, and hence with the wavelength of the exciting radiation. This arises not only from geometrical considerations, but from differences in the amount of self absorption in the forward and backward directions. This problem has been discussed

by Wright,⁴ who finds that the method is strictly valid only if the fluorescent converter does not re-absorb its own radiation. An ideal method of converting the incident radiation would be to introduce it at the center of a large spherical volume of the fluorescent converter. In this case, the efficiency with which the fluorescent radiation emerges to the surface of the converter is independent of the depth of penetration of the exciting radiation, so long as that depth is small compared with the radius of the volume occupied by the converter. The experimental method used in these experiments is an attempt to approximate this ideal condition. The method is illustrated in Fig. 14.

The liquid scintillator is placed in the inner chamber, whose walls are made of fused quartz of optical grade. The scintillator is excited by Co^{60} gamma rays from a source contained inside a small blackened brass tube. The source is at the center of the scintillator. Both the source and the scintillator are introduced through the slender neck of the inner chamber. The volume in the inner chamber is about 4 ml. The outer chamber holds

about 40 ml of fluorescent converter. The converter surrounds the scintillator to a minimum depth of 1 cm. Outside the outer chamber all areas except the lower surface, where the photomultiplier is attached, are covered with an efficient diffuse reflector. Since the gamma rays can excite the fluorescent converter as well as the scintillator, the converter is used in alcohol solution so that it is a very poor scintillator. Never-

Fig. 14. Arrangement for measuring the quantum output of liquid scintillators.

⁴ G. T. Wright, Phys. Rev. 100, 587-8 (1955).

theless, the background correction, obtained by taking a reading without the scintillator present, can, in some cases, be as much as 10% of the reading with the sample present. From the results of a series of experiments it was estimated that the error in the corrected sample readings due to background was not more than 0.3%. Light output is determined by measuring the anode current of the photomultiplier with an electrometer. The currents measured are in the range 10^{-10} to 3×10^{-9} amperes.

In order to test the hypothesis that the fluorescence yield is independent of exciting wavelength, the scintillation outputs of the nine standard solutions were compared with each of three different fluorescent converters: (1) uranine, (2) rhodamine 6G, and (3) rhodamine B. All were used at 1 g/l concentration in absolute ethyl alcohol. For a path length of 1 cm, all solutions transmitted less than 1% of all wavelengths below their respective absorption edges. The long-wave limits for less than 1% transmission are: uranine, 5360 Å; rhodamine 6G, 5700 Å; rhodamine B, 5960 Å. When these measurements were first carried out, the agreement was very poor indeed. This disagreement, however, proved to be due to the presence of impurities. All three compounds were readily purified by recrystallization from alcohol. After such purification, agreement of the light-output ratios among the three converters was within 1%. Measurements of absorption spectra of the compounds correlated with the results of the fluorescence measurements as the impurities were being removed. The good agreement obtained is strong evidence in favor of the correctness of the assumption that the quantum efficiency of fluorescence is independent of the wavelength of the exciting radiation. This assumption has also been verified recently by Melhuish,⁵ who used rhodamine B to measure the spectrum

⁵ W. H. Melhuish, N. Z. J. Sci. Tech. 37 (B), 142-149 (September 1955)

of a tungsten lamp. The agreement of the observed spectrum with the calculated spectrum supports the assumption stated above. In using this method, the photomultiplier current in each case is a measure of the average number of photons emitted per scintillation.* No corrections for wavelength of emission need be applied. The excitation by gamma rays is constant, since the volumes and densities of all the solutions are the same.

The results of all three methods are tabulated in Table V. The relative light outputs are normalized to a value of unity for the POPOP solution. The authors feel that the results obtained with the fluorescent converter are the most accurate. The agreement of that method with the method using the calibrated phototube is also quite good, except for the case of the TP solution. The pulse height for the CPO solution was too small to measure because of the insensitivity of the phototube to its scintillation. The measurements with a calibrated phototube are being repeated now, using a type 6903 (RCA) photomultiplier. This tube has a quartz window, and preliminary measurements indicate that its response is almost constant over the wavelength region of interest. Use of this tube should reduce the importance of errors in the determination of $s(\lambda)$ so that the three methods of calibration should then be almost completely independent of each other.

The principal usefulness of the results reported here will probably be in the future measurement of light outputs of other liquid scintillators. In order to make such measurements, two alternative methods seem attractive. First, one may use the method of the fluorescent converter, using rhodamine B in alcohol or glycerol. The results so obtained yield relative numbers of photons. A less accurate, but often more convenient, method consists of comparing the unknown with one of the solutions listed in Table V. It is first necessary to determine which of

* A small contribution $\sim 1\%$ from Cerenkov emission is included in the response. No correction has been made for this in these experiments.

those solutions has a spectrum most closely matching the unknown. If one has the facilities to measure the spectrum of the unknown, the comparison may be made with the aid of Fig. 12. If a spectrum of the unknown is not available, the following approximate method may be used for selecting the best solution for comparison. The unknown and several likely reference solutions are measured in the arrangement shown in Fig. 11. The measurements are then repeated after replacing the aluminized reflector with a diffuse reflector of TiO_2 pigmented paint. The ratio of the response of the phototube, which we will call the TiO_2/Al ratio, will be a function of the emitted wavelength, decreasing monotonically with decreasing wavelength. Location of the unknown on the TiO_2/Al scale will determine its spectral position approximately.

All measurements described here were carried out in the temperature range $25^\circ - 27^\circ \text{C}$ and all solutions were air saturated. The air-quenching factor is nearly the same for all solutions except DPA, so that reasonable variations in air pressure may be tolerated so long as all measurements are made at the same pressure. The value given for the DPA solution was measured under an atmospheric pressure of 745 mm Hg.

139-6

Liquid Scintillators

(5230)

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

One aspect of this project has been a comparison of the efficiencies of various scintillating solutions in terms of the electrical current produced in a photomultiplier in response to the scintillation light from the different solutions, under conditions of identical excitation and

with the same cell and reflector assembly. The apparatus employed and results obtained have been described previously.^{1,2}

When the scintillators compared in this way have different emission spectra, the results will depend upon the spectral characteristics of the particular cell, reflector, and photomultiplier used. During an investigation of the spectral response of photomultipliers (see section I-138-3 of this report) it became apparent that the spectral characteristic of the apparatus referred to above was not representative of that which might be expected in practical use of scintillation counters.

In order to obtain a more useful evaluation, a number of toluene-solution scintillators have been compared by two different techniques, namely (a) comparison of pulse heights from a photomultiplier, using a Du Mont 6292 photomultiplier especially selected as having a spectral sensitivity most nearly typical of its type, and (b) comparison of the average number of photons per scintillation, using an external fluorescent "converter" in conjunction with a photomultiplier to achieve a detector whose sensitivity is essentially independent of wavelength. These techniques are more fully described in section I-138-3 of this report.

Table VI presents the results of these measurements on 26 different toluene solutions, all solutions having been saturated with air at a pressure of approximately 745 mm Hg, and the results having been normalized to unity for the solution containing 10 grams of PBD per liter. The solute concentrations chosen are approximately those which yield maximum light output for air-saturated solutions, except for a few cases in which low solubility prevents use of the optimum concentration.^{1,2} In general, the optimum concentrations for oxygen-free solutions are somewhat lower.

¹ ANL-5554, Report I-139-3, pp. 76-95.

² ANL-5609, Report I-139-4, pp. 67-75.

Table VI. Relative scintillation efficiencies of air-saturated toluene solutions. (a)

First solute (b)	Second solute (b)	Relative photon yield (c)	Relative photomultiplier pulse height (d)	Relative photomultiplier current (e)	Air: Argon Ratio (f)
CPO (10)	-	0.31	-	0.15	0.75
BP (800)	-	0.13	-	0.06	~ 0.6
NL (400)	-	0.08	-	0.07	0.19
m-TP (100)	-	0.67	0.51	0.46	0.59
p-TP (5)	-	0.98	0.75	0.68	0.76
MTP (10)	-	0.97	0.86	0.82	0.77
PPO (5)	-	0.82	0.82	0.83	0.76
PBD (10)	-	1.00	1.00	1.00	0.81
BPO (5)	-	0.91	0.95	1.09	0.76
BBO (1)	-	0.65	0.69	0.87	0.59
α NPO (5)	-	0.78	0.81	1.00	0.75
AC (2)	-	0.13	0.14	0.15	0.70
DMAPBT (2)	-	0.68	0.72	0.79	0.65
DEAMC (1.8)	-	0.60	0.63	0.76	0.59
POPOP (1)	-	0.56	0.70	0.91	0.60
DPH (1.3)	-	0.35	0.42	0.60	0.58
DPA (7)	-	0.68	0.69	0.91	0.51
p-TP (5)	α NPO (0.5)	0.83	0.86	1.04	0.74
p-TP (5)	BBO (0.5)	0.96	1.00	1.26	0.76
p-TP (5)	POPOP (0.5)	0.96	1.00	1.31	0.76
p-TP (5)	DPH (0.05)	0.70	0.66	0.92	0.57
p-TP (5)	DPA (0.5)	0.73	0.73	0.96	0.54
p-TP (5)	NOPON (0.04)	0.87	0.85	1.21	0.74
MTP (10)	POPOP (0.5)	0.96	1.00	1.30	0.78
PPO (5)	POPOP (0.5)	0.88	0.93	1.19	0.75
PBD (10)	POPOP (0.5)	0.98	1.02	1.32	0.78

Footnotes for Table VI

- (a) Determined at a temperature of approximately 24°C and an air pressure of approximately 745 mm Hg.
- (b) Numbers in parentheses indicate grams of solute per liter of toluene. Chemical names of the solutes are abbreviated as follows:

CPO	2-cyclohexyl-5-phenyloxazole.
BP	biphenyl
NL	naphthalene
m-TP	meta-terphenyl
p-TP	para-terphenyl
MTP	4-methylterphenyl
PPO	2,5-diphenyloxazole
PBD	2-phenyl-5-(4-biphenyl)-1,3,4-oxadiazole
BPO	2-(4-biphenyl)-5-phenyloxazole
BBO	2,5-di(4-biphenyl)-oxazole
α NPO	2-(1-naphthyl)-5-phenyloxazole
AC	anthracene
DMA PBT	2-(p-dimethylaminophenyl)-benzothiazole
DEAMC	7-diethylamino-4-methylcoumarin
POPOP	1,4-di-(2-(5-phenyloxazolyl))-benzene
DPH	1,6-diphenylhexatriene
DPA	9,10-diphenylanthracene
NOPON	1,4-di-(2-(5-(2-naphthyl)-oxazolyl))-benzene

- (c) Proportional to average number of photons emitted per scintillation for identical excitation.
- (d) As determined using a quartz cell, evaporated aluminum reflector, and a Du Mont 6292 photomultiplier with "average" spectral response characteristic.
- (e) As determined using the apparatus described in ANL-5554, Report I-139-3, pp. 76-95.
- (f) Ratio of photomultiplier currents obtained with an air-saturated solution to that obtained with the same solution after bubbling with argon.

For purposes of comparison, Table VI also lists relative photomultiplier currents obtained with the earlier apparatus described in Reference 1. Since the solutions are listed roughly in order of increasing wavelength of emission, it follows that this apparatus discriminates unduly against those scintillators emitting at short wavelengths in favor of those emitting at long wavelengths. Also obtained with this apparatus, and listed in the last column of Table VI for each of the solutions, is the ratio of the light output from an air-saturated solution to that from the same solution after dissolved oxygen has been removed by bubbling argon through the solution.

In a comparison of scintillators, knowledge of the spectral distribution of the light emitted during the scintillation process may be of interest. Figure 15 shows photographs of the fluorescence spectra of the toluene solutions listed in Table VI, as recorded on Ilford Ordinary plates with a Hilger Intermediate quartz prism spectrograph. Fluorescence was excited by 2537 Å ultraviolet light obtained from a Bausch and Lomb grating monochromator and was viewed through a 1-cm thickness of the solution. Certain lines of the Hg emission spectrum appear superimposed upon the fluorescence spectra; they result from stray light coming from the monochromator and being transmitted by the solution.

Comparison of the optical extinction coefficients of toluene and the various solutes at 2537 Å indicates that in the solutions studied the exciting light is absorbed mostly by the toluene, so that energy transfer to the solutes may be assumed to have occurred very much as in the scintillation process. The fluorescence spectra obtained in this way are therefore believed to correspond to the emission spectra excited by ionizing radiation.

Solutes

CPO (10)
 BP (800)
 NL (400)
 m-TP (100)
 p-TP (5)
 MTP (10)
 PPO (5)
 PBD (10)
 BPO (5)
 BBO (1)
 α NPO (5)
 AC (2)
 DMAPBT (2)
 DEAMC (1.8)
 POPOP (1.0)
 DPH (1.3)
 DPA (7)

Solutes

p-TP (5) + α NPO (0.5)
 p-TP (5) + BBO (0.5)
 p-TP (5) + POPOP (0.5)
 p-TP (5) + DPH (0.05)
 p-TP (5) + DPA (0.5)
 p-TP (5) + NOPON (0.04)
 p-TP (5) + POPOP (0.5)
 MTP (10) + POPOP (0.5)
 PPO (5) + POPOP (0.5)
 PBD (10) + POPOP (0.5)

Fig. 15. Fluorescence spectra of toluene-solution scintillators. Beside each spectrum are indicated the solutes and their concentrations in grams per liter of solvent. See Table VI for the meanings of the abbreviations of the solutes. Fluorescence was excited by 2537 Å ultraviolet and viewed through 1 cm of solution. All solutions were air-saturated. At top and bottom is the Hg emission spectrum. The wavelength scale reads in hundreds of angstroms. Hilger quartz-prism spectrograph with Ilford Ordinary plate.

142-8 Electron Accelerator (5220)

Robert K. Swank

The system was put into operation during this quarter and the first photographs were made of scintillation pulses. The performance of the new TW oscilloscope is very encouraging; however, we have not yet determined the minimum rise time of this instrument. The photographs taken so far were made with the accelerator set for a pulse width of 10^{-9} seconds. The minimum pulse width (10^{-10} sec) has not been used.

The chief limitation to the equipment at present is the lack of a suitable means of calibrating the time base. A C. W. oscillator may be used for single-trace photography, but is not suitable where repetitive signals are displayed. For this work a pulsed calibration signal is required. Preliminary experiments have been carried out with a shock-excited LC tank circuit. The results are encouraging.

143-8 Plastic Scintillators (5230)

Louis J. Basile

A paper entitled "Characteristics of Plastic Scintillators" has been accepted for publication in the Journal of Chemical Physics.

145-1 Handbook of Nuclear Instruments and Techniques (5230)

R. K. Swank

Some time has been spent assisting in the preparation of the above Handbook. Contributions have been made on the following subjects: (1) Nuclear Track Chambers, (2) Photographic Materials, and (3) Scintillation Counters. Other contributions are in preparation. The Handbook will be published under the auspices of the National Research Council.

149-6

Dynamic Condenser Magnetometer (5220)

Bradley Burson and Loren C. Schmid
Reported by Bradley Burson

Some minor changes are being made in the mechanical system of the dynamic condenser. Until the shop work is completed, little can be said about their merit. It is hoped that the harmonic content of the comparison signal generated by the condenser can be reduced by changing the shape of the rotor plates slightly. In dismantling, one of the rotor sections was found to be cracked. The design is being changed in an effort to obviate this difficulty.

The rest of the equipment is complete and the report is in final draft form. As soon as final tests are made, the report will be submitted for publication.

II. MASS SPECTROSCOPY18-6 Lead Ages of Meteorites (5220)

David C. Hess and Royal Marshall*
*(Enrico Fermi Institute of Nuclear Studies)
Reported by David C. Hess

Some measurements were made on lead which had been extracted from meteorites and on "calibration" lead. These measurements were made on mass spectrometer MA23 which had been temporarily adapted for surface ionization. The results showed a spread of about 5%.

Measurements were made on a sample of lead which had been measured at Berkeley. Our results differed from theirs by about 3%.

Further work has been halted since MA23 has been adapted for use in identifying the products of radioactive decay. It is hoped that further measurements can be made but this will depend on availability of a mass spectrometer. MA23 may become available for this some time in the next six months. No further reports will be made until results warrant.

20-2 Tritium Age Measurements of Meteorites (5220)

Frederick Begemann,* Johannes Geiss* and
David C. Hess
*(Enrico Fermi Institute for Nuclear Studies)
Reported by David C. Hess

This experiment has been completed and the results have been submitted to the Physical Review for publication.

28-1 Kinetics of Chemical Reactions in the Gas Phase (5230)

Joseph Berkowitz (U. of Chicago) and William A. Chupka
Reported by William A. Chupka

An apparatus has been developed for the study of the reaction kinetics of "active nitrogen". It is similar to the arrangement used by Berkowitz, Chupka and Kistiakowsky¹ for the same purpose, but includes several important improvements. The technique involves the production of active nitrogen by either an rf or microwave discharge. The active nitrogen then flows rapidly through a pyrex glass reaction chamber which has a small pinhole leak for continuous sampling of the gas by a mass spectrometer. The gas effusing from the pinhole is collimated into a molecular beam which then traverses the ionization chamber of the mass spectrometer where it is bombarded by an electron beam of controlled energy. The resulting ions are analyzed by the mass spectrometer. In addition, the light emitted by the gas in the reaction chamber is filtered by an optical interference filter (peaked at 5370 Å to pass one of the most intense bands of the nitrogen afterglow) and monitored by a photomultiplier cooled by liquid nitrogen.

The technique has been applied to the study of active nitrogen and most of the results obtained so far confirm the results of Berkowitz, Chupka and Kistiakowsky.¹ However, the present results are much less open to question because of the improved apparatus. These results show that our active nitrogen contains about 1-2% ground state nitrogen atoms and no detectable amounts of metastable atoms or molecules or N_3 molecules. No N_3^+ ions were detected and the N_3^+ ion intensity was shown to be less than 1 part in 10^7 of the N_2^+ ion intensity.

The present results also confirm the earlier finding that the intensity of the nitrogen afterglow is proportional to the square of the concentration of nitrogen atoms. The concentration of N atoms was varied by a

¹ J. Berkowitz, W. A. Chupka and G. B. Kistiakowsky, J. Chem. Phys. 25, 457 (1956).

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factor of about 20 (while light intensity varied by a factor of about 400) as compared to a factor of about 2 in the work of Berkowitz, Chupka and Kistiakowsky.¹

The dependence of the afterglow intensity on the N₂ pressure was anomalous in that it was found to be distinctly less than linear. If this is confirmed by more accurate experiments, it will necessitate a change in currently proposed mechanisms for the reaction producing the afterglow. However, there was some indication that possibly these results may be explained by a predominance at lower pressure of a continuous afterglow caused by oxygen impurity in the nitrogen.

In another experiment, nitric oxide (NO) was introduced into the active nitrogen in the reaction chamber. This resulted in the emission of a strong continuum in the visible region of the spectrum and a very rapid depletion of the concentration of N atoms. It has been postulated by previous workers that this reaction involves production of oxygen atoms and their subsequent recombination which, when catalyzed by NO, is known to result in emission of such a continuum. A search was made for oxygen atoms and they were detected in readily measured amounts.

The apparatus has been dismantled to make improvements and additions.

29-8 Gaseous Species in Equilibrium at High Temperatures (5230)

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

The mass spectrometric technique described in previous reports¹ has been used in the study of barium sulfide, the tantalum oxide-tungsten

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

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system and boron metal.

I. BARIUM SULFIDE

This system was chosen for investigation since available data indicated that barium sulfide might evaporate with sufficient decomposition to give measurable amounts of S atoms and S_2 molecules in the vapor. When barium sulfide was evaporated from a tantalum Knudsen cell, Ba and S atoms and BaS and S_2 molecules were identified and measured in the vapor. The dissociation energy of the S_2 molecule was calculated from the measured S and S_2 partial pressures. The value is $D_0^0(S_2) = 3.8 \pm 0.2$ ev. The dissociation energy of the BaS molecule was also determined, both directly and from a measurement of the heat of vaporization of BaS used in a thermochemical cycle. The considerable discrepancy between these two values is attributed to the fact that much of the evaporating BaS(g) appears to come from the surface of the Knudsen cell rather than from the effusion hole. After the run, visible amounts of some material, probably BaS, are found on the surface of the Knudsen cell around the effusion hole. The substitution of a platinum cell for the tantalum one did not clear up this difficulty since again the BaS vapor appeared to originate largely from the surface of the cell. Further studies are being made in an attempt to eliminate this difficulty.

II. TANTALUM OXIDE-TUNGSTEN SYSTEM

Our previously reported studies of the tantalum-oxygen system² have been extended to the study of the evaporation of tantalum oxide (Ta_2O_5) from a tungsten crucible. This provides a less reducing condition than that which prevailed in the previous experiments. As in the previous

² W. A. Chupka, M. G. Inghram and J. Berkowitz, ANL-5609, p. 90, (Nov. 1956).

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experiments, the vapor consisted predominantly of TaO and TaO₂ molecules and the thermodynamic data for these molecules were the same as those found earlier. No oxide species of higher molecular weight were found, their possible upper limit being 1 part in 300 of the TaO₂ concentration. The results of the investigation of the tantalum-oxygen system have been incorporated in a paper which has been accepted for publication in the Journal of Chemical Physics.

In addition to the TaO and TaO₂ molecules, the vapor from the tungsten crucible containing Ta₂O₅ consisted of appreciable amounts of WO₃ and WO₂ molecules. This indicates that these molecules are quite stable and that by appropriate choice of conditions one can determine their atomization energies.

III. BORON

The previously reported³ experiments on the vaporization of boron are being carefully repeated since they are in serious disagreement with unpublished results obtained by Dr. Alan W. Searcy of the University of California. So far the new results appear to be in agreement with our earlier ones.

³ Berkowitz, Chupka and Inghram, ANL-5667, p. 72, (Jan. 1957).

34-12 A⁴⁰ -K⁴⁰ Dating of Meteorites (5220)

Peter Eberhardt, Johannes Geiss and David C. Hess
Reported by David C. Hess

The experiments with Geiss have been concluded and the material has been prepared for publication. It has not yet been submitted to a journal.

The argon-potassium work is to be continued with the cooperation of Dr. Eberhardt at the Enrico Fermi Institute for Nuclear Studies.

38-4 Mass Spectrometric Study of Charged Atomic and Molecular
Products of Nuclear Transformation (5230)

D. C. Hess and S. Wexler
Reported by S. Wexler

Investigation of the ionic dissociation products of compounds from internal conversion of 4.5-hr $\text{Br}^{80\text{m}}$ and β - γ decay of 36-hr Br^{82} has begun. A gaseous mixture of active $\text{C}_2\text{H}_5\text{Br}^{80\text{m},82}$ and $\text{C}_2\text{H}_4\text{Br}_2^{80\text{m},82}$ of high specific activity was used in the initial experiments. Preliminary results indicate the presence of peaks in the vicinities of masses 29 and 110, both of which are at least double. There is some indication of mass 2. These peaks are tentatively assigned to C_2H_3^+ , C_2H_5^+ , $(\text{C}_2\text{H}_5\text{Br}^{79})^+$, $(\text{C}_2\text{H}_5\text{Br}^{81})^+$ and H_2^+ , respectively. Peaks which could be associated with singly or multiply charged Br were not observed.

Experiments are now being made in order to find out which of the above ions are the result of decay of $\text{Br}^{80\text{m}}$ and which are from Br^{82} . A revised procedure for synthesis will make available for study a single compound rather than a mixture. The detector will be shielded more effectively to reduce the relatively high background count, which results from accumulation of active material in the traps. The high background may have obscured the several Br peaks expected from the isomeric transition of $\text{Br}^{80\text{m}}$.

The runs with the radioactive gases were performed with a 1.2-liter cone installed in the mass spectrometer. This cone was a modified Erlenmeyer flask with platinum bands painted on the inside. Tungsten lead-ins allowed setting the potential of each band so as to produce an electric guide

field directed along radii from the aperture at the mouth of the flask. The "slit" was a hole of 0.140-inch diameter. A filament was introduced for ionization by electrons when calibration was desired.

The large cone to be used ultimately has been modified and is being tested for leaks.

40-1 Fragmentation of Methane and Methyl Bromide (5230)

Henry E. Stanton

In discussions with James Morrison of the University of Chicago, it became evident that a study of the fragmentation processes in the simple paraffins could give information on some of the fundamental questions of carbon bonds. Of some importance was the question of how much kinetic energy the carbon atom would have as a result of a complete rupture from molecules like methane.

In order to study this question, the mass spectrometer MA17 was provided with its usual gas ion source and adjusted as an energy-selecting instrument. Methane and neon were introduced into the gas chamber where ions were formed; and an energy analysis was made of each of the fragments C^+ , $(CH)^+$, $(CH_2)^+$, $(CH_3)^+$ and $(CH_4)^+$. Also, in order to monitor the behavior of the machine, Ne^+ and Ne^{++} were measured. A typical trace of the results obtained from the machine is shown in Fig. 16. In this figure, the upper curve represents the number of ions of mass 16 which were recorded in the final collector as the voltage on the condenser was varied to make the spectrometer responsive to ions of differing kinetic energies. The lower curve represents the total beam measured after passage through the condenser and secondary accelerating system but prior to mass analysis. This distribution for the total beam represents the kinetic

energies averaged over all the different masses of ions. It will be relatively little affected by any characteristics peculiar to just one kind of ion and can, therefore, serve as a suitable reference for studying the behavior of the different types of ions. Figure 17 shows a typical energy distribution for the ion H^+ formed in methyl bromide. If the ions of just one particular mass are formed with initial kinetic energy, this should appear as a displacement of the distribution curve of the fragment involved with respect to the distribution curve of the total beam. The method used here consisted of measuring the actual displacements between corresponding half-maximum points on the two curves and converting them to the kinetic energy of the fragments in electron volts. A sample of the actual measurement is shown in Fig. 18. Both the high-energy side and the low-energy side of the distribution curves were measured and the mean was taken to represent the displacement of the maximum points of the two distributions. These values

Fig. 16. The kinetic energy distribution of ions of mass 16 from methane under impact by electrons.

Fig. 17. The kinetic energy distribution of ions of mass 1 from the dissociation of $CH_3 Br$ by electrons.

Fig. 18. The kinetic energy distribution of ions of mass 4 from He.

Fig. 19. The energies of the various ionic fragments from the dissociation of CH_4 and CH_4Br under impact by electrons.

are shown plotted in Fig. 19, together with other similar measurements made during the period.

The measured energies of the fragments from methane were found to be quite small and possibly not real since the displacements of the curves were considerably less than the energy spread of the apparatus. If one formulates a simple picture of the processes which go on, a fast moving electron will transfer energy to a methane molecule and

thereby excite it; this excitation will cause disruption and create the fragments which the apparatus then measures. In the case of methane, the energy of the recoil fragments from the emission of hydrogen ions, atoms or molecules may not be very

great; and, in fact, if some sort of molecular explosion takes place, the C^+ atom could conceivably be left without any kinetic energy. If the results shown in Fig. 19 are real, this latter type of mechanism is certainly not indicated since the ions of mass 12 appear to have some energy. Furthermore, a steady increase in the energies of fragments for progressively smaller masses in the range from 16 to 12 would seem to

indicate that the recoil energy of the heavy fragment is a simple addition of the energies derived from successive emissions of hydrogen atoms or ions,

Because of the smallness of the effects observed with methane, it was decided to try methyl bromide in the hope that the bromine atom would have a sufficiently large inertia to give a larger share of the energy to the fragments with masses between 12 and 15 and thereby make their energies easier to measure. The same procedure used in the analysis of the methane was also used with the methyl bromide except that all possible fragments were analyzed for initial kinetic energy. He, Ne and Kr were used as monitors. These results are also shown in Fig. 19. It is curious to note in this experiment that the Br^+ ions had initial kinetic energies which were different from zero and the same for both isotopes of bromine, as should be the case. One notes, however, the general absence of kinetic energy for any other ions in the two higher mass groups.

In the methyl group of ions (masses 12 to 15), the distribution of kinetic energies appeared much as it did with methane but with only approximately $2/3$ the energy. The very light fragments, H_2^+ and H^+ , appeared to have kinetic energies which were quite high compared to the other fragments.

Unfortunately, unexplained machine difficulties arose during the course of the experimental analysis. In Fig. 18 is shown a direct copy of an experimental trace for mass 4 and for the total beam. One notes that, relative to the total beam, the peak for mass 4 is displaced toward higher energies in this particular example. Although it is difficult to envisage the He^+ ion as being formed with anything but thermal kinetic energies, the observed energies were an order of magnitude higher. The exact reason for this apparent displacement is sufficiently subtle to have escaped

explanation to date but is thought to be a characteristic of the apparatus. Electron voltages used to generate the ions are much too low to have created triply-charged carbon and it is highly doubtful if H_4^+ exists. Since helium was introduced along with the methyl bromide, this ion peak must be attributed solely to it. The cause of the apparent displacement will be the subject of further investigation. For this reason the large energies indicated for H^+ and H_2^+ may not be real. Other discrepancies of a similar nature were found at all ionic masses but generally were not as large, and the data shown in Fig. 19 were corrected on the assumption that these errors were machine errors as evaluated by the monatomic gases used. The validity of this procedure seems borne out at least in the case of the methyl groups, for which Ne^+ and Ne^{++} gave essentially the same displacements although their total accelerating voltages differed by a factor of 2.

Following the experiments, a rather extensive series of tests of the machine characteristics relative to these displacements was carried out in order to see if some of the machine parameters could change the results. As mentioned above, the apparent kinetic energy seemed to be substantially independent of the total accelerating voltage from the point of ion formation to ground. The ion source and energy-selecting systems were carefully kept in the same conditions except for the voltage sweep of the condenser, even though changes in the source potentials appeared to make no change in the displacements unless the changes were so extreme as to all but obliterate the beam. In this connection, at one time the adequacy of the energy transmission of the apparatus was confirmed by deliberately upsetting the distribution of potential inside the ion box to create ions with apparent energies up to 10 v or more. Altering the voltages on the centering electrodes in the

intermediate stack of accelerating slits caused no indication of change in the displacements of the kinetic energy distributions.

As far as is now known, therefore, the initial kinetic energies shown in Fig. 19 are real. During the course of the experiment they could be repeated within about 0.05 ev or less.

The half-width of the peak gives, theoretically, a measure of the energy dispersion in the beam. Throughout this sequence of measurements, the half-widths of the total beam remained remarkably constant, as one would expect. On the other hand, however, whenever a particular ion peak showed initial kinetic energy, it is interesting to note that the half-width of that peak was always greater than for other peaks for which the ions were formed with zero kinetic energy. Generally the half-width of the distribution increased with the initial kinetic energy of the ion. Although the energy spread of the machine was only about double the theoretical value (because of slit widths, etc.), the resolving power was still too poor to resolve thermal energies. With poor machine adjustment, the half-width of the peak for either the ion beam or the total beam would generally be broader than with proper machine adjustment, but this seemed to have no systematic effect on the energy displacements of the two peaks relative to each other.

Up to the present time, no theoretical explanation of these results has been attempted, but efforts will be directed to that phase during the next period.

V. THEORETICAL PHYSICS, GENERAL2-14 Excited States of Light Nuclei (5220)

Dieter Kurath

The results of the computation of M1 and E2 transition widths in the lp-shell are scheduled for publication in the Physical Review, June 1, 1957, under the title: "Radiative Transition Widths in the lp-shell." Since these results indicated a possible need for allowing for some collective behavior, an attempt is being made to introduce such a feature into the model.

3-4 Dynamics of Nuclear Collective Motion (5220)

D. R. Inglis and Kiuck Lee

Reported by D. R. Inglis

STABILITY OF PEAR-SHAPED NUCLEI

When the ellipsoidal oscillator potential that gives rise to the nucleon wave functions in a symmetrically distorted nucleus is modified by a pear-shaped distortion, the mixture of odd and even nucleon states near the highest occupied levels lowers the energy of the asymmetric system. Whether this stabilizes an asymmetric shape depends on how one treats the competing effect associated with keeping the nuclear volume approximately constant. Keeping the volume enclosed by the equipotentials constant, as is done in standard treatments of ellipsoidal deformations, gives a stronger effect acting on all the nucleons and favoring mirror symmetry. It remains to be seen whether among the heavy nuclei special cases can be found in which the proximity of odd and even levels may sufficiently favor

asymmetry to make the existence of stable pear-shaped nuclei plausible.

CHARGE DISTRIBUTION IN PEAR-SHAPED NUCLEI

In order to indicate how the charge distribution may differ from the mass distribution, an extreme model of a heavy nucleus such as Ra^{224} was considered. It pictures the nucleus as two unequal spheres in contact, each sphere consisting of closed neutron shells so as to leave only a few nucleons to fill in the space between them. Minimization of the energy, expressed by means of the empirical constants for the neutron-excess term and the electrostatic term, shows that the displacement of the center-of-charge from the center-of-mass may give an effective dipole moment about equal to that of a proton at the edge of a nucleus.

5-2 Intermediate Surface Coupling in Even-Even Nuclei (5220)

B. James Raz

In order to investigate the transition region between weak and strong coupling in the Bohr-Mottelson collective model, a series of calculations using intermediate surface coupling have been initiated. This study is aimed at explaining the observed deviations from pure rotational spectra by examining the variation of theoretically predicted spectra of even-even nuclei with changes in a) the two-particle interaction and b) the strength of surface coupling. Specifically, the spectra of two equivalent particles with $j = 7/2$ are being calculated, taking account of the two-particle interaction found suitable for Ca^{48} and including varying strengths of surface interaction.

During this reporting period, the energy levels and wave functions of spin $I = 0$ and $I = 2$ have been computed on the AVIDAC for the deformation parameter x between 0 and 2. The energy levels for the $I = 4$ and $I = 6$ states are now also being computed on the AVIDAC, as is the reduced transition

probability $B(E2)$ for the quadrupole transition between the lowest $I = 0$ state and lowest $I = 2$ states for the various values of x .

This quantity $B(E2)$ is experimentally measurable in Coulomb-excitation experiments and there are many data on the variation of $B(E2)$ with A for even-even nuclei. Thus, these calculations can be compared directly with existing experimental data.

15-4 Energy-Level Density of a System of Fermi Particles (5220)

Norbert Rosenzweig

The influence of shell structure on the level density of a highly excited nucleus has been studied on the basis of a simple model for which asymptotic formulas can be obtained in closed form. Our results indicate that the large level spacings which are observed at neutron binding energies in the regions of the magic numbers cannot be explained on the basis of energy differences only. Another consequence of our considerations is that the level density of nuclei should increase more rapidly with energy than is predicted by Bethe's ¹ formula. A paper on the subject is being prepared.

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

17-3 Analysis of Angular Distributions and Correlations (5220)

William C. Davidon

It has become necessary to re-examine the theory underlying the calculation of the beta-decay matrix elements because recent experiments

by Wu,¹ Garwin et al.² and Telegdi,³ require the inclusion of matrix elements previously excluded on grounds of parity conservation. As a result, the program for analysing the angular correlation measurements of T. Novey was temporarily interrupted. It seems likely that a reinterpretation of the unknown parameters will permit the continued use of the program which has been set up, though these parameters now would be different combinations of the matrix elements.

A short paper was written describing the hunting procedure which was developed for this calculation. It will be submitted for publication in the near future.

¹ C. S. Wu, E. Ambler, et al., Phys. Rev. 105, 1413 (1957).

² R. Garwin, L. Lederman, and M. Weinrich, Phys. Rev. 105, 1415 (1957)

³ J. P. Friedman and V. L. Telegdi, Phys. Rev. 105, 1681 (1957).

19-3 Ingoing-Wave Condition in Scattering Theory (5220)

Melvin Hack

The time-dependent method reported previously has been extended to rearrangement collisions. The results provide expressions for the transition amplitudes for rearrangement collisions in terms of modified plane waves. Symmetrical forms of these expressions in terms of modified initial as well as final states have been obtained.

20-2 Angular Distribution of Inelastically-Scattered Deuterons (5220)

Paul Fischer and Morton Hamermesh

Reported by Paul Fischer

The differential cross section for a process which can proceed

via two interaction mechanisms may be written

$$\frac{d\sigma}{d\Omega}(\theta) = \frac{2\pi}{h} |I_1 + I_2|^2,$$

where I_1 and I_2 are the (complex) matrix elements between the initial and final states. Conversely, the observed angular distributions for such a process should yield information about the relative phase angle between the two matrix elements.

As indicated in the last Summary Report, we have been treating inelastic deuteron scattering by such a combined interaction. Results based on an over-simplified treatment using the Born approximation do provide some definite improvements in the "fit" to the data of Haffner.¹ Assuming that this explanation (i. e., that Coulomb excitation and direct nuclear interactions both contribute) is essentially correct, inelastic scattering of deuterons is not as useful as "stripping" or "pick-up" reactions for determining spins and parities of nuclear states, but does possibly provide more detailed information.

Various improvements in the theoretical treatment are being considered since better experimental data will now be available (see Project I-22).

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

42-3 Irreversible Processes in Quantum Mechanics (5230)

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

Reported by Hans Ekstein

A revised version of the paper has been completed, and will be further discussed with the co-author.

43-1 Field Theory of Nonrelativistic Moving Nucleons (5230)

Hans Ekstein

Continuing the line of research outlined previously in connection with program V-44, the methods developed are now being applied to the next order of complexity. Leaving out the complications of the fully relativistic theory, this step takes into account the effect of nucleon motion. The nucleons are described by a nonrelativistic spinor field, the mesons by a pseudoscalar charge-symmetric relativistic field, and the interaction is of the pseudovector type. The primary problem is the magnetic moment of the nucleon. The work probably will be in cooperation with D. Kaplan.

44-7 Fixed-Source Meson Theory (5230)

H. Ekstein, J. C. Swihart and K. Tanaka

Reported by K. Tanaka

The following two papers were presented at the 1957 Midwest Conference on Theoretical Physics at Iowa City.

H. Ekstein "Representationless Formulation of Fixed-Particle Field Theories".

K. Tanaka "Properties of Fixed Nucleons with Pseudoscalar Coupling".

The final version of the paper on the Fixed-Source Meson Theory has been completed and will shortly be submitted for publication.

45-7 Meson-Nucleon Interaction (5230)
(Formerly "Renormalizable Field Theory")

Katsumi Tanaka

Relativistic dispersion relations derived by Chew et al.* are used to study the energy dependence of the S-wave phase shifts in low-energy meson-nucleon scattering. We carry out an S- and P-wave analysis and an S-, P-, and D-wave analysis under the assumption that the ($I = 3/2$, $J = 3/2$) resonance dominates the dispersion integral. The P-wave zero scattering lengths

$$a_{2I, 2J} = \lim_{q \rightarrow 0} \frac{\sin \delta_{2I, 2J}}{q^3},$$

where q is the momentum of the incoming meson in the center-of-mass system and $\delta_{2I, 2J}$ is the P-wave phase shift, are determined numerically from experiments.

* Preprint.

46-4 Scattering of Pions by Complex Nuclei (5210)

Melvin Ferentz and Morton Hamermesh
Reported by Melvin Ferentz

During this quarter it was decided to suspend computations on AVIDAC and to recode the problem for George. This will enable us to restore to the code all of the features that were removed in order to fit AVIDAC's limited memory. It is hoped this problem will be coded in the near future and be one of the first problems done on George after its completion.