ARGONNE NATIONAL LABORATORY
P. O. Box 299
Lemont, Illinois

PHYSICS DIVISION
SUMMARY REPORT

April through August, 1956

Louis A. Turner, Division Director

November, 1956

Preceding Quarterly Reports:

ANL-5497 March and April, 1955
ANL-5498 May through October, 1955
ANL-5554 November 1955 through March 1956

Operated by The University of Chicago
under
Contract W-31-109-eng-38

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

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.

TABLE OF CONTENTS

Titles given in parentheses are those of continuing programs in which no progress has been made, either in work done or in publication, during the current quarter.

		PAGE
 I: <u>EXPERIMENTAL NUCLEAR PHYSICS</u>		
1-12	The Argonne Fast Neutron Velocity Selector Robert E. Cote'	1
2-12	Neutron Detectors George E. Thomas	3
3-12	Cross-Section Measurements with the Fast Neutron Velocity Selector Lowell M. Bollinger	5
6-11	Spiral Velocity Selector for Slow Neutrons Roy Ringo	9
11-12	Installation and Operation of the Van de Graaff Generator Jack Wallace	10
12-2	Integrator of Current in an Ion Beam Frank Lynch	12
14-11	Pulsed Neutron Beam for the Van de Graaff Generator Robert Holland	13
15-8	Stopping Cross Sections of Gases for Heavy Ions Merle T. Burgy	14
16-5	A New Neutron-Counting System F. Paul Mooring	14
17-5	The Energy Spread of Neutrons from Lithium Targets F. Paul Mooring	15

18-3	Differential Cross Sections for Neutron Resonance Scattering Raymond O. Lane	15
20-12	Energy States of Light Nuclei from Charged-Particle Reactions Linwood L. Lee, Jr.	18
21-1	Study of Gamma Rays in Nuclear Reactions Stanley S. Hanna and Luise Meyer + Schützmeister.....	18
22-3	Scattering of Charged Particles Jan Yntema	19
23-1	Resonant Detection of Neutron Energy Groups F. Paul Mooring	19
24-3	The Decay of Sn^{123} (125-day) S. Bradley Burson	24
30-2	Decay of Mo^{101} (14.6-min) and Tc^{101} (14.0 min) David W. Martin	25
31-3	Decay of Yb^{177} (1.9 hr) David W. Martin	31
34-2	Decay of $_{28}\text{Ni}^{65}$ (2.56 hours) S. Bradley Burson	34
49-5	The Decay of $_{50}\text{Sn}^{125}$ (9.7 day and 9.4 min) S. Bradley Burson	34
52-12	Gamma Rays From Fission Induced by Thermal Neutrons Charles M. Huddleston	39
55-4	Capture Gamma-Ray Spectra for Neutrons with Energies from 0.1 to 10 ev. Sol Raboy	41
56-3	Compton-Electron Magnetic Spectrometer for Neutron-Capture Gamma Rays Richard S. Preston	42

57-2	Lifetime Measurements from Recoil Studies Stanley S. Hanna	43
58-2	Energy of Delayed Neutrons from Fission Gilbert J. Perlow	44
60-12	7.7-Meter Bent Crystal Spectrometer Bernard Hamermesh	47
70-12	Measurements of Nuclear Moments by Angular Correlation Victor Krohn	49
80-12	Molecular Beam Studies Leonard Goodman	49
90-12	Cross Sections for 14-Mev Neutrons Harvey Casson, Jack Haugsnes and Louis A. Rayburn....	52
91-12	Neutron Transport Cross Sections; Angular Distribution of Scattered Neutrons Alexander S. Langsdorf, Jr.	55
98-11	(Total Neutron Cross Sections in the Kev Region).....	56
106-1	Calibration of a NaI Crystal and a Long Counter F. Paul Mooring	56
108-6	An He^3 Neutron Spectrometer Frank Lynch	57
109-2	A 10-kv Regulated DC Supply Frank Lynch	59
117-1	Measurement of Neutron Half-Life Using a Diffusion Cloud Chamber Charles M. Huddleston	59
133-12	Design Study for a Multi-Bev Proton Synchrotron John J. Livingood	60
134-4	Atomic Excitation Following β -Decay of Tritium Sol Wexler	61
135-11	Electron-Neutron Interaction Roy Ringo	63

138-1	Characteristics of Multiplier Phototubes Robert K. Swank	64
139-4	Liquid Scintillators Warren L. Buck	67
140-8	A Gaseous Scintillation Counter Charles Egler	75
142-6	Electron Accelerator Robert K. Swank.	76
143-6	Plastic Scintillators Louis J. Basile	76
148-6	Electrical Conduction in Dielectrics Raymond J. Munick	81
149-4	Dynamic Condenser Magnetometer S. Bradley Burson	86
152-3	Radiation Damage to Dielectrics Raymond J. Munick	87

II. MASS SPECTROSCOPY

3-2	Rebuilding of MA-15 William A. Chupka	89
17-7	Long-Lived Activities David C. Hess	89
18-4	Lead Ages of Meteorites David C. Hess	89
27-2	Measurement of Top Gas for Borax III David C. Hess	90
29-6	Gaseous Species in Equilibrium with Metal-Metal Oxide Systems William A. Chupka	90

32-2	Electron Multipliers in Mass Spectrometry; Effects of Molecular Structure Henry E. Stanton	91
34-10	$A^{40} - K^{40}$ Dating of Meteorites David C. Hess	92
36-8	Field Emission Studies Mark G. Inghram	92
37-4	Ion Bombardment of a Solid Target Henry E. Stanton	92
38-2	Mass-Spectrometric Study of Charged Atomic and Molecular Products of Nuclear Transformation Sol Wexler	99

V. THEORETICAL PHYSICS, GENERAL

1-12	The Interpretation of the Energy States of Light Nuclei David R. Inglis	102
2-12	Excited States of Light Nuclei Dieter Kurath	102
3-2	Dynamics of Nuclear Collective Motion David R. Inglis	104
6-2	Polarization of High-Energy Protons by Scattering Maria Goeppert Mayer	105
8-2	Double K-Capture Maria Goeppert Mayer	105
9-1	Multiple-Quantum Transitions of a System of Coupled Angular Momenta Melvin Hack	105
10-8	The Effect of Inelastic Scattering in the Analysis of Scattering Resonances James E. Monahan	106

12-5	Investigation of Neutron Scattering under the Feshbach-Porter-Weisskopf Model of the Nucleus Morton Hamermesh	108
14-5	Analysis of the (d,p) Reactions B. James Raz	109
15-2	The Energy-Level Density of a System of Fermi Particles Norbert Rosenzweig	110
17-1	Analysis of Angular Distributions and Correlations William C. Davidon	111
19-1	Ingoing-Wave Condition in Scattering Theory Melvin Hack	112
35-1	On the Consequences of the Possible Existence of the Hyper-Deuteron Melvin I. Ferentz and Sol Raboy	113
40-1	Quantum Mechanical Ergodic Theorem Hans Ekstein	113
41-1	Scattering in Field Theory Hans Ekstein	113
42-1	Irreversible Processes in Quantum Mechanics Hans Ekstein	114
43-8	The S-Matrix Katsumi Tanaka	114
44-5	Fixed-Source Meson Theory Hans Ekstein	114
45-5	Renormalizable Field Theory Katsumi Tanaka	115
46-2	Scattering of Pions by Complex Nuclei Melvin Ferentz	115
48-1	Dispersion Relations William C. Davidon	116

55-1	Spectra of UF_6 , NpF_6 , PuF_6	
	Maria Goeppert Mayer	116

VII. APPLIED MATHEMATICS

2-12	The Use of the AVIDAC	
	Jean F. Hall	118
13-7	REAC Problems	
	Nye F. Morehouse	119

I. EXPERIMENTAL NUCLEAR PHYSICS1-12 The Argonne Fast Neutron Velocity Selector (5220)

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

With the exception of time taken for routine maintenance, the fast chopper has been operated continuously during the period of this report.

The initial plans for this chopper called for two interchangeable rotors to be used with the same housing and drive system. The first rotor was designed to give high counting rates for partial cross-section experiments utilizing a 25-m flight path and to give resolution which, when used with a 60-m flight path, was about twice as good as that obtainable with the old chopper. The second rotor was to be designed primarily for high-resolution transmission experiments to be done with a flight path of 60 m or more. This second rotor has been designed and construction has been started. This rotor will be different from the first in several respects.

1. Although its slits will be of the same general shape, they will be narrower in order to produce neutron bursts of only 1 to 1.5- μ sec duration.
2. There will be only one set of slits through the rotor instead of two in order to reduce the ambiguity produced

by the simultaneous arrival at the detector of neutrons from consecutive bursts.

3. The uranium-alloy core of this rotor will be larger since operating experience with the first rotor has indicated that more uranium in the beam would be desirable in order to reduce background.

The slits in the new rotor will be cigar shaped and will be formed in the following fashion. The central portion of the slits will be straight and will be cut in one piece of uranium alloy 2-1/2" in diameter. This piece will fit into a 6" uranium-alloy ring in which the slits will taper from 0.045" at the inside to 0.031" at the outside. These two pieces will be held in the main monel portion of the rotor in which the slits will taper from 0.031" to 0.015" at the outside surface of the rotor. It was felt that in order for the pieces to have sufficient strength to withstand speeds up to 22 000 rpm, it would be necessary to cut the slits in solid sections rather than trying to form the slits from many segments. Since this appeared to be a job which was beyond the range of conventional machining techniques, recourse was made to an electric disintegration machine manufactured by the Elox Corporation. This machine had been used to cut the slits in the uranium-alloy core of the first rotor so some firsthand knowledge of its capabilities was available. However, since this new job called for some extension of the technique beyond the point to which it had been proven, preliminary tests

were made in order to determine if certain operations were possible.

These tests have been completed; and on the basis of these, work has begun on the rotor itself. All of the major pieces have been machined approximately to size and the operation of cutting the slits in the central core has been started.

2-12   Neutron Detectors (5220)

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

Further experimentation is being undertaken with noble gas scintillation fission chambers of the type described previously in the quarterly. The purpose of the project is to build a completely closed system which shows no deterioration of pulse quality over a prolonged period. With this system one would hope to use a gas such as xenon and thereby obtain a larger pulse and have a faster response time. A pulse of this type would enable one to differentiate to a greater degree between the alpha-pile-up pulses and the fission pulses and obtain a higher counting efficiency. Such a system has been constructed and is being used for experimentation.

A neutron detector of the boron-plate type has been constructed for use with the fast chopper for relative-flux measurements. One of the electrodes consists of a foil 6.5" x 11" coated with boron to a thickness of

0.05 mg/cm² and mounted on the bottom of the detector housing. The other electrode consists of a grid of 0.002" diameter stainless steel wires spaced at half-inch intervals along the length of a frame.

A single-plate fission detector has been constructed. The foil is 4.9 cm x 17.8 cm and is coated with enriched U²³⁵ to a thickness of 0.5 mg/cm². This detector is for use in the absolute cross-section measurement described in project I-3-12 of this report.

The investigation of boric oxide-zinc sulfide, silver-activated wafers for neutron detection, which has been previously reported in the quarterly, is still in progress. It is hoped that further results will be available for reporting in the next Physics Summary Report.

It has been reported¹ that the decay time of electrons and alpha particles in several organic crystals differ by approximately a factor of two. The suggestion has been made that one may differentiate between two types of radiation by their decay times. With this in mind, an experiment has been set up to attempt to separate gamma and neutron pulses using a boron-loaded liquid scintillator.

---

1. G. T. Wright, Proc. Phys. Soc. B, 69, 358 (1956).

3-12

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

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

a) Pu^{239} - THERMAL MEASUREMENTS

Measurements of the total cross section σ_t , fission cross section σ_f , and η in the energy range from 0.02 to 0.6 ev have continued. Our previous finding that these three independently measured quantities are consistent with a constant value of ν has been confirmed. The results obtained show that the apparent need to allow ν to vary, which was reported from Brookhaven, was caused by errors in their measurements of η .

b) TOTAL AND FISSION CROSS SECTIONS OF Pu^{239}

Total and fission cross sections of Pu^{239} have been measured from thermal energies to about 20 kev. From these data, preliminary parameters have been obtained for the 15 resonances below 42 ev. The probability distribution of the fission widths for these levels is exponential in form within the statistical accuracy of the results.

c) DIRECT MEASUREMENT OF η FOR Pu^{239}

The thick-sample method first used to obtain the energy dependence of η in the thermal-energy range has been extended to

higher energies. In this way directly measured values of η have been obtained near the peaks of the nine levels at energies less than 23 ev. These results are shown in Figure 1, where the upper part of the figure shows the transmission of the sample used. The measurements of η contain no known systematic errors greater than 2 percent. Small corrections have been made for multiple scattering in the sample as well as for the transparency of the sample. Values of η calculated from the resonance parameters are generally in good agreement with those given in Figure 1.

d) INTERFERENCE BETWEEN FISSION RESONANCES

One of the most interesting features of the data on Pu^{239} outlined above is that many of the resonances studied have an asymmetric shape which can not reasonably be explained in terms of single-level Breit-Wigner resonances. The asymmetry can be explained in terms of a multi-level treatment, however; in the most clear-cut case, the measured cross sections in the neighborhood of the 10.9 and 11.9 ev resonances are quantitatively fitted by assuming the fission reaction to have only a single exit channel.

e) MEASUREMENT OF FISSION CROSS SECTIONS BY A NEW METHOD

In the conventional method of measuring fission cross sections, the occurrence of a fission event is identified by the

Figure 1

detection of a fission fragment. We have used an alternative method, that of detecting prompt-fission neutrons, in a measurement of the fission cross section of Pu^{239} in the range from 6 ev to 20 kev. The detector used was that employed in direct measurements of η . Its detection efficiency for fission events is about 5 percent. The new technique has several advantages:

a) The same foil may be used for fission and total cross-section measurements.

b) Since the foil can be thick as compared to that in a fission chamber, higher counting rates can be obtained under some conditions.

c) A high α -activity in the sample does not influence the measurements.

The results that were obtained for Pu^{239} are most encouraging although their analysis is incomplete.

f) CROSS SECTION OF Pu^{242}

Using a sample prepared by H. Diamond and R. Barnes of the Chemistry Division, the total cross section of Pu^{242} is being measured. Within the energy range studied, from 1 to 4 ev, one resonance has been found.

g) ABSOLUTE FISSION CROSS SECTION OF U^{235}

A new method of measuring absolute fission cross sections is being developed and used in measurements on U^{235} . The method will be described when useful results have been obtained.

h) CROSS SECTION OF NIOBIUM

The resonance structure of niobium is being studied over the energy range from 30 ev to 15 kev. Four different sample thicknesses are being used so as to be able to obtain resonance parameters for many levels. These parameters are of interest because of the exceptionally small $\bar{\Gamma}_n^o / \bar{D}$ value for niobium.

6-11   Spiral Velocity Selector for Slow Neutrons   (5220)

. Roy Ringo

This apparatus has been tested at speeds up to 5000 rpm, at which it should transmit neutrons with wavelengths of about 6 Angstroms. A number of small troubles were found and corrected and the selector now appears to operate reliably at this speed. A shield has been built which serves the twofold purpose of keeping scattered radiation down to low levels in the reactor room and protecting the room from flying fragments in the event of an accident to the rotor.

In a test with a thermal-neutron beam, it was found that the selector was too transparent to thermal neutrons. An attempt is being made to remedy this by heavier cadmium plating on the selector laminations and new positions for the laminations.

11-12   Installation and Operation of the Van de Graaff (5220)
Generator

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

This report covers the operation of the Van de Graaff
 Generator in D-203 for the period April 2, 1956 to August 31, 1956 .

The generator was used to accelerate the following particles:

<u>Particle</u>	<u>Energy Range</u>	<u>Beam Currents</u>
protons	1.0 Mev to 3.75 Mev	1 to 20 microamperes
deuterons	2.0 Mev to 2.90 Mev	1 to 2 microamperes
He ⁺	0.5 Mev to 3.20 Mev	~ 1 microampere
alphas (He ⁺⁺)	1.0 Mev to 2.10 Mev	{ Sufficient for Stopping - Power Experiment

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

1. Stopping Cross Section of Gases for Heavy Ions	302.1 hours
Burgy	
2. Lifetime Measurements of Nuclear States	186.9 hours
Everett, Hanna, Krone	
3. Study of Gamma Rays from Nuclear Reactions	138.6 hours
Everett, Hanna, Meyer	

4. Resonance Measurement of Neutron Energies	97.8 hours
Lee, Mooring	
5. $F^{19} (p; \alpha, \gamma) O^{16}$	28.2 hours
K. Clark	
6. Checking Counter	12.8 hours
A. Smith	
7. Total Cross Sections	62.7 hours
C. Hibdon	
8. Beam Squeezer	17.4 hours
R. Lane	
9. Irradiation to obtain Be^7	4.1 hours
P. Mooring	
10. Time of Flight	36.8 hours
R. Holland	
11. $S^{32} (d, \alpha) P^{30}$	84.5 hours
Lee, Mooring	
Total hours	<u>969.9 hours</u>

Time Available

(109 days x 15 hours) + (34 days x 8 hours)	1907.0 hours
Start-up and daily maintenance (143 x 0.5)	71.5 hours
Air Conditioning installation	139.8 hours
Machine breakdown, experimental set-up time, and machine time available but not used	726.8 hours

Due to the great variety of experiments performed during this period the machine was opened many times to make minor changes so that the scheduled experiments could be accomplished.

A new Wobble Target assembly has been completed and installed. It is hoped that with it we will be able to obtain and maintain better lithium targets. We also believe it will give us longer periods of trouble-free operation.

We are now having the Electronics Division design and build new magnet circuits and an energy-control circuit. This is a start in the direction of improving our circuitry with the aim of better reliability and trouble-free operation in the near future.

Preliminary tests have been made on the possible use of a Titanium Evapor-Ion type high-vacuum pump. Further tests are awaiting parts for the pump. Tests will be made of the pumping speeds and ultimate vacuum and will be reported in the next quarterly report.

12-2

Integrator of Current in an Ion Beam

(5220)

Frank Lynch

A report describing this device is being prepared for publication.

14-11   Pulsed Neutron Beam for the Van de Graaff Generator (5220)

Robert Holland

Although it is desirable to use trigger circuits as pulse shapers in circuits for time-to-pulse-height conversion, their use introduces a variable delay or "time jitter" which reduces the time resolution obtainable. A time-to-pulse-height converter has been built using the following scheme in an effort to reduce this effect. The counter pulse is first sent to a biased trigger circuit. If the input pulse is large enough, the trigger puts out a standard pulse which is used to gate a second trigger circuit. The counter pulse is sent also through a time delay and limiter to the second trigger. If the second trigger is gated "on", then since it receives a standard input it will produce a pulse after a uniform time delay, thus removing the "time jitter". Although the circuit reduced the "time jitter", it failed (because of a poor limiter circuit) to eliminate it. Work on this circuit will continue.

Some preliminary work on the reaction $\text{Mn}^{55}(\text{p},\text{n})\text{Fe}^{55}$ has been performed. Neutrons with energies corresponding to transitions from the compound nucleus to the ground state and to the first two excited states of Fe^{55} have been observed in agreement with previous work done using nuclear plates.¹

---

1. P. H. Stelson and W. M. Preston, Phys. Rev. 82, 655 (1951).

15-8   Stopping Cross Sections of Gases for Heavy Ions   (5230)

Merle T. Burgy

The measurements of the stopping cross section of argon gas for a helium-ion beam were extended from 900 kev to 4.2 Mev using the Argonne Van de Graaff accelerator. The results at the higher energies were obtained with the use of the doubly-charged helium ions produced by the ion source of the accelerator. The results carry the stopping cross-section curve from the region of its maximum (obtained earlier) to the region in which the change of charge of the helium ions is negligible and the Bethe formula for stopping power is applicable.

A short time was spent checking earlier results using Professor Allison's kevatron at the University of Chicago.

A detailed report of the results obtained thus far in this project is being prepared for publication.

16-5   A New Neutron-Counting System   (5220)

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

The design of the assemblies has been completed and drawings have been presented to the shop for construction.

Until the construction phase is completed, the project will be inactivated.

17-5   The Energy Spread of Neutrons from Lithium Targets (5220)

F. Paul Mooring

Because of the press of Van de Graaff time, the fact that an auxiliary study of the problem is being conducted at St. Louis University, and greater immediate interest in other problems, no work on this project has been undertaken during the past quarter. No further work is being contemplated on the project in the immediate future. Hence the project should be inactivated.

18-3   Differential Cross Sections for Neutron Resonance Scattering (5220)

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

The apparatus¹ employed earlier in making the survey measurements of differential neutron scattering with broad energy resolution has been used with narrow resolution to study the properties of the 585-kev resonance in S^{32} . This resonance is relatively isolated and narrow so that it provides a good standard for the measurement of the energy spectrum of neutron beams. Neutrons produced by the $Li^7(p, n)Be^7$ reaction with the electrostatic accelerator were scattered from a sulfur sample into detectors placed at five fixed angles. The differential cross sections were analyzed in terms of the coefficients, B_L , in a series expansion in Legendre poly-

---

1. A. Langsdorf, Jr., and R. O. Lane, Phys. Rev. 98, 1147 (1955);
A. Langsdorf, Jr., R. O. Lane, and J. E. Monahan, Argonne National Laboratory Report ANL-5567, 1956.

nominals. These experimental coefficients are indicated as circles in Figure 2 and plotted as a function of energy in the center-of-mass (c.m.) system. The measured half-width is 3.8 kev. For B_L to be resonant, $L \leq 2J$, so $J \geq 5/2$, $\ell \geq 2$ for this resonance, as indicated by the strong resonance in B_4 . The solid curves are calculated on the assumptions of $J = 5/2$, $\ell = 2$, a rectangular resolution spectrum 3.7 kev wide, and $\Gamma = 1$ kev. These are seen to give a good fit to the data. Two other independent runs were made over this resonance with the same results. Peterson, Barschall, and Bockelman² concluded from total-cross-section measurements that $J = 3/2$, $\ell = 1$ or 2 and $\Gamma = 1.5$ kev.

The cases of $J = 5/2$, $\ell = 3$ and $J = 7/2$, $\ell = 3$ require observations at more angles for correct analysis since higher terms in the expansion become significant. Hence the detecting tanks are being mounted on a circular track which will afford a means for determining beyond what point the expansion coefficients become negligible. While no multiple scattering corrections have been made, these are not expected to have any serious effect on the basic conclusions concerning the resonance parameters.

---

2. R. E. Peterson, H. H. Barschall, and C. K. Bockelman, Phys. Rev. 79, 593 (1950).

Figure 2

20-12   Energy States of Light Nuclei from Charged-Particle Reactions   (5220)

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

Work on the $S^{32}(d, \alpha)P^{30}$ reaction has been completed and a paper, "Low-Lying T = 0 Levels in P^{30} ", based on this work has been accepted for publication in the Physical Review. Equipment is now under construction for particle- γ -ray coincidence studies using the 180° magnetic spectrometer.

21-1   Study of Gamma Rays in Nuclear Reactions   (5220)

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

It is now possible, on the basis of suitable nuclear models, to compute the spin and parity of nuclear energy levels. In some instances the comparison between theoretical and experimental results remains inconclusive because of discrepancies in the experimental data. In other cases there is disagreement between theory and experiment.

In an attempt to resolve some of these difficulties in nuclei of especial interest, we have undertaken an investigation of the gamma rays produced in nuclear reactions. The program will include the measurement of angular distributions, angular correlations, and polarization.

The reactions $Li^7(\alpha; \gamma, \gamma)B^{11}$ and $Li^6(\alpha; \gamma, \gamma)B^{10}$ are two examples of interest for which the experimental results in the

literature are incomplete and not entirely in agreement with theoretical predictions.

We have made observations on the $\text{Li}^7 (\alpha; \gamma, \gamma) \text{B}^{11}$ reaction using a 3" x 3-1/2" sodium iodide crystal as a detector. A very satisfactory alpha beam was obtained from the Van de Graaff generator. The rotating lithium target assembly, used for the production of neutrons, was ideal for this investigation.

In order to test the experimental arrangement, the gamma rays in the well-known $\text{F}^{19} (\text{p}, \alpha \gamma) \text{O}^{16}$ reaction were investigated. These measurements and the angular distributions obtained in the $\text{Li}^7 (\alpha, \gamma \gamma) \text{B}^{11}$ reaction will be reported when a complete analysis is available.

22-3   Scattering of Charged Particles   (5220)

Jan Yntema

The design of the 60-inch scattering chamber has been completed. Construction of the chamber is approximately 75% completed.

The circuits for detection and current integration are being tested.

23-1   Resonant Detection of Neutron Energy Groups   (5220)

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

A technique for measuring excitation energies of residual nuclei in (p, n) and similar reactions has been developed. Figure 3 is a schematic

SCHEMATIC DIAGRAM OF EXPERIMENTAL SET-UP

(S) POINT OF PARTICLE-NEUTRON REACTION.
SERVES AS NEUTRON SOURCE.

(C) NEUTRON COLLIMATOR.

(R) RESONANT SCATTERER.

(D) RING-SHAPED NEUTRON COUNTER.

(B) NEUTRON COUNTER.

Figure 3

diagram of the experimental set-up. "S" is the point at which the particle - neutron reaction takes place and hence serves as the neutron source.

Neutrons from "S" pass through the collimator "C" and strike a resonant scatterer, "R". A ring shaped neutron detector "D" counts neutrons scattered from "R" while the detector "B" counts neutrons transmitted by "R". The ratio of the number of neutrons scattered to the number transmitted is measured as a function of the energy of the incident particles.

If the cross section of the scatterer is due to a single scattering resonance superposed upon a nearly constant potential-scattering cross section (as in lithium) the measured ratio will remain nearly independent of the energy of the incident particle unless the energy of a neutron group passes through the resonance energy of the scatterer. When this occurs, the ratio will undergo a fluctuation. Knowing the resonance energy of the scatterer and the energy of the incident particle, one can calculate the Q-value for the production of the resonant neutron group and hence the excitation energy of the corresponding state in the residual nucleus.

As a test of the technique we chose to study the reaction, $\text{Mn}^{55} (p, n) \text{Fe}^{55}$. This reaction has been studied previously.¹ Lithium was used as the resonant scatterer. The results of our measurements are shown in Figures 4 and 5. Figure 4 shows, as functions of incident proton energy, the yield of scattered neutrons, the yield of transmitted neutrons,

---

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

Figure 4. Experimental results of the measurements on the $\text{Mn}^{55}(\text{p}, \text{n})\text{Fe}^{55}$ reaction. Top curve - the yield of neutrons scattered from lithium. Middle curve - the yield of neutrons transmitted by lithium. Bottom curve - the ratio of the scattered to the transmitted neutron yields.

Figure 5. Energy-level diagram of Fe^{55} as deduced from our results compared with that deduced from the results of Stelson and Preston.¹

and the ratio of the scattered to transmitted yields. Figure 5 shows an energy level diagram of Fe^{55} as deduced from our measurements together with one deduced from the results of Stelson and Preston.¹ We were not able to obtain significant results below an incident proton energy of 2.00 Mev since the neutron yield was too low. For this reason we did not see the ground state or the first excited state at 420 kev in Fe^{55} . It is planned to use other resonant scatterers to obtain information on these two states in the near future.

24-3   The Decay of Sn^{123} (125-day)   (5220)

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

Previously, three gamma rays were reported to be present in the spectrum of a source which was produced by neutron activation of a sample of Sn enriched in Sn^{122} ; these have energies of 0.252, 0.60, and 1.08 Mev. Intensities of the unassigned gamma rays are being measured relative to the intense 0.395-Mev peak associated with the decay of the 112-day Sn^{113} contaminant which is the only identifiable component of the spectrum.

The 0.252-Mev peak has been observed in samples of normal Sn which were chemically purified after activation. Its intensity in these sources is much greater relative to the 0.395-Mev gamma ray of Sn^{113} than it is in the Sn^{123} source. Therefore this radiation probably cannot be

assigned either to Sn^{123} or to Sn^{113} . Efforts to ascertain its correct isotopic assignment and lifetime continue.

The data of April 24, 1956, from which intensities of the 0.60- and 1.08-Mev gamma rays were estimated, have been evaluated more carefully. At that time, the 0.60- and 1.08-Mev radiations represented approximately 0.32% and 0.75% of the 0.395-Mev gamma ray, respectively. The relative intensities after 149 days had increased to 0.41% and 0.85%. Thus the 0.60-Mev gamma ray decays with a half-life of about 152 days and the 1.08-Mev gamma ray about 126 days. Both results are sufficiently close (well within experimental error) to the reported half-life of 130 days for Sn^{123} to be indicative if not conclusive. The source is too weak to provide adequate data, coincidence experiments being impossible. A new one must be procured before this study can be completed.

30-2   Decay of Mo^{101} (14.6 -min) and Tc^{101} (14.0-min) (5220)

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

In extensive gamma-gamma coincidence experiments the existence in the Mo^{101} decay of all the previously suggested gamma rays was confirmed. A number of additional weaker transitions not visible in the normal spectrum were also resolved in one or another of the coincidence spectra. A total of 22 separate gamma rays are believed to be seen; three of these are weak transitions whose energies are very close to those of

other stronger transitions. For one of these, whose energy is 0.193 Mev, a very weak conversion line can be discerned on the spectrograph plates about 0.002 Mev higher in energy than the K-shell line of the strong 0.1912-Mev transition. The relative intensities of all of these transitions have been estimated by the usual method from the normal collimated spectrum; for some of the weakest unresolved transitions the figure given is really only an upper limit.

Beta-gamma coincidence experiments provided positive evidence for the existence of at least five distinct beta-ray components. It was found that the component of highest energy, previously given as 2.2 Mev, proceeds to an excited level at 0.590 Mev in Tc^{101} .

The proposed level scheme shown in Figure 6 is consistent with all of the experiments, and contains all of the observed transitions except for a pair of 3%-intensity gamma rays of energies 0.080 and 1.66 Mev. These two are coincident with each other, but neither was seen to be in coincidence with any other gamma rays; in particular, the 0.080-Mev transition is definitely not in coincidence with the 0.510-Mev gamma ray. The absolute intensities shown for the gamma rays were established from the intensity of the 0.307-Mev peak, known (see below) to represent about 91% of the total intensity of the daughter Tc^{101} activity. The set of intensities shown in Figure 6 are the original estimates and can be seen to form a consistent set within the uncertainties.

The beta-ray intensities shown were not directly measured, but were deduced from the gamma-ray intensities. The resulting log ft values

PROPOSED DECAY SCHEME OF Mo^{101}

Figure 6

lie between 4.1 and 5.7 for all components except for the 2.2-Mev branch, for which it is 6.6. This may therefore be either ℓ -forbidden or first forbidden, while all the others seem to be ordinary allowed. The experiments show that there is no appreciable ground-state transition.

It may be noted that the scheme contains a pair of coincident gamma rays given as 0.51 and 0.510 Mev. Although this energy was in fact indistinguishable from that of the annihilation radiation from a Zn^{65} source, there was found to be less than a 10% angular correlation in the coincidence rate. From this and from intensity considerations, it is believed to be certain that there are two real gamma rays near this energy, although one is several times as intense as the other.

The 0.191-Mev peak is relatively only about one-tenth as intense in the spectrum in coincidence with all beta rays as it is in the normal spectrum. This fraction was found to be independent of the coincidence resolving time. The conclusion is that the intense 0.191-Mev transition follows a delayed state of lifetime much greater than a microsecond, while the ten-times-weaker 0.193-Mev transition is in prompt coincidence with the beta rays. The delayed coincidences between the 0.191-Mev gamma ray and the beta rays were observed by gating the gamma spectrometer with beta pulses that were delayed about 3 microseconds. From the observed delayed coincidence rate, the known resolving time, and an evaluation of the coincidence efficiency, the half-life of the delayed state was determined to be 9.1×10^{-4} second. Gamma-gamma coincidences observed in this energy region are ascribed to the 0.193-Mev transition.

The only strong K-conversion line observed in the Mo^{101} activity is that of the 0.191-Mev transition. Thus the K-conversion coefficient of this gamma-ray can be determined from the intensity of the K x-ray in a fresh source, before the intensities of the lines of the Tc^{101} daughter have become appreciable. The value obtained was 0.30 ± 0.06 . From this fact and from the lifetime of the parent state, it appears that the transition is either M2 or E3, or perhaps a mixture. There seems to be no possibility that it is M4.

Sources of Tc^{101} were extracted chemically from fairly large samples of normal molybdenum that had been irradiated for one half-life and then aged for a second half-life. Six gamma rays were observed, all of which had been seen before either in studies of the Tc^{101} decay or in Coulomb excitation of the Ru^{101} daughter nucleus. (References are in the previous report). The energies and relative intensities are shown in the level scheme in Figure 7, which has been confirmed by coincidence experiments. No ground-state beta transition was observed. The lower-energy branches shown were not actually observed either because of their low intensity and interference from residual Mo^{101} contamination in the sources. The gamma-gamma coincidence experiments suggested the possibility that there is a weak 0.53-Mev transition in the position shown, but it cannot be the same as the relatively intense 0.543-Mev transition. The latter must be identified with the level reported at 0.522 Mev from the Coulomb excitation studies. The log ft values deduced for the three beta components are all less than 5.8, so all three are allowed.

DECAY SCHEME OF Tc^{101}

Figure 7

The $d_{5/2}$ assignment of the Ru^{101} ground state is established by a measurement of the spin. Among the several possibilities suggested by the shell model for the Tc^{101} ground state, only $g_{9/2}$ thus seems to be tenable. If this is correct, the delayed 0.191-Mev excited state of Tc^{101} cannot be the expected $p_{1/2}$ state, but must be a negative-parity state of spin 3/2 or 5/2. The shell model provides no very ready explanation for such a state. The Mo^{101} ground state may be given the expected $d_{5/2}$ assignment. If the 2.2-Mev beta transition from Mo^{101} is interpreted as first forbidden, the 0.590-Mev level of Tc^{101} would have to be a negative-parity state of spin 7/2 or more. This would be quite difficult to reconcile with the shell model.

The results of this research are being prepared for publication, and it is not anticipated that any more work will be done on these activities.

31-3   Decay of Yb^{177} (1.9 hr)   (5220)

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

No new data have been obtained in this period, but a more detailed analysis of some of the previous data has been made.

The point-by-point difference of normal spectra taken 2 hours apart produces a picture of the short-lived spectrum in substantial agreement with the spectrum obtained in coincidence with high-energy beta rays. Either of these spectra is essentially free of interference from the longer-lived Yb activities. From them the relative intensities of the four gamma rays and of the short-lived portion of the K x-ray peak have been evaluated. The

results are shown in Figure 8. The x-ray intensity can be used to determine the K-conversion coefficient of the 0.150-Mev transition, since this is the only one that gives an observable conversion line in the spectrographs. The value obtained is 0.41 ± 0.04 . This datum can indicate either an M1-E2 mixture with about 96% E2, or an E1-M2 mixture with about 95% E1. The latter explanation has been favored by previous investigators and by a recent report¹ largely because of the observed 1.2×10^{-7} -second lifetime of the 0.150-Mev excited state. It would then be required that the ground and 0.150-Mev states of Lu^{177} have opposite parity. However, the log ft values deduced for the beta rays to these states (the 88% intensity of the ground-state branch has been assumed from previous reports) are 6.2 and 6.9, respectively. Further, the 1.20-Mev state is believed to be a rotational state with the same parity as the ground state, and log ft = 7.9 for the beta ray to this level.

If, on the other hand, it is assumed that the 0.150-Mev transition is predominantly E2, but is abnormally slow for some reason, then the set of assignments shown in Figure 8 is fully consistent and is in agreement with the shell model in all respects. These assignments must be regarded as only very tentative, however, unless an explanation can be found for the lifetime anomaly.

This project is completed, and no further reports will be issued.

---

1. Mize, Bunker, and Starnes, Phys. Rev. 103, 182 (1956).

DECAY SCHEME OF Yb^{177}

Figure 8

32-2   Decay of $_{28}\text{Ni}^{65}$ (2.56 hours)   (5220)

S. Bradley Burson

No further experiments have been carried out on this project. Work was suspended during the design and installation of a new detection system for the 180° beta-ray spectrometer. When this equipment is in operation, the study will be resumed.

49-5   The Decay of $_{50}\text{Sn}^{125}$ (9.7 day and 9.4 min)   (5220)

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

9.7-DAY ACTIVITY

All experimental data have been analyzed and the final results summarized as follows:

The best values of the energies of the seven gamma rays associated with the decay of 9.7-day Sn^{125} , as obtained from both the normal spectrum and various coincidence experiments, are summarized in Table I. (Percentages refer to the total intensity of all beta transitions to excited states, which represent only about 5% of the total decay. The principal beta component constitutes about 95% and decays directly to the ground state of Sb^{125} . This branching was not measured here, but was taken from the results of previous investigators.)

TABLE IGamma Rays Observed in the Decay of 9.7-day Sn^{125}

<u>Energy (Mev)</u>	<u>Relative Intensity</u>
0.342 ± 0.003	9%
0.468 ± 0.003	10%
0.811 ± 0.005	20%
0.904 ± 0.005	18%
1.068 ± 0.004	73%
1.41 ± 0.01	3%
1.97 ± 0.02	24%

The intensities indicated in Table I were obtained by measurement of the areas of the photo-peaks associated with each of the gamma rays. The necessary corrections for photo-peak efficiency as a function of energy were made from empirical curves. For the most part, the beta-ray intensities were deduced from the relative gamma-ray intensities.

9.4-MINUTE ACTIVITY:

The gamma rays found in the 9.4-minute activity, together with their relative intensities, are listed in Table II.

TABLE IIGamma Rays Observed in the Decay of 9.4-Minute Sn^{125}

<u>Energy (Mev)</u>	<u>Relative Intensity</u>
0.326 ± 0.003	99.7%
0.64 ± 0.02	0.3%
1.07 ± 0.02	0.3%
1.39 ± 0.01	1.9%

THE DECAY SCHEME FOR Sn^{125} :

The decay scheme for these two activities as deduced from the entire body of experiments is depicted in Figure 9.

The single-particle assignments shown for the two isomeric states of Sn^{125} and for the ground and first excited states of Sb^{125} have been proposed previously.¹ There are no other choices for these states within the framework of the single-particle model that are compatible with the data. If these are accepted, the observed intensities of the various gamma rays and beta rays permit certain deductions about the spins of the remaining states.

It can be confidently stated that all the excited states of Sb^{125} involved in the decay of 9.7-day Sn^{125} have spins of at least 9/2. Furthermore it seems reasonably certain that all have positive parity; tentative

---

1. M. Goldhaber and R. D. Hill, Rev. Mod. Phys. 24, 179 (1952).

assignments of negative parities to any of them invariably involve serious conflicts of one kind or another with the data. The specific assignments that seem at all possible are indicated. Where only one assignment is shown, it indicates that this one seems to be definitely preferred, although it is not meant to be implied that we regard it as established. The choice of $15/2$ for the 1.88-Mev level is possible only in conjunction with an $11/2$ choice for the 1.07-Mev level. No set of assignments among those shown is without one or more mild objections; in particular, the large log ft of the 1.28-Mev beta ray and the lack of a gamma transition from the 1.97-Mev level to the 1.41-Mev level are hard to reconcile with the other facts.

In the 9.4-minute activity, the lowest-energy beta ray appears to be allowed, indicating that the 1.72-Mev level also has positive parity. It is, however, possible that this beta ray is first-forbidden, and that the level has negative parity. The intermediate state of the 0.64-Mev, 1.07-Mev gamma cascade may have negative parity since no beta ray to it is seen. In any case, it appears that it must have a low spin value, which would indicate that it is not the same level as the one at 1.07 Mev in the 9.7-day decay. Since the order of the cascade is not determined by any experiment, the level may lie either near 1.07 Mev or at 0.64 Mev.

The energies of the principal beta components of the two activities of Sn^{125} , as quoted throughout this study and as shown in Figure 9, were taken from the literature.^{2,3,4} Our own absorption measurements of

2. B. H. Ketelle, C. M. Nelson and G. E. Boyd, Phys. Rev. 79, 242 (1950).
C. M. Nelson, B. H. Ketelle, and G. E. Boyd, ORNL-828 (unclassified) (1950).
3. Raymond W. Hayward, Phys. Rev. 79, 409 (1950).
4. R. B. Duffield and L. M. Langer, Phys. Rev. 77, 743 (1950).

Figure 9

these energies were, within experimental uncertainty, in complete accord with these values. However, we do not, on the basis of our measurements, take any stand on the question of which of the two isomeric states of Sn^{125} lies lower in energy. With the quoted energies it appears that the $h_{11/2}$ state lies lower by about 0.03 Mev. It has been pointed out¹ that this may represent a singular case of an $h_{11/2}$ ground state. However, the value of 2.35 Mev for the 9.7-day beta energy is the average of two independent values which disagree by 0.04 Mev, and the only spectrometer measurement of the 9.4-minute beta energy⁴ is from a different source than either of these. Consequently, we do not believe that the question of which is the ground state can be regarded as settled.

52-12   Gamma Rays From Fission Induced by Thermal Neutrons
(formerly "Neutron Capture Gamma-Ray Studies with a Scintillation Spectrometer")
Charles M. Huddleston and Carroll C. Trail
Reported by Charles M. Huddleston

A study is being made to determine the number of gamma rays per fission and the energies of those gamma-rays as a function of the mode of fission of U^{235} induced by thermal neutrons.

A uranium source, containing more than 90% U^{235} is deposited on a thick nickel backing. The source is 1 microgram/cm² thick.

A gas scintillation counter gives an energy analysis of the fission fragments and subtends a 50% solid angle at the source. The gamma-ray detector is a NaI crystal, which subtends a 1% solid angle at the source and is located along a line normal to the plane of the source in the hemisphere opposite the gas cell.

Figure 10

An angular correlation has been tentatively established between the fragments and the gamma rays. It appears that the gamma rays are emitted preferentially in the same hemisphere as the light fragments.

In Figure 10, the energy spectrum of fission fragments in coincidence with gamma rays of energy greater than 1.2 Mev is compared with that fission spectrum obtained when no coincidences with gamma rays are required. The two curves have been normalized to the same low-energy peak height.

The krypton-filled gas scintillation counter has been stable for the past several months.

55-4   Capture Gamma-Ray Spectra for Neutrons with Energies
from 0.1 to 10 ev.   (5220)

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

The large rings of NaI (Tl) have arrived. The entire package for the detector and anti-coincidence unit has been designed and is now in the shop.

The design of the big lead shield has been finished and is now in the central shops. The collimator is about seventy-five percent completed.

56-3

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

Richard S. Preston

Tests have been carried out with a gamma-ray spectrometer which uses 90° magnetic deflection of the forward Compton-electrons, and detects them in coincidence with the recoil photons scattered at 180° . Attempts were made to detect gamma rays of known energy emitted by materials located in a region of high neutron flux inside the CP-5 reactor. It became apparent, however, that much better shielding than was immediately available would be necessary to keep down the rate of accidental coincidences in the scintillation-counter circuits.

The shielding problem was avoided, for the present, by removing the spectrometer from the region of high background near the reactor. The equipment was then tested with gamma radiation from radioactive sources. The 1.6-Mev gamma ray from La^{140} could be detected with this equipment if a source in the range of 5 to 10 curies was used; however, the thickness of Compton-electron radiator required to make this line prominent was also sufficient to produce an electron-momentum resolution of about 10%. This large line width is caused by the scattering of electrons as they leave the radiator and, in a 90° spectrometer, can be reduced only by decreasing the thickness of the radiator.

This test instrument is now being converted for use as a 270° spectrometer. It is expected that the resolution will be improved.

57-2   Lifetime Measurements from Recoil Studies   (5220)

Stanley S. Hanna

The fast coincidence circuit was delivered by the Electronics Division. The resolving time of the circuit is in the range 10^{-9} to 10^{-8} sec. The equipment may be used with either sodium iodide or plastic scintillators. In addition to the usual tests with various common sources, observations were made on the neutron-gamma coincidences in the $\text{Be}^9 (\alpha, n) \text{C}^{12*} (\gamma) \text{C}^{12}$ reaction produced in a Po-Be source. A plastic scintillator was used for detecting the neutrons and a sodium iodide crystal for recording the gamma rays. As expected, an isotropic directional correlation between neutrons and gamma rays was measured.

The program of measuring nuclear lifetimes by recoil-coincidence techniques can now continue with the aid of this fast coincidence circuit.

Meanwhile, an experiment was undertaken to measure the lifetime of the first excited state of Na^{23} by a Doppler-shift technique, which does not require coincidence detection. The investigation was made in collaboration with R. W. Krone, summer visitor from the University of Kansas, and Allen Everett, student associate from Harvard University.

As a preliminary to the experiment, the sodium iodide detector was calibrated carefully and checked for stability and reproducibility. As

a by-product of this work, a rather accurate value of 480 ± 1 kev was obtained for the energy of one of the Hf^{181} gamma rays.

The reaction selected for the measurement was the inelastic process, $\text{Na}^{23} (p, p') \text{Na}^{23*} (\gamma) \text{Na}^{23}$. When the incident protons have the resonant energy, $E_p = 1.288$ Mev, Na^{23*} nuclei are projected with velocities between 0.6 and 1.7×10^8 cm/sec into a forward cone of $\theta < 30^\circ$. The radiation emitted by the excited nuclei was observed with the sodium iodide scintillator mounted first at 0° and then at 150° with respect to the proton beam. Electronic stability and magnetic drifts were investigated frequently during the measurements with suitable radioactive sources. The Doppler energy shift produced by this change of angle was measured for Na^{23} nuclei traveling in various media: vacuum, xenon gas, sodium chloride (the target material itself), and tantalum. The measured shift of about 0.6 percent is eliminated when the Na^{23} nuclei are stopped in tantalum, indicating a lifetime in the range 10^{-12} to 10^{-13} sec. It is hoped this range can be narrowed by using still other materials for stopping the Na^{23} recoils.

58-2   Energy of Delayed Neutrons from Fission   (5220)

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

The 55-second delayed-neutron period found in fission follows the β decay of Br^{87} which is believed to be formed directly¹. The 22-second

---

1. A. F. Stehney and N. Sugarman, Phys. Rev. 89, 194 (1953).

period has I^{137} as precursor.² In addition, four shorter periods are known, of which the next shortest (5.9 sec) has a bromine precursor.³

Ideas concerning the energy spectra of the various groups have been obtained by paraffin absorption giving mean energies,⁴ by recoils in a cloud chamber,^{5,6} and most recently by use of the He^3 proportional-counter technique.^{7,8} The latter two methods yield actual spectra. The groups are separated by irradiating a sample for time t_1 , waiting until t_2 and measuring in the interval $t_3 - t_2$, these times being chosen appropriately to enhance a given period. Except for the group having the longest period, there is a theoretical maximum (less than 100%) to the purity of the group being examined; and even in the excepted case, considerations of relative abundance make it impractical to effect perfect separation. Therefore one has a set of linear equations connecting the observed spectrum $N_i(E)$ of the i th measurement with the true spectrum $f_j(E)$ of the j th period:

$$N_i(E) = \sum_j a_{ij} f_j(E),$$

where the a_{ij} depend on the periods, the times t_1 , t_2 and t_3 , and the number

-
2. Snell, Levinger, Meiners, Sampson and Wilkinson, Phys. Rev. 72, 545, (1947).
  3. N. Sugarman, J. Chem. Phys. 15, 544 (1947).
  4. Hughes, Dabbs, Cahn, and Hall, Phys. Rev. 73, 111 (1948).
  5. Bonner, Bame and Evans, LADC-2083
  6. Burgy, Pardue, Willard and Wollen, MDDC-16
  7. Batchelor, Aves and Skyrme, Rev. Sci. Instr. 26, 1037 (1955).
  8. R. Batchelor and H. R. Hyder, Harwell report NRDC 87

of cycles and recycling time if the sample is re-irradiated before completely decaying. The desired spectra are obtained by solving for the f_j , a process whose accuracy is strongly dependent on the errors in the N_i and the a_{ij} . Chemical isolation of the groups improves the accuracy.

There has recently become available a spectrometer for neutrons in the energy range 0.05 to about 1.5 Mev⁹ which possesses certain advantages for measurements on the delayed neutrons. It was decided to look at the 55-second group with chemical separation using the techniques of reference 1. Uranyl nitrate hexahydrate (UNH) samples were irradiated at the "rabbit" of CP-5 and the bromine was isolated in about 1 minute. It was apparent after a few separations that the spectrum was continuous within the 10% resolution possible, and therefore that the acquisition of a useful number of counts would take many more separations than would be required for a spectrum containing only a few discrete lines. This method was abandoned as being too time-consuming.

A preliminary look was then taken at the 22-second group, isolated without chemistry to a purity of about 80% by choice of t_1 , t_2 and t_3 . This spectrum was also observed to be continuous.

At present a method of continuous-flow chemical separation is being used for the isolation of Br⁸⁷ and if it fulfills its present promise,

---

9. G. J. Perlow, Rev. Sci. Inst. 27, 460 (1956).

it will be modified and tried also on I^{137} . A solution of enriched UNH in dilute HNO_3 is irradiated continuously in a beam in the thermal column of CP-5. A mixture of air and bromine is bubbled through the solution. The carrier bromine rapidly exchanges with active bromine (except for that fraction occurring as BrO_3^-) and is swept out. Iodine is strongly discriminated against by its greater solubility in aqueous solution and by its shorter life-time. Bubbling through acid permanganate solution removes additional iodine. The gases pass down a drift tube to permit the decay of activities shorter than 22 seconds and are then bubbled through CCl_4 where the bromine remains for a considerable time. The neutron spectrometer observes the neutrons emitted from the CCl_4 vessel acting as a source. The source strength is about 5×10^5 neutrons/sec and the purity is $\geq 90\%$ as determined by decay data taken with a long counter.

60-12   7.7-Meter Bent Crystal Spectrometer   (5220)

Bernard Hamermesh, David Rose and Robert K. Smither
Reported by Bernard Hamermesh

The spectrometer is being used with the 6" x 4" quartz crystal. A new quartz crystal, 12" x 12" in size and 4 mm thick, was received. An attempt to bend it will be made soon. A report describing the detailed design and constructional features of the spectrometer has been completed.

The study of the spectrum of capture gamma rays from gold is still in progress. The region from 440 kev down to 80 kev has been studied in detail. A preliminary study of the region from 440 kev up to 7 Mev was made. Very few lines were found in this latter region—in contrast with the large number found in the region of lower energy. At the present time the following lines have been found. The energy in kev is given first and the intensity in photons per 100 neutron captures is then given in parentheses: 439.0 (1.73), 380.8 (5.44), 370.4 (1.40), 354.5 (1.05), 350.4 (2.42), 343.5 (2.53), 328.6 (3.63), 316.5 (1.85), 311.6 (1.45), 307.4 (1.40), 291.6 (2.82), 276.7 (1.97), 271.2 (2.08), 261.0 (13.02), 247.3 (11.84), 239.0 (2.72), 235.4 (8.24), 219.2 (1.03), 215.1 (22.19), 208.0 (1.53), 204.0 (1.85), 193.7 (9.19), 187.9 (1.50), 185.4 (0.71), 180.7 (1.24), 170.0 (4.10), 168.3 (10.47), 166.1 (1.14), 162.7 (0.80), 158.5 (8.06), 145.1 (0.58), 97.1 (10.76).

It has been possible to make a tentative decay scheme using the above lines. The scheme predicts certain lines that have energies lower than the 80-kev limit that has been covered to date. It is planned to look for these lines in order to check the tentative decay scheme.

70-12   Measurements of Nuclear Moments by Angular
Correlation   (5220)

Victor Krohn and Sol Raboy
Reported by Victor Krohn

An attempt is being made to improve the precision of the measured value of the gyromagnetic ratio of the 10^{-8} -sec state in Ta^{181} , but up to the present time the results are no better than those obtained about two years ago. Considerable time has been spent improving the new coincidence apparatus.

80-12   Molecular Beam Studies   (5220)

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

Atomic-beam magnetic-resonance experiments have been carried out with the radioactive isotope, metastable In^{113} . The first resonance observed was at 5 Mc/sec. This resonance was broad and distorted and showed the effects of too much R. F. power. This observation did, however, allow us to infer that the value of the spin is $1/2 \hbar$ and to make a fairly good estimate for a higher-frequency resonance. The measurement was therefore not repeated with higher precision.

Higher-frequency resonances of $\text{In}^{113\text{m}}$ in the atomic $P_{1/2}$ state were found at 12.297, 24.933, and 65.065 Mc/sec at homogeneous fields such that the atomic $P_{3/2}$ In^{115} resonances were 12.297, 25.015, and 65.788 Mc/sec, respectively. The precision of these measurements was

limited by drifts in the homogeneous magnetic field during the collection period and gave rise to uncertainties of 20 to 30 kc/sec. Equipment is being designed to monitor the homogeneous field continuously during the collection period so that the precision of the measurements may be improved in the future.

The above data establish the spin of $\text{In}^{113\text{m}}$ to be $I = 1/2 \hbar$, the magnitude of the magnetic moment $\mu = 0.217 \pm 0.002 \text{ nm}$, and $\Delta\nu = 805 \pm 8 \text{ Mc/sec}$ for the hyperfine interaction.

Our present program is to search for resonances at higher frequencies until the hyperfine interaction is predicted well enough to differentiate between positive and negative magnetic moment by means of a direct hyperfine interaction measurement.

The preparation of the source is somewhat novel and deserves, perhaps, some comment. Two grams of normal tin metal were irradiated in the MTR reactor for about four months. The 1% isotope, Sn^{112} , captures neutrons with a one-barn cross section to form 105-day Sn^{113} which decays via K-capture to the 1.7-hour $\text{In}^{113\text{m}}$. Metallic antimony was added to the irradiated tin metal, and the mixture was heated in the regular oven system to drive off the relatively more volatile antimony. The 2-year Sb^{125} was thus largely eliminated. Normal indium metal was then added to the sample to serve as a detectable material for line-up and for homogeneous-field calibration.

The beam of indium is limited not so much by the vapour pressure at the oven temperature as by the rate of diffusion of indium in liquid tin. For a fixed temperature, the normal-indium beam decreases in time in a manner which indicates that the rate at which indium metal leaves the tin-indium alloy is proportional to the amount of indium left in the alloy. The $\text{In}^{113\text{m}}$ is, however, created continuously from the Sn^{113} decay. The oven is maintained at a temperature such that the rate of escape of indium is too small to disturb the radioactive secular equilibrium appreciably. Under these conditions the evolution of the $\text{In}^{113\text{m}}$ is steady for a given oven temperature and independent of the magnitude of the normal-indium beam.

An important aspect of this technique is that it makes it possible to have in the same molecular beam two materials with quite different vapour pressures but with similar diffusion constants in the involatile liquid matrix. For example, it is possible to investigate the atomic-beam radio-frequency spectroscopy of radioactive antimony using normal indium metal in the same beam to calibrate the homogeneous magnetic field and to line up the beam; both materials would be diffusing out of a common Sn-In-Sb alloy.

90-12

Gross Sections for 14-Mev Neutrons

(5220)

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

GENERAL REMARKS.

Considerable trouble was encountered in the proper operation of the palladium leak assemblies that we have been using in the accelerator. The palladium leak was replaced by a mechanical leak in order to eliminate these troubles and to eliminate the periodic replacement of the palladium sleeve in the leak. This mechanical leak has given excellent service for the past month.

The following changes were made in order to reduce the operating temperature of the ion-source so that tube life would be prolonged and more stable operation could be obtained: (1) A large copper cooling plate was bolted to the chassis in the interior of the pressure tank. (2) A cooling jacket was mounted on that part of the exterior of the pressure tank that is adjacent to the accelerating tube.

Additional remote-control devices have been fabricated and are awaiting installation so that it will soon be possible to operate most of the ion-source controls remotely. Provision has also been made for the installation of a Pu alpha source in the alpha collimator of the machine so that the operation of the alpha counter may be checked more conveniently.

The Pu is deposited on a small metal flag whose position is controlled from the exterior by a small magnet.

Three Zr targets (each target consisting of a 0.003-inch thick by 3/8-inch diameter layer of Zr on a 1/32-inch thick by 3/4-inch diameter Ta backing) were filled with tritium with the able assistance of S. Wexler. The Zr was melted onto the Ta backings by electron bombardment. The targets were then heated to about 1700° C, using an induction furnace, and then allowed to absorb tritium. Enough tritium was absorbed so that the atomic ratio of tritium to Zr was approximately 1.3 to 1. These targets have been in use for the past three months.

A circuit to convert from time-of-flight to pulse-height has been constructed and tested, and is now in use. The circuit is essentially that of Neilson and James¹ with a few modifications. The ultimate time resolution of the circuit appears to be about 0.1 millimicrosecond (measured using pulses from a mercury pulser). A time resolution between 4 and 5 millimicroseconds is obtained using the alpha particles and neutrons from the D-T reaction. The fast coincidence circuits were replaced by the time-of-flight to pulse-height converter-circuit because of the better inherent stability of such a circuit, the greater ease in the daily checking out of the circuit, and the greater number of uses for such a circuit.

---

1. G. C. Neilson and D. B. James, R. S. I. 26, 1022 (1955).

2. ANGULAR DISTRIBUTION OF ELASTICALLY SCATTERED 14-MEV NEUTRONS

This program was interrupted for four months due to machine trouble and the press of more urgent work. Measurements of the differential elastic-scattering cross section of lead have now been resumed.

3. TOTAL CROSS SECTIONS FOR 14-MEV NEUTRONS

The cross sections listed in Table III are intended to supersede the tentative cross sections reported in the previous quarterly report. These results have been communicated to the data-compilation group at Brookhaven National Laboratory for inclusion in a supplement to BNL-325 "Neutron Cross Sections".

TABLE III

<u>Element</u>	<u>Total Cross Section in Barns</u>
Cadmium	4.45 ± 0.14
Palladium	4.32 ± 0.04
Neodymium ²	5.06 ± 0.12
Samarium ²	5.05 ± 0.16
Hafnium	5.38 ± 0.08
Tantalum	4.99 ± 0.08

Transmission measurements have been started on Er^2 , Gd^2 , Ta, Pb, and Fe.

---

2. Made available through the courtesy of Dr. Frank S. Spedding, Iowa State College, Ames Iowa.

The Ta is being re-measured in an attempt to remove a possible discrepancy that was reported in the previous quarterly report.

4. INELASTIC SCATTERING OF 14-MEV NEUTRONS.

Measurements on this phase of the project have been suspended pending the arrival of a multichannel pulse-height analyzer. The latter will analyze the output of the time-of-flight to pulse-height converter.

91-12   Neutron Transport Cross Sections; Angular Distribution of
Scattered Neutrons (5220)

Alexander S. Langsdorf, Jr.

The report, ANL-5567, covering the survey work of this project up to this time, has been issued (dated June 1956, available since August).

The circular track (upon which the detectors can be pivoted) mentioned in previous report ANL-5497, I-91-11, p. 50, has been built and installed. We will have the apparatus reassembled and make more measurements later this year. Earlier data will be rechecked by measurements at more angles, and data will be obtained on several elements not previously measured. Plans are being initiated to do polarization measurements of scattered neutrons using this equipment.

98-11   (Total Neutron Cross Sections in the Kev Region) (5220)

New developments in the theoretical interpretation of the data were under way at the end of the period of this report. Hence it seems desirable to withhold all results until the theory can be tested by applying it to new data obtained recently.

106-1   Calibration of a NaI Crystal and a Long Counter (5220)

F. Paul Mooring and Richard Walter
Reported by F. Paul Mooring

During the measurements on the inelastic scattering of neutrons from sodium¹ it became increasingly evident that it would be desirable to measure the cross section rather than to compare the gamma-ray yield with that from the reaction $B^{10}(n; \alpha, \gamma) Li^7$ whose cross section was known.² To do this one must use a gamma-ray detector calibrated with the geometry of the experiments and also monitor the neutron flux with a calibrated neutron detector. For this and other reasons, measurements were made during the summer to calibrate the sodium iodide crystal used to measure the yield of gamma rays arising from the inelastic scattering of neutrons from sodium and to calibrate the long counter used to monitor

---

1. ANL-5498, V-10-6, p. 122.

2. Petree, Johnson and Miller, Phys. Rev. 83, 1148 (1951).

the neutron flux. Conventional techniques were used. $^{3,4} \text{Be}^7$ was used as a gamma-ray source. Los Alamos Ra-Be neutron sources No. 129 and No. 73 were used as standard neutron sources. As yet the results have not been fully analysed.

108-6   An He^3 Neutron Spectrometer   (5220)

Frank Lynch

Experimental fillings were made of the proportional detector with the epoxy-bonded quartz-insulator assembly. With fillings of 120 psi Argon and 1 psi CO_2 , pulses produced by alpha particles had a rise time of about 1 μsec and a distribution of 6.7 % half-width. The alpha source used was Po on the center wire and cathode. Because of difficulty in keeping this detector tight, a filling with He^3 has not been attempted.

Since high-pressure (up to 300 psi) proportional detectors require extreme gas purity, a large portion of the time has been directed to the development of a detector using brazed ceramic insulators and gold gaskets which may be baked out and evacuated at 500-600° C. The active-metal process of brazing ceramic to metal, widely used in the electronic industry, must be carried out at around 1000° C in a vacuum or an inert atmosphere. A vacuum furnace was set up inside the bell jar of the evapor-

-
3. Maeder, Müller, Wintersteiger, *Helv. Phys. Acta* 27, 3 (1953).
Van Loef, "Gamma Rays from Inelastic Neutron Scattering", Thesis, University of Wisconsin; Bell, Davis, Lazar, ORNL-1975, p. 72.
  4. Allen, AERE-NP/R - 1667 "Flux Measurements with the BF_3 'Long Counter' ".

ation equipment using a molybdenum -ribbon heater and radiation shields. After extensive experimentation, alumina ceramic was brazed to kovar with silver and silver-copper eutectic brazing metal, and Titanium as an active metal. The insulator assemblies and gold gaskets were found to be gas tight. However, upon disassembly of the detector, to install the anode wire and alpha source, one of the seals was broken. Because the center ceramic part which supports the field tube is only 1/8" in diameter where it goes through the outer ceramic disc, breakage frequently occurs at this point. Ceramic parts for a more rugged construction have been ordered and are expected late in October. A furnace is being designed in which the brazing can be done in a He atmosphere. This should greatly facilitate the fabrication since brazing in vacuum results in evaporation of the silver and requires many hours for the work to cool sufficiently to be removed.

Considerable difficulty has been experienced in preventing sticking of the solenoid pump which circulates the gas through the purifiers. Apparently small particles of dust in the system are responsible. The system is being rebuilt for one-pass purification. This will permit passing the filling gas through a molecular sieve to remove water vapor, and through hot uranium turnings and NaK to remove oxygen and water vapor. Because of relatively poor resolution with CO₂ as polyatomic additive, other gases such as N₂ will be tried.

109-2   A 10-kv Regulated DC Supply   (5220)

Frank J. Lynch

This work is completed. No report has been written, since similar work has been reported recently.

117-1   Measurement of Neutron Half-Life Using a Diffusion Cloud Chamber

N. D'Angelo, H. Bryant, G. Cagliotti, and C. M. Huddleston
Reported by C. M. Huddleston

A project has been initiated to measure the half-life of the free neutron with an accuracy higher than that yielded by other experiments.

The proposed experimental arrangement calls for using a crystal spectrometer at CP-5 to select a beam of monochromatic neutrons. The neutrons will then pass through a diffusion cloud chamber in which some of them will decay. Stereoscopic pictures will be taken of the diffusion chamber in order that a photographic record may be made of tracks of decay electrons originating in that volume of the sensitive layer of the cloud chamber which is traversed by the neutron beam.

A bismuth absorber between the crystal spectrometer and the diffusion chamber will absorb gamma rays in the beam more than it will attenuate the neutron intensity. The cloud chamber will have to be surrounded by shielding in order to reduce the background of gamma rays

in the room and to lower the rate of (n, γ) reactions due to scattered neutrons.

The various effects expected in the chamber during operation are:

- (a) electrons due to neutron decay
- (b) electrons due to residual gamma rays in the neutron beam and in the room
- (c) effects connected with neutron scattering and capture in the gas of the chamber and in the bismuth windows of the chamber.

These effects have been calculated on the basis of preliminary measurements of the monochromatic neutron flux in the beam, the gamma-ray background in the reactor room, and the known scattering and reaction cross section of materials to be used.

The main source of error will probably lie in determining the neutron flux.

The cloud chamber and its cooling system are now under construction, and some work has been done on the photographic apparatus.

133-12   Design Study for a Multi-Bev Proton Synchrotron (5240)

John J. Livingood

Due to the expanding nature of the activities of the Particle Accelerator group and the concomitant increasing complexities of admini-

stration, the work of the group was separated from the Physics Division and an independent Particle Accelerator Division of the Laboratory was inaugurated on April 2, 1956. Subsequent Summary Reports of progress on the accelerator will be issued by this new Division.

The report on the activities of the Particle Accelerator Division for the period from April through September, 1956 is being issued as a Summary Report, ANL-5630.

134-4   Atomic Excitation Following β Decay of Tritium (5230)

Sol Wexler

Calculations of the light intensity expected in the 30-ft spectrograph available here indicate that a 5 to 10 percent concentration of atomic tritium in T_2 at 0.5 mmHg is the minimum necessary to make possible the proposed detection of the ultraviolet and visible spectra of the $(He^3)^+$ daughter from the β^- decay of T. The previous report described the conditions under which this steady-state pressure could be achieved. However, this level of dissociation was obtained with the walls of the discharge tube and exposure cell coated with syrupy H_3PO_4 to reduce recombination of the atoms; so the possibility of exchange of the atomic T in the gas phase with the hydrogen of the H_3PO_4 must be considered. The rate of this exchange was measured, employing deuterium as a stand-in for T_2 , by circulating equal amounts of the gas through the discharge for increasing lengths of time. After each discharge period the gas was removed for

isotopic analysis.¹ The results appear in Table IV. It is clear that rapid exchange takes place between atomic D and H_3PO_4 ; after a circulation period of 15 minutes only five percent of the gas is deuterium. This means that the concentration of atomic D toward the end of the 15-minute period was only 0.5 percent since, in the steady state maintained by the discharge, 10 percent of all gaseous species was in the atomic state.

TABLE IV

Exchange of Atomic D with the H in H_3PO_4

(Initial concentration of D_2 in gas) = 99.39 mole percent

Duration of Discharge (minutes)	Mole Percent in Gas			Mole Percent of Deuterium in Gas after Discharge Period
	H_2	HD	D_2	
15	90.10	9.63	0.27	5.1
30	92.95	6.90	0.15	3.6
60	95.70	3.96	0.07	1.9

Similar conditions would undoubtedly prevail if tritium were the gas.

Therefore phosphoric acid (and probably any of the usual hydrogen-containing compounds) is unsuitable as an inhibitor of atomic recombination on the walls.

---

1. The analyses were performed by the group under D. A. Hutchison of the Chemistry Division.

Crystalline KCl and a methyl silicone polymer (General Electric Co. Dri-Film SC-87) were also tried as inhibitors without success. With the former the steady-state concentration of atomic H (in the H_2 gas used in these experiments) was only 0.3 percent. When the polymer was used as surface coating, the atomic concentration fell from five percent on first striking the arc to about one tenth this value after a period of ten minutes.

Because of the difficulties in maintaining a reasonably high steady-state pressure of the atomic species, the resolution of the emission lines of the excited $(He^3)^+$ will be attempted with interference filters rather than the 30-ft spectrograph. This device allows the gas source and the detector to be brought sufficiently close together to increase the solid angle seen by the detector by a factor of 5×10^3 . Either KCl or H_3PO_4 would then be suitable as a wall coating.

A conical gas cell, a light trap and a light-tight holder for the interference filters are being constructed.

135-11   Electron-Neutron Interaction   (5220)

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

Apparatus for the measurement of the anisotropy of the scattering of thermal neutrons by gaseous argon, krypton and xenon has been completed and preliminary measurements have been made. Since it is hoped to reach an accuracy of 1 part in 10^4 in the ratio of the scattering

at 45° to that at 135° extreme care must be taken to exclude sources of error.

So far it has been found that there will be no great trouble in achieving sufficient statistical accuracy and that the apparatus is generally very reliable. The most important effect which has been found is a depression of the efficiency of the BF_3 -filled neutron counters in strong fields of gamma radiation. Thus 0.7 r/hr. dropped the efficiency 1% and 2 r/hr dropped it 8%. (Apparently the plateau had been moved to an appreciably higher voltage.) It will be necessary to use considerable care to make the γ -ray fluxes negligible, or at least nearly equal, at all the counters. Other aspects of the experiment—such as effects of the dead time of the counters, gas purification, beam collimation, effects of gas pressure, etc.—are still under study.

An improved calculation of the correction for center-of-mass motion is being done by W. F. Miller and others in the computer section. The very awkward integral obtained in a straightforward attack on this problem is hard to evaluate even with the computer. However, a promising new approach has been found.

138-1   Characteristics of Multiplier Phototubes   (5230)

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

Some difficulty has been experienced in comparing our observations of the light output of liquid scintillators with those of workers

in other laboratories. Recent discussions with Dr. F. N. Hayes of Los Alamos Scientific Laboratory led to the conclusion that this lack of agreement resulted from variations in the spectral-sensitivity characteristics of multiplier phototubes. Apparently, deviations from the published characteristics are greater than generally assumed. Furthermore, the measured "sensitivity" of the phototube with respect to the scintillator is influenced by spectral characteristics of the reflector and cell.

Since a reliable method of comparing scintillators is of the utmost importance, an investigation of the spectral characteristics of multiplier phototubes (and incidentally of some combinations of reflectors and cells) has been undertaken.

The investigation contemplated may be broken down into four parts:

- (1) Comparison of the relative light outputs of a group of liquid scintillators having a graduated sequence of emission wavelengths, each output being measured by each of a random sample of type-6292 multiplier phototubes;
- (2) Measurement of the emission spectra of the scintillators used in part (1);
- (3) Measurement of the spectral-response characteristics of a few selected phototubes;
- (4) Measurement of the relative light output of the solutions used in part (1) by first converting the light emitted to a common wavelength by means of a fluorescent converter.

Part (4) is useful only as check on parts (1) - (3), since it is not certain that the efficiency of the fluorescent converter is independent of exciting wavelength. However, the theory of luminescence indicates that this should be the case, and it has been shown experimentally to be true for a few materials.

During the period covered by this report, work has been done in setting up equipment, and some measurements have been made. Modifications were made in the single-channel pulse-height analyzer to provide for automatic scanning. Two cells were built for measuring the light output of liquid scintillators. One cell, closed by a ground glass stopper, is made of Pyrex with aluminum oxide packed around the outside as a reflector. The other is an open cup, made of fused quartz, with a reflector consisting of a front-surface evaporated-Aluminum mirror. Although the cells differ in construction and materials, we believe that they will perform identically over the wavelength region of interest: 3300A to 4500 A.

Preliminary measurements of relative light output have been made. Measurements of the emission spectra of the liquid scintillators are in progress, using a Hilger quartz-prism spectrograph and 2537 A ultra-violet excitation.

139-4

Liquid Scintillators

(5230)

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

Using the apparatus and technique described previously in ANL -5554, I-139-3, determinations of optimum concentration, relative scintillation light output, and oxygen quenching have been made for a number of liquid-scintillator solutions not included in the previous report. These new results are listed in Table V. Data obtained thus far indicate that the use of p-xylene as solvent gives somewhat greater light output and about the same oxygen quenching as the use of toluene, while the use of triethylbenzene or phenylcyclohexane as solvent gives reduced light outputs and also reduced oxygen quenching.

HEAVY ELEMENTS IN LIQUID SCINTILLATORS

Some additional information has been obtained on the effectiveness of various "intermediate solvents" in reducing the quenching of scintillation light output resulting from the presence of diphenylmercury in toluene scintillator solutions.

The variation of light output with solute concentration for a solution of 2, 5-diphenyloxazole (PPO) in toluene was compared to that for a similar solution containing, in addition to PPO, a fixed concentration (25 gm/per liter) of diphenylmercury. It was found that approximately 40 gm of PPO per liter of solution were required to obtain maximum light output from the solution containing diphenylmercury, while 5 gm per liter sufficed in the absence of diphenylmercury. Moreover, the maximum relative

TABLE V

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

Solvent ^(a)	Solute	Gas ^(b)	Optimum ^(c) Conc., g/liter	Relative ^(d) Light Output
TL	4-methylterphenyl	argon	20*	0.53
		air	20*	0.40
TL	9,10-diphenylanthracene	argon	10	0.85
		air	7	0.43
TL	2,5-di-(4-biphenyl)-oxazole (BBO)	argon	1*	0.70
		air	1*	0.40
TL	2-(p-dimethylaminophenyl)- benzothiazole	argon	1.0	0.53
		air	1.9	0.32
p-XL	p-terphenyl	argon	5*	0.50
		air	5*	0.36
p-XL	2,5-diphenyloxazole (PPO)	argon	4	0.59
		air	5	0.44
p-XL	2-phenyl-5-(4-biphenyl)- 1,3,4-oxadiazole (PBD)	argon	10*	0.68
		air	10*	0.55
TEB	2,5-diphenyloxazole (PPO)	argon	8	0.46
		air	9	0.37
PCH	2,5-diphenyloxazole (PPO)	argon	12	0.33
		air	10	0.29

(a) TL = toluene; p-XL = p-xylene; TEB = triethylbenzene; PCH = phenylcyclohexane.

(b) Solutions saturated with indicated gas at one atmosphere.

(c) Solute concentration for maximum light output.

(d) MgO reflector and RCA-6342 photomultiplier. On the same scale, air-saturated toluene + 5 g/liter PPO gives a light output of 0.40, and an anthracene crystal gives approximately 1.0.

* Approximate limit of solubility. Light output measured at this concentration.

light output obtained in the presence of diphenylmercury was only 0.185, compared to 0.54 in its absence. Qualitatively similar results have been noted in the study of quenching by dissolved oxygen.

Next, a study was made of the variation of light output from solutions containing fixed concentrations of PPO and diphenylmercury as the solvent toluene is partially replaced by various "intermediate solvents". The latter were selected on the basis of being highly soluble in toluene and possessing spectral characteristics consistent with the requirement for transfer of excitation energy to PPO. As shown in Figure 11, naphthalene proved to be the most effective in overcoming the quenching produced by diphenylmercury, while 2-methylnaphthalene is the least effective of the intermediate solvents investigated. Except for the latter material, the effectiveness of the intermediate solvent increases with concentration up to the limit of solubility.

Finally, the variation of light output with PPO concentration was determined for toluene solutions containing a fixed concentration of diphenylmercury and of each of the three most effective intermediate solvents in turn. As may be seen from Figure 12, the use of such an intermediate solvent increases the available light output while decreasing the required concentration of PPO, producing an effect similar to a decrease in the concentration of diphenylmercury.

Tentative interpretation of the data obtained thus far indicates that diphenylmercury quenches the excitation of both the solvent and the

Figure 11

Figure 12

solute. Quenching of the solvent may be reduced by increasing the solute concentration or by the use of a solvent, such as naphthalene, which is less subject to quenching during the period of its excitation.

OXYGEN QUENCHING IN LIQUID SCINTILLATORS.

It was noted in the previous report (ANL-5554) that an anomaly existed in the observations of air quenching of liquid scintillators containing two solutes. The air quenching factor for toluene containing PPO and diphenyloxazolybenzene (POPOP) was not the product of the air quenching factors for toluene plus PPO and for toluene plus POPOP as expected.

Additional observations have been made of this effect. The results are illustrated by Figure 13 which shows the data for the system: toluene plus p-terphenyl plus naphthylphenyloxazole (α NPO). Curves (1) and (2) show the light output under beta-particle excitation vs. concentration of α NPO in toluene. Curve (1) is for argon-bubbled and curve (2) for air-bubbled solutions. The absolute magnitude of the light output has been normalized to facilitate comparison. Only the change produced by air bubbling is of interest here. As previously reported, fitting of the data to the formula of Kallman and Furst shows the reduction in the limiting value of the light output at high solute concentrations to be a result of quenching of the solute molecules by oxygen. Curves (3) and (4) show similar data for p-terphenyl in toluene. The measured values of light output are smaller than those for α NPO because of the lower sensitivity of the phototube for

OXYGEN QUENCHING OF TOLUENE SCINTILLATOR SOLUTIONS WITH BETA-PARTICLE EXCITATION

Figure 13

the wavelengths emitted by p-terphenyl.

Curves (5) and (6) of Figure 13 show the enhancement of the phototube response when small amounts of α NPO are added to toluene plus 7 g/liter p-terphenyl. This enhancement results from the fact that the terphenyl light is absorbed by the α NPO molecules and re-emitted by them at a longer wavelength (fluorescence). Using the air quenching of α NPO from curves (1) and (2), one would predict that adding α NPO to 7 g/liter p-terphenyl in air-bubbled toluene would result in curve (7). Instead, curve (6) is obtained. This same type of anomaly is obtained when one compares any of the double-solute systems studied with the corresponding single-solute curves.

In the previous report it was suggested that this result might be caused by a non-radiative transfer of energy from one solute to the other. However, the low concentrations of the secondary solute would require that this transfer occur over very large distances (~ 100 Å). On the other hand, the concentrations agree very well with those to be expected on the basis of absorption and re-emission of the terphenyl light by the α NPO. Therefore an alternative explanation is desired. Any alternative explanation requires that the Kallmann-Furst theory be modified. Instead of picturing the quenching of the solvent as a simple competitive kinetic process, suppose that there are two types of quenching which can occur in the solvent: (1) a static quenching, which does not compete with the other processes, and (2) a

kinetic process which is competitive with the processes of emission and energy transfer. In a toluene solution under one atmosphere of air there is one oxygen molecule for about 7000 toluene molecules. The experimental data require that one toluene molecule in four be quenched statically. This requires that each oxygen molecule statically quench 1750 toluene molecules. We are not ready to propose a mechanism by which such quenching can occur, but several possibilities are being considered.

A second alternative explanation of the oxygen quenching of two-solute solutions discards the theory of Kallman and Furst and substitutes a theory proposed by Birks¹. In this theory the electronic-excitation energy from the first level in the solvent is transferred to the solute by radiation and re-absorption. In order to account for the failure to observe emission from the pure solvent, Birks assumes that this radiation is re-absorbed. Upon addition of the solute, absorption by the solute competes with re-absorption by the solvent, and an increase in light output is observed. To obtain agreement with the data on light output vs. concentration for p-terphenyl in toluene, the wavelengths of toluene emission must lie in the region between 2700A and 2900A with the most probable emission wavelength around 2770A. At this wavelength the photon mean free path in toluene is 0.2 mm. Since in our experiment the light generated by the beta particles must pass through about 1 cm of toluene to reach the phototube, it is not unreasonable that we do not observe the postulated emission. However, this theory does present some difficulties, which will not be discussed here.

---

1. J. B. Birks, Scintillation Counters (McGraw-Hill Book Co., Inc., New York, 1953), Chapters 6 and 7.

Proposed experiments using ultraviolet excitation, rather than beta particles, should dispose of any uncertainty about the first of the above postulates. Deciding between the second and third possible explanations is much more difficult, since for macroscopic thicknesses of scintillators they usually predict similar results. However, it is hoped that the use of ultra-violet excitation will greatly simplify the interpretation of results.

140-8

A Gaseous Scintillation Counter (5230)

Charles Egger and Charles M. Huddleston
Reported by Charles Egger

No significant results were obtained this period, partly because of other work. A search is being made for ways of increasing the efficiency of the gas cell.

142-6   Electron Accelerator   (5220)

Robert K. Swank

The electron accelerator was tested under pulsed operation. The pulses from a 1P28 multiplier phototube looking at a plastic scintillator were observed visually on our 5XP11 fast oscilloscope. The time resolution was quite obviously better than we had formerly obtained with the old x-ray pulser setup. As yet no quantitative measurements have been made.

The life of the electron gun has been greatly extended by the simple expedient of raising the heater voltage to compensate for loss of cathode activity. A useful life of more than month may now be obtained.

The operation of this equipment was interrupted because our supply of electron guns was exhausted during the early phases of testing. Shipment of a new supply of guns has now been received. However, the resumption of operation may be further postponed until a new faster oscilloscope is obtained from the Edgerton, Germeshausen and Grier Co. In the meantime, priority is being given to other measurements on liquid scintillators.

143-6   Plastic Scintillators   (5220)

Louis J. Basile

The use of α NPO, BBO, and DPS as wavelength shifters in plastic scintillators has been investigated. These compounds were studied

in combination with either TP or PBD as the fluor additive. In all cases studied, polyvinyltoluene (PVT) was used as the plastic material.

2-(1-NAPHTHYL)-5 PHENYL OXAZOLE (α NPO):

Typical results obtained on our studies with α NPO are shown in Figure 14. α NPO in polyvinyltoluene gave a maximum light response of approximately 33%.¹ A plastic containing α NPO as a wavelength shifter is much more efficient. With a scintillator containing p-terphenyl (TP) as a fluor and α NPO as wavelength shifter, a light response of 44% can be obtained. In combination with phenylbiphenyloxadiazole-1, 3, 4 (PBD) it is interesting to note that α NPO acts as a light quencher. Even with this quenching action, this system is much more efficient than TP + α NPO. This is due to the fact that PBD as a fluor is much superior to TP.

2,5-DIBIPHENYLYLOXAZOLE (BBO)

Results obtained in our studies with BBO are shown in Figure 15. A plastic containing BBO acts as a good scintillator. The curve appears to approach 44% as a maximum. We could not prepare more concentrated solutions of BBO in PVT because of solubility limitations.

In plastic solution, BBO is one of the most efficient wavelength shifters thus far studied. Used in combination with TP, 50% light output is readily obtained. A trace amount of BBO greatly increases the light output as indicated by the sharp rise in the curve. With a scintillator

---

1. All light-output measurements are compared to the output of our standard anthracene crystal which is taken as 100 %.

containing PBD and BBO, light output values as high as 52 - 53% are observed. As is typical of wavelength shifters, an increasing amount of BBO leads to self quenching and results in a decrease of light output.

p,p' DIPHENYLSTILBENE (DPS)

Results obtained on our studies with DPS are shown in Figure 16. The compound is not very soluble in vinyl toluene, hence we were not able to determine the maximum light output of a plastic containing DPS in PVT. As can be seen the curve is still rising.

DPS is the most efficient wavelength shifter studied. In combination with TP, about 51 - 52% light output is observed. The combination of PBD plus DPS gives the most efficient plastic scintillator we have developed. The maximum light output observed is 54%.

HEAVY ELEMENTS IN PLASTIC SCINTILLATORS

We investigated the effect on the light output when diphenylmercury was added to the previously discussed plastic scintillators. Typical curves that were obtained are shown in Figure 17.

Diphenylmercury in a plastic scintillator acts as a quencher. As can be seen from the curves, this quenching action is quite marked. It is interesting to note that there is very little difference between BBO and DPS as wavelength shifters. Although examples are not shown, results using PBD are very similar.

EFFECTS OF POLYMERIZATION TEMPERATURE ON LIGHT OUTPUT

It is well known that the average molecular weight of a polymer chain is dependent on the temperature of polymerization and the degree of polymerization. In general, the higher the polymerization temperature, the lower will be the time for completion of reaction and also the lower will be the average molecular weight. We were interested to see if the polymerization temperature had any effect on the light output of the plastic scintillator.

Preliminary studies were carried out on TP and PBD in vinyl toluene. Samples were polymerized at two different temperatures but for equal periods of time. Results that were obtained are shown in Figure 18. The temperature effect is quite apparent. In general, it appears that polymerizing at a higher temperature results in a plastic scintillator that gives a higher light output. This matter will be investigated more thoroughly in the future.

148-6

Electrical Conduction in Dielectrics

(5230)

Raymond J. Munick

Significant new data were not obtained during this period, but data obtained previously were analyzed and organized. Three results are worthy of note: the conductivity-temperature relationship found for Plexiglas M2, the possibility of a connection between this relationship and the

Figure 18

Light Output vs. Concentration of Fluor

glass transition, and the production of transient electric currents by changes in temperature.

While plexiglas M2 was subjected to a constant potential difference of 313.3 volts, the temperature was varied from 21 to 90°C, and conduction currents were observed that ranged from 1.8×10^{-15} to 2.3×10^{-10} ampere, or, in terms of conductivity, from 3.0×10^{-20} to 3.9×10^{-15} mho per cm. Before measuring current, a given temperature was maintained at least overnight in order to attain thermal equilibrium. In converting current into conductivity, a correction was made for thermal expansion, based on the results of Loshaek.¹ It was thought that the data would fit a curve of the form

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

where σ is the conductivity, T is the absolute temperature, k is Boltzmann's constant, and the σ_i 's and W_i 's are constants. Application of the method of least squares to evaluate the constants gave the result that

$$\sigma_1 = (1.82 \pm 0.40) \times 10^5 \text{ mhos/cm},$$

$$W_1 = 1.4511 \pm 0.0060 \text{ ev},$$

$$\sigma_2 = (2.1 \pm 3.2) \times 10^{23} \text{ mhos/cm},$$

$$W_2 = 2.730 \pm 0.068 \text{ ev}.$$

In Figure 19 are shown the experimental points, the least-squares curve, and the separate exponentials. The curve is similar to that reported for Plexiglas M3.²

---

1. S. Loshaek, J. Polymer Sci. 15, 391 (1955).

2. ANL-5554, I-148-5, p. 101.

Figure 19. Temperature dependence of electrical conductivity of Plexiglas. Solid line is least-squares curve consisting of two exponentials, which are represented separately by the dashed lines.

A conductivity-temperature relationship, such as that shown in Figure 19, is found to be typical of solid dielectrics over the extreme range from high conductivity materials (such as germanium) to low conductivity materials (such as quartz).

The two exponentials contribute equally to the conductivity at 84° C for Plexiglas M2 and at 82° C for Plexiglas M3. These particular specimens of Plexiglas may change from the glass-like to the rubber-like state in the neighborhood of these temperatures, since values as high as 105° C and as low as 70° C have been reported¹ for the transition temperature. It is therefore suggested as a possibility that the first exponential is associated with the glassy state of Plexiglas and that the second exponential is associated with the plastic state.

In a recent abstract³ it was mentioned that changes in temperature produce transient electric currents from Plexiglas. One indication of this was that oscillations in current, even with no potential difference across the specimen, were associated with oscillations in the surrounding temperature.⁴ Another indication was that the current would first decrease and then increase to a higher value as the temperature was increased from one value to another. Dr. B. Gross has informed me of observing similar effects from carnauba wax.⁵

---

3. R. J. Munick, Bull. Am. Phys. Soc. 1, 302 (1956).

4. ANL-5498, I-148-4, p. 94.

5. B. Gross and L. F. Denard, Phys. Rev. 67, 253 (1945); Ann. Acad. Bras. Ci. 14, 349-369 (1942).

149-4

Dynamic Condenser Magnetometer

(5220)

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

None of the remaining mechanical work has been done on the magnetometer itself. The instrument has, however, been used to control the current supply for the spectrometer magnet. The output signal from the magnetometer remains at zero voltage so long as the magnetic field is at the value indicated by the dial settings and swings positive or negative depending upon whether the field is too high or too low. This signal is applied to the controlling grid of the balanced amplifier in the stabilized current supply. Hence the current supply receives its error signal from the magnetometer rather than from the sensing standard resistor in the supply itself. It is thus possible to adjust the field to any desired value by one adjustment with complete disregard for hysteresis effects. Using this method of control, two independent runs were made over the "K" internal-conversion peak of Cs^{137} . After 24 hours, the peak was found to have shifted about 0.3%. Whether this instability is due to variation in frequency in the AC power lines or to drift in the stator voltage has not yet been determined.

152-3   Radiation Damage to Dielectrics   (5230)

Raymond J. Munick

A recalibration was made of the entire apparatus; thermistor thermometer to within 0.02°C , current-measuring resistors and capacitors to within 0.3 to 0.5 percent, vibrating reed electrometer, and recording potentiometer. The calibration of the latter two is not critical, since a null method is used in determining the conduction currents.

Plexiglas M3, which had received an accumulated dose of 10^7 roentgens in the Argonne High Level Gamma Irradiation Facility, was kept near 120°C overnight with electrodes connected together before electrical measurements were resumed. Such a procedure had been found to diminish the background current due to temperature fluctuations.¹ Even so, a thermally produced transient² was observed as the specimen was warmed to 51°C with no potential difference across it. After a voltage was applied, other transients were observed when the temperature was changed.

Comparisons of measurements at 51°C before and after irradiation revealed increases of 30 percent in the steady (conduction) current, of 40 percent in the discharging current (polarization current after removal of voltage), and of more than 40 percent in the charging current (polarization current after application of voltage). That the charging current

---

1. ANL-5498, I-148-4, p. 94.

2. ANL-5609, I-148-6, . last paragraph.

was greater than the discharging current was a change from the equality of the polarization currents observed from unirradiated Plexiglas under the same circumstances. A repetition of the measurements after 4-1/2 months revealed no significant changes. A curve that was the sum of two exponentials was fitted to the conduction current vs. temperature data by retaining the activation energies that had been observed before irradiation³ but adjusting the dimensional constants by the method of least squares.

To sum up, the results to date indicate that intense gamma irradiation produces a permanent increase in the polarization currents and electrical conductivity of Plexiglas, but the activation energies for the conductivity remain unchanged. Thermally produced transient electric currents, similar to those seen before irradiation, were also observed from the irradiated specimen.

---

3. ANL-5554, I-148-5, p. 101.

II. MASS SPECTROSCOPY

3-2   Rebuilding of MA-15   (5230)

William A. Chupka

The rebuilding of MA-15 has been completed and the instrument is now in use. Hence there will be no further reports on this project.

17-7   Long-Lived Activities   (5220)

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

Attempts to rehabilitate MA-2 for measurements on this program have been unsuccessful so far because of leaks in the vacuum system. This machine will be repaired when time permits.

18-4   Lead Ages of Meteorites   (5220)

David C. Hess and Royal Marshall
Reported by David C. Hess

Nothing has been done on this project during the report period. The fact that at present this group lacks a mass spectrometer which is available for measurements with a surface-ionization source will make future work more difficult.

Until such time as a suitable mass spectrometer becomes available, no further reports will be made on this project.

27-2   Measurement of Top Gas for Borax III   (5220)

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

No further work has been done since the Borax group has not submitted further samples.

This project will report hereafter only at such times as samples have been received.

29-6   Gaseous Species in Equilibrium with Metal-Metal
Oxide Systems   (5230)

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

Our mass spectrometric technique has been applied to the study of the vaporization of Ta-Ta₂O₅ mixtures from tantalum Knudsen cells. The major molecular species in the vapor were found to be TaO (g) and TaO₂ (g). The Ta-Ta₂O₅ system was not invariant, however. This was indicated by the severe attack of Ta₂O₅ (s) on the tantalum cell, apparently by the formation of an intermediate phase. The ratio TaO (g)/TaO₂ (g) was observed to increase with time, and the vapor pressures of both species diminished with time. As a result, the variation of vapor pressure with temperature was not considered a reliable method for obtaining thermodynamic data for these molecules. Instead only the absolute vapor pressures were employed for the thermodynamic calculations. A

more trustworthy value for the heat of formation of the TaO molecule was obtained from a study of the evaporation of Ta-ZrO₂ mixtures. The following reaction was found to occur:

The temperature variation of ZrO (g) and TaO (g) was measured and the heat of formation of TaO (g) was calculated. These experiments yielded the following dissociation energies: $D_0 (\text{TaO}) = 8.5 \pm 0.3 \text{ ev}$ and $D_0 (\text{TaO}_2) = 15.5 \pm 0.3 \text{ ev}$. This work will be reported at the Thanksgiving meeting of the American Physical Society.

The investigation of the titanium oxides is continuing but there are no conclusive results as yet.

A review article which contains a summary of all our past work with this technique has been accepted for publication in the Proceedings of the International Symposium on Astrophysics of July, 1956.

32-2   Electron Multipliers in Mass Spectrometry; Effects of
Molecular Structure   (5230)

Henry E. Stanton

Nothing was done on this project. It is convenient to carry on this study when the machine is adjusted for high masses. At present the mass range is too low.

34-10   A⁴⁰-K⁴⁰ Dating of Meteorites   (5220)

Johaness Geiss and David C. Hess
Reported by David C. Hess

Measurements have been made on the argon content of several meteorites. Preliminary measurements of the potassium content have also been made in order to check the validity of the spectrophotometer measurements as well as to measure potassium contents below the limit of the spectrophotometer. These measurements were made by isotope dilution with a potassium-41 spike.

Further work will be done and the data reduced this quarter.

36-8   Field Emission Studies   (5230)

Mark G. Inghram

Equipment is being constructed in order to extend the work on field emission to liquid-helium temperatures. Until this construction is complete and the equipment is again in operation no further report will be made.

37-4   Ion Bombardment of a Solid Target   (5220)

Henry E. Stanton

Since the period of the last report, studies of the spectrum of masses associated with the positive-ion bombardment of beryllium have

been continued. It was found that merely deflecting the primary bombarding beam off the target allowed analysis of the background gases under conditions more nearly approaching those under which the Be was emitted. This was the result of improved machine adjustments and performance, and better techniques.

It appears probable that most of the peaks which appear are at least partly associated with the target surface, perhaps with occluded gases. For reasons which will appear later, at least a portion of the ions seen as background peaks arise from material which is driven directly off the surface of the target, and which may even partially hide the underlying beryllium from the beam. This seems to be indicated by the results shown in Figure 20. In this figure the maximum values of the ionic yields of a series of kinetic-energy sweeps for the peak at mass 9^+ are shown as the target temperature was first increased from room temperature to about 260°C (lower branch) and then lowered to about room temperature again (upper curve). The final value of the yield of Be^+ ions at room temperature was five times the initial value, presumably due to the cleaning of the target by the heating.

In Figure 20 one notes that on initial heating, the intensity of the Be^+ ion beam increases most rapidly as the temperature of the target rises from 120° to 200°C . Other studies have indicated that the intensities of most of the background peaks reach broad maxima in this

74

Figure 20

same temperature range— as one would expect if the gases were adsorbed on the surface of the target. The peak at mass 23 (Na^+) showed anomalous behavior.

For all the many peaks which were examined, the kinetic-energy distribution of the ions was found to have the high-energy tail characteristic of ions driven from a surface by ion bombardment. The distribution for the Be peak was quite different from all other peaks which were examined. Approximately half of the ions of the Be^+ peak had kinetic energies in excess of 6 ev, whereas the background peaks had less than 10% with energies above this same value. The kinetic-energy distribution for Be^+ ions is shown in Figure 21. The principal difference between this distribution and those for the background ions was its relatively sharp maximum at low energies and its slower decrease in number with increasing energy. Other ions showed a much more pronounced low energy maximum (which was generally broader) and smaller values at high energies. This would seem to show the effects of charge-exchange mechanisms near the target surface which would be expected to make a contribution principally at thermal energies.

One conclusion from this phase of the bombardment investigations is that the troublesome background peaks originate partly on the target surface and partly in the residual gas in the target chamber. They can be reduced greatly (but apparently cannot be eliminated entirely) by

Figure 21

heating the target to 200° C or more.

BERYLLIUM STUDIES

The examination of the yield of Be^+ ions as a function of the mass of the primary bombarding ions has been continued by using neon gas as the source of primary ions.

This filled in a gap which appeared in the last report.

According to the simple theory outlined there, neon ions should produce Be^+ ions more copiously than either helium or air; and such was found to be the case. Some preliminary results indicated that the yield was approximately of the expected magnitude; but investigations of the background show that changes in contamination of the target make it desirable to repeat the measurements.

The distribution in kinetic energy of the Be^+ ions produced by bombardment by neon is shown in Figure 22. Two curves are shown—a linear plot and a log-log plot. One notes that the distribution has a very long high-energy tail reaching to over 300 v. This is almost 10 times the range obtained when helium supplied the bombarding ions (Figure 21). This large range of ion energies caused some difficulties in making the various parameters of the machine track properly. It is possible that lack of tracking could extend the distribution in Figure 21, and this point will be checked as soon as possible. For purposes of comparison, a Maxwell

KINETIC ENERGY DISTRIBUTION OF Be^+ IONS
FORMED BY BOMBARDMENT OF A Be TARGET
BY 1000-eV NEON IONS

TARGET CURRENT $\sim 1.48 \times 10^{-8}$ AMP

Figure 22

distribution calculated for 14000° K is superposed. In Figure 23 the low-energy portion of a similar distribution curve, as taken directly from the recorder trace, is shown together with a Maxwell distribution plotted for the same temperature but adjusted for a different total intensity. The actual distribution of ion energies certainly does not approximate a Maxwell distribution for a single temperature very closely.

38-2

Mass-Spectrometric Study of Charged Atomic and
Molecular Products of Nuclear Transformation

David C. Hess, Sol Wexler and Robert Dimick
Reported by Sol Wexler

During this period the designs of the many parts of the spectrometer were completed, and construction, testing and installation of many of the sections were finished. The following are the major accomplishments in this program:-

1. Design and construction of the slit mechanisms for the source and detector, the modifications of the detector housing, the manifold of the fore-vacuum system, and the gas-circulating system.
2. Completion and vacuum testing of the traps, tube, differential-pumping sections, detector housing and pumps.
3. Accurate alignment of the tube and slits.
4. Design of the spherical deflector and a large conical source. Machining of these is nearing completion.

Figure 23

5. Installation of the electrical power and water lines.
6. Mounting of all the housings of the various sections of the spectrometer (other than the source) and vacuum testing of the assembled apparatus.
7. Design of the vacuum line for preparation of the radio - active gases.

V. THEORETICAL PHYSICS, GENERAL1-12   The Interpretation of the Energy States of Light Nuclei
(5220)

David R. Inglis

This program, which was initiated with the development of the material published in the article entitled "The Energy Levels and Structure of Light Nuclei" in Rev. Mod. Phys. 25, 390 (1953), is now being pursued further by D. Kurath under project V-2, Excited States of Light Nuclei.

Recent work on a closely related topic is being continued under project V-3, Dynamics of Nuclear Collective Motion, and no further reports on this project will be made.

2-12   Excited States of Light Nuclei   (5220)

Dieter Kurath

The computation of M1 and E2 transition probabilities is nearly completed. The results for B^{10} seem to disagree with experimental measurements of branching ratios of gamma rays coming from the excited states $(2,1)^+$ and $(2,0)^+$. The E2 transition from the first excited state to the ground state has an experimentally measured lifetime of:

$$\tau = (7 \pm 2) \times 10^{-10} \text{ sec.}$$

In Table VI the computed lifetime is listed as a function of a/K , the ratio of spin-orbit to central-force parameters.

TABLE VI

$\bar{a}/K$	τ (assuming $r^2 = 10^{-25} \text{ cm}^2$)
1.5	$6.3 \times 10^{-10} \text{ sec}$
	(∞)
3.0	5890
	(∞)
4.5	34.0
6.0	23.5
7.5	20.4

The (∞) insertion means that the nuclear matrix element changes sign between the indicated values of a/K . From the expression for the electric quadrupole moment one can determine $\langle r^2 \rangle$ by comparison with experiment and obtain $\langle r^2 \rangle \sim 1.5 \times 10^{-25} \text{ cm}^2$. Since τ is proportional to $\langle r^2 \rangle^{-2}$, this will lower the lifetimes given in Table VI and will yield the correct magnitude of the E2 lifetime for a/K near 1.5 or near 6.0 and higher.

A summary of results of gamma-transition lifetimes in the 1p-shell will be prepared for publication shortly.

3-2

Dynamics of Nuclear Collective Motion (5220)

David R. Inglis

The contributions of individual nucleons to the angular momentum of a nuclear system, as calculated by wave-mechanical perturbation theory for a rotating spheroidal harmonic-oscillator potential, can also be understood very graphically in terms of classical orbits in such a potential. In two dimensions one has Lissajous figures in the absence of rotation; with rotation these are modified by the Coriolis force into elliptical orbits corresponding to normal coordinates. The lower-frequency orbit, with its long axis along the original low-frequency direction, circulates in the forward direction making a positive contribution to the angular momentum which is large because the orbital motion is faster than the applied rotation. In a quantized treatment such orbits are the first ones filled in a shell, but toward the end of the shell their angular momentum is cancelled by the negative contributions of the higher-frequency orbits which circulate retrogressively. When the $\frac{h}{\Lambda}$ spheroidal distortion is determined by minimizing the oscillator energy, the calculated angular momentum is the same as for the rigid rotation, but this result is found to be quite sensitive to deviations from the oscillator approximation.

The energy-minimization calculation gives an explanation of the intriguing experimental preponderance of positive quadrupole moments.

In the oscillator approximation, prolate deformations are more stable in the first half and oblate in the last half of a shell. A plausible modification of the oscillator potential extends the prolate stability to the last half of the shell also. The mechanism for doing this is the mixing of states (such as 1d and 2s) which are degenerate in a spherical oscillator potential. States with low values of the projection quantum number Ω_1 favor a prolate deformation, and there are more pairs with low values than with high values to be mixed.

6-2   Polarization of High-Energy Protons by Scattering (5220)

Maria Goeppert Mayer

No report on this program is available because of the absence of the author.

8-2   Double K-Capture   (5220)

Maria Goeppert Mayer

No report on this project is available since the author is on leave.

9-1   Multiple-Quantum Transitions of a System of Coupled Angular Momenta   (5220)

Melvin Hack

A multiple-quantum transition is a transition in which several

quanta supply the energy, so that a generalized Bohr frequency condition holds of the form

$$\tilde{E}_f - \tilde{E}_i = n_1 \hbar \omega_1 + \dots + n_r \hbar \omega_r.$$

The n 's are positive integers, with $\sum n_j \geq 2$, and the initial and final-state energies, $\tilde{E}_i$ and $\tilde{E}_f$, include the energy-level shifts due to virtual absorption and emission of quanta. Although these transitions are rare events in the optical region, many cases of multiple-quantum transitions have recently been observed in electric and magnetic resonance transitions between hyperfine levels. The principal characteristics of the multiple-quantum transitions as observed in these experiments are: (1) generalized Bohr frequency condition for resonance, (2) narrow uncertainty resonance width, (3) preferential suppression of transition intensity with decreasing amplitude of the applied radiofrequency field, and (4) dependence of transition intensity on the location of intermediate states.

A paper on the theory of multiple-quantum transitions has been written and has appeared in the Physical Review 104, 184 (1956).

10-8   The Effect of Inelastic Scattering in the Analysis of
Scattering Resonances   (5220)

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

The cross section at 90° and the relative gamma yield at 44° and 88° for the inelastic scattering of neutrons from Na^{23} are shown in Figures 24 and 25, respectively. An attempt was made to analyze the gamma-yield

Figure 24

Figure 25

data using parameters which were found to be consistent with total and inelastic cross-section measurements.¹ The anisotropy in the vicinity of 650 kev, which is almost certainly due to interference between resonance levels, can be explained only by assuming that the resonance at 710 kev is a superposition of two or more levels. In general, however, the data are not sufficiently accurate to resolve any of the remaining questions concerning this reaction. For example, any consistent assumption for the multipolarity of the gamma transition gives results which are within the statistical uncertainties of the experiment.

Although the possibility of an absolute determination of this cross section and also of an extension of this type of experiment to other reactions are being considered, there are at present no definite plans to pursue this investigation in the near future. Reports under the present title therefore will be discontinued.

12-5   Investigation of Neutron Scattering under the Feshbach-
Porter-Weisskopf Model of the Nucleus   (5220)

Morton Hamermesh and Jack Sokoloff
Reported by Morton Hamermesh

The calculations of angular distributions for both the square well and the harmonic oscillator were completed. The final results were expressed in terms of the coefficients in an expansion of the differential cross section in Legendre Polynomials in order to facilitate comparison with experiment.

---

1. ANL-5317, Report V-10-2, p. 97 and ANL-5498, Report V-10-6, p. 122.

Variational expressions were obtained for the phase shifts from a square-well potential. In the few cases tried, the approximate angular distributions thus obtained agree well with the exact calculations.

All the material so far covered was reported in a thesis of J. Sokoloff, accepted by Northwestern University in partial fulfillment of the requirements for the Ph. D.

We have begun examination of the effect of spin-orbit coupling on this model.

14-5   Analysis of the (d, p) Reactions   (5220)

B. James Raz

A full report of the work on the calcium isotopes, entitled "Angular Momentum Coupling and the Internucleon Interaction in the Calcium Isotopes", has been accepted for publication in the Physical Review. This paper with appendices containing all the numerical results has been issued as U. S. A. E. C. report NYO No. 7460 (University of Rochester, Unpublished).

Additional new experimental results on (d,p) reactions have been interpreted and a paper entitled "An Interpretation of New (d,p) Experimental Data in Terms of the j-j Coupling Shell Model" will be given at the Chicago Meeting of the American Physical Society.

15-2

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

Norbert Rosenzweig

Some aspects of the work described in the last ANL Summary Report were reported at the 1956 New Haven meeting of the American Physical Society.¹

A paper entitled "On a Degeneracy Criterion for the Level Density of a System of Fermi Particles" has been submitted for publication in the Physical Review. The formulas derived therein for the level density are valid for all values of the excitation energy, and thus provide a criterion for the validity of the usual (high degeneracy) formulas. It is shown that as the energy of the system increases, the degree to which the usual (high degeneracy) formulas are modified depends strongly on the distribution of the individual-particle levels. If the levels are spaced uniformly, the corrections are especially small. Applications to nuclei are discussed briefly.

---

1. N. Rosenzweig, Bull. Am. Phys. Soc. 1, 304 (1956).

17-1

Analysis of Angular Distributions and Correlations
(5220)

William C. Davidon

A general method has been developed for determining the best values for a set of parameters used for describing a physical situation, together with their errors and correlations. Mathematically, it optimizes a function of n variables, and while doing so, determines the inverse of the matrix whose coefficients are those of the quadratic form in the Taylor expansion of the function in the neighborhood of this maximum. The procedure is similar to that of the Conjugate Gradient Method.¹

Some aspects of this procedure were used by the author for determining the phase shifts in pion-nucleon scattering. Work is now in progress on setting up the complete procedure for the AVIDAC in order to analyze the beta-gamma correlation experiments of T. Novey and possibly the neutron-scattering experiments of A. Langsdorf.

To find the extremum and the error matrix for a quadratic function in N variables requires little time beyond that spent in computing the gradient N times. For more complicated functions, the procedure is an iterative one but converges rapidly. No additional time is required for the matrix inversion usually performed in making a least-square analysis.

---

1. Hestenes and Stiefel, Natl. Bur. Standards, No. 1659 (1952).

19-1

Ingoing-Wave Condition in Scattering Theory (5220)

Melvin Hack

In the calculation of transition amplitudes for scattering problems by use of modified plane-wave final states, a difficulty arises concerning the correct choice of boundary condition for the continuum eigenfunctions which describe the final states. This question arises in connection with a variety of physical problems, familiar examples being bremsstrahlung and ionization collisions. It is known that for such processes the appropriate final states for the calculation of the transition amplitudes employing modified plane -waves are the ingoing-wave continuum states.¹

However no general derivation of the ingoing-wave choice of boundary condition had been given within the framework of the time-independent (stationary-state) formulation of scattering theory. We have developed a uniform time-independent treatment which is applicable to both the cases of bound and continuum initial states, and have shown that a complete expansion in terms of outgoing-wave solutions in the time-dependent theory leads to the same result (ingoing-wave modification of the final state). The method is applicable to the general case of rearrangement collisions.

---

1. G. Greit and H. A. Bethe, Phys. Rev. 93, 888 (1954); M. Gell-Mann and M. L. Goldberger, Phys. Rev. 91, 398 (1953).

35-1

On the Consequences of the Possible Existence of the
Hyper-Deuteron (5210)

Melvin I. Ferentz and Sol Raboy
Reported by Melvin I. Ferentz and Sol Raboy

A paper with this title was published in Il Nuovo Cimento IV, 487-490 (1956). No further work on this contemplated. The following is an abstract of the paper.

It is suggested that the observation of a hyperdeuteron is an indirect method for detection of the neutral cascade particle which is predicted by the scheme of Gell-Mann and that of Salam and Polkinghorne. The consequences for these schemes are examined and some possible methods for preferential selection of one of these schemes are suggested.

40-1

Quantum Mechanical Ergodic Theorem (5230)

Hans Ekstein

A paper on this subject is being prepared, using essentially the mathematical methods developed by von Neumann in 1929.

41-1

Scattering in Field Theory (5230)

Hans Ekstein

A paper has been completed and submitted to Il Nuovo Cimento. The page proofs have been returned, so that the paper will probably appear in November.

42-1   Irreversible Processes in Quantum Mechanics (5230)

Hans Ekstein, in collaboration with N. Rostoker
(General Dynamics, San Diego)
Reported by Hans Ekstein

This paper was begun when the authors were at the Armour Research Foundation. I have completed my part of it. It is now being reviewed critically by N. Rostoker and will be submitted when agreement is reached.

The subject of the paper is the motion of a system under the influence of a periodic time-dependent external force. The main result is a quantum-mechanical derivation of the Boltzmann transport equation.

43-8   The S-Matrix   (5230)

Hans Ekstein and Katsumi Tanaka
Reported by Katsumi Tanaka

A paper entitled "Insensitivity of the Scattering Matrix" has been accepted and scheduled to appear in the October 1, 1956 issue of the Physical Review. This will be the final report of this program.

44-5   Fixed-Source Meson Theory (formerly The Tamm-Dancoff Method) (5230)

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

The meson-nucleon scattering and the magnetic moment

of the fixed nucleon have been considered from the viewpoint of a method which will be reported in Il Nuovo Cimento in November. A new renormalization formalism is used. A report is being prepared for publication.

45-5   Renormalizable Field Theory   (5230)

Katsumi Tanaka

The lowest order, old Tamm-Dancoff equation for pion-nucleon scattering without the closed-loop contribution is renormalized using Cini's method. It is found that the spurious pole of the modified propagator including the nucleon self-energy effect does not appear for any momenta, and for energies of the system in which the lowest-order renormalization scheme is expected to be valid. For the $P_{3/2}$ state with $T = 3/2$, a good fit with the experimental results up to 300 Mev is obtained with $G_1^2/4\pi = 11.6$. For the $S_{1/2}$ state with $T = 3/2$, the value $G_1^2/4\pi = 12.5$ is required to give rough agreement with the experimental results up to 200 Mev.

46-2   Scattering of Pions by Complex Nuclei   (5210)

Melvin Ferentz and Morton Hamermesh
Reported by Melvin Ferentz

There has been nothing worthy of mention done on this problem due to the press of other work.

Work on this problem has been reactivated in September 1956.

48-1

Dispersion Relations

(5210)

William C. Davidon, Marvin L. Goldhaber (University
of Chicago)

Reported by William C. Davidon

The following is essentially the abstract of an article scheduled
to appear in the November 15, 1956 issue of the Physical Review:

The dispersion relations for the spin-flip, forward-scattering
amplitude have been tested against pion-nucleon scattering data for energies
up to 300 Mev. The Fermi set of phase shifts satisfy these relations while
the Yang set do not. From the P-wave phase shifts an approximate value
of 0.1 is obtained for the renormalized coupling constant, $f^2 = (g^2/4M)^2$.

- 1
55-1Spectra of UF_6 , NpF_6 , PuF_6

(5230)

Maria Goeppert Mayer

NpF_6 and PuF_6 have absorption bands in regions where UF_6
has none.¹ These bands must be ascribed to transitions of the 5f electrons
in Np and Pu. The frequencies of the electronic transitions are determined
by an interplay between spin-orbit coupling and the octahedral field of the
six fluorine atoms. Calculations were made to determine these frequencies
as a function of the ratio of the strengths of the two interactions.

1. James K. Brody, Howard H. Claassen and Bernard Weinstock, "Spectra
of UF_6 , NpF_6 and PuF_6 ", Spectroscopy Symposium, Argonne National
Laboratory, February 15, 1956. (Not yet published).

For N_pF_6 , the calculations are relatively easy and seem to agree with the experiments. The spectrum of PuF_6 is much more complicated and comparison with experiment has not yet been made.

VII. APPLIED MATHEMATICS

(Formerly VII. Electronic Digital Computers and VIII. Applied Mathematics and Computation, General. Project numbers under these headings are unchanged.)

2-12

The Use of the AVIDAC

Joseph M. Cook, Mary Anne Fisherkeller, Donald A. Flanders, Burton S. Garbow, Herbert L. Gray, Willard G. Greenhow, Charles Harrison, Jr., Howard E. House, Robert T. Julke, Loretta I. Kassel, Richard F. King, William F. Miller, Diana P. Satkus, William J. Schnoebelin, and Anthony J. Strecok
Reported by Jean F. Hall

Quite a few tabulations of functions were made in this period.

These included (1) the evaluation of certain integrals arising in Fermi Statistics, (2) a table of vapor pressures, (3) a table for thermopile calibration and (4) a table of gamma-ray yields for use in lifetime measurements by the recoil technique.

New data-analysis programs included: (1) wavelength calculations from grating data, (2) a least-squares determination of partial order number from interferometer data and (3) Fourier analysis of neutron diffraction data.

Among the other computations run on the AVIDAC were: (1) a calculation of detector responses using fluxes from the Univac calculations, (2) a Monte-Carlo calculation of the nuclear scattering of pions, (3) buildup of uranium isotopes during pile operation, (4) the solution of the parabolic partial differential equation governing changes of concentration of solute molecules and radicals, (5) the solution of equations outlining the path of a

particle as it gains energy in a circular accelerator after starting with a chosen velocity and position, and (6) calculation of transformations which describe the motion of a particle in a Fossitron accelerator.

13-7

REAC Problems

Jerald Dick and Nye F. Morehouse
Reported by Nye F. Morehouse

Some fuel burnout problems were solved for J. Carter and B. Howard of the Reactor Engineering Division. The work is being reported on by B. Howard.

A study of the control system for the Army Package Reactor is currently being made. The work so far has been reported by D. Shaftman in ALPR-97 and ALPR-106.