-1-

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

PHYSICS DIVISION

QUARTERLY REPORT

DECEMBER, 1953, JANUARY AND FEBRUARY, 1954

Louis A. Turner, Division Director

August, 1954

Preceding Quarterly Reports:

ANL-5140 June, July, and August, 1953

ANL-5141 June, July, and August, 1953 (Secret)

ANL-5174 September, October, and November, 1953

ANL-5175 September, October, and November, 1953 (Secret)

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.

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.

TABLE OF CONTENTS

	Page
I. <u>EXPERIMENTAL NUCLEAR PHYSICS</u>	
1-5 The Argonne Fast Neutron Velocity Selector Lowell M. Bollinger	10
2-5 Liquid Scintillation Neutron Detector George E. Thomas, Jr.	10
3-5 Transmission Measurements with the Fast Neutron Velocity Selector Duane A. Dahlberg	11
5-4 The Absorption and Scattering of Neutrons by Hafnium Lowell M. Bollinger	12
6-4 Spiral Velocity Selector for Slow Neutrons Roy Ringo	12
11-5 Installation and Operation of the Van de Graaff Generator	
1. Instability of the Position of the Ion Beam F. Paul Mooring	12
2. Control Circuits R. Ray Weeks	13
3. Safety Circuits R. Ray Weeks	14
4. The 90° Electrostatic Analyzer R. Ray Weeks	14
5. Targets R. Ray Weeks	18

TABLE OF CONTENTS CONTINUED

	Page
6. Operational Experience	
Jack R. Wallace	19
7. Design of a Fast Rotating Target for Lithium and Tritium	
Alexander S. Langsdorf	21
14-4 (Pulsed Neutron Beams from the Van de Graaff Generator)	
Robert E. Holland	23
15-1 Cross Sections for Stopping of Heavy Ions	
Merle T. Burgy	23
20-5 Energy States of Light Nuclei from Charged Particle Reactions	
David R. Inglis	24
30-5 Scintillation Coincidence Spectrometer	
S. Bradley Burson	27
31-5 (The 1.42 min Isomeric State in $^{192}_{77}\text{Ir}$)	
S. Bradley Burson	28
35-5 Decay Schemes of Long-Lived Rare-Earth Isotopes	
Eugene L. Church	29
38-3 The Radiations from $^{160}_{65}\text{Tb}$	
S. Bradley Burson	32
40-3 The Decay Scheme of $^{52}_{23}\text{V}$	
James M. LeBlanc	33
41-3 The Decay Scheme of $^{117}_{48}\text{Cd}$ and $^{117}_{49}\text{In}$	
James M. LeBlanc	34
43-2 The Decay of the 3.5-min Metastable State of $^{122}_{51}\text{Sb}$	
James M. LeBlanc	34
44-1 The 49-sec Isomeric State in $^{75}_{32}\text{Ge}$	
S. Bradley Burson	34

4

TABLE OF CONTENTS CONTINUED

		Page
45-2	The Short-Lived Activities of Zn James M. LeBlanc	35
46-2	The Decay of $^{77}_{32}\text{Ge}$ (12 hours) and $^{77\text{m}}_{32}\text{Ge}$ (52 sec) S. Bradley Burson	36
47-1	The Decay of 30-min Pt^{199} James M. LeBlanc	41
50-5	Internal Conversion of Capture Gamma-Rays Associated with Gd Carl T. Hibdon	42
51-5	Characteristics of a Scintillation Counter Spectrometer Arthur Recksiedler	43
52-5	Capture Gamma-Ray Spectra Arthur Recksiedler	43
60-5	7.7-Meter Bent Crystal Spectrometer Bernard Hamermesh	44
70-5	Measurements of Nuclear Moments by Angular Correlation Sol Raboy	44
71-5	Angular Correlation of β -Rays and Delayed Neutrons from Br^{87} Leonard S. Goodman	47
80-5	Molecular Beam Studies Leonard S. Goodman	47
90-5	Cross Sections for 14-Mev Neutrons Harvey Casson	48
91-5	Angular Distribution of Scattered Neutrons Raymond O. Lane	49
92-5	Neutron Scattering Cross Sections by Use of the Scattering Chamber Carl T. Hibdon	50

TABLE OF CONTENTS CONTINUED

	Page
96-5 (Pile Absorption Cross Sections)	
David Rose	50
98-4 Total Cross Sections in the kev Region	
1. Analysis of Cross Section Data	
Carl T. Hibdon	50
2. Resonances of Li^6 and Li^7 near 250 kev	
Carl T. Hibdon	64
99-3 Standards for Measurements of Thermal Neutron Absorption Cross Section	
Roy Ringo	66
101-2 A Method for Measuring Radiative Capture Cross Sections	
F. Paul Mooring	67
102-2 (Neutron Cross Sections by Self Detection)	
William A. Reardon	68
109-4 Neutron Diffraction Apparatus	
Roy Ringo	69
110-4 Crystal Spectrometer for .1 to 100 ev Neutrons	
Sol Raboy	69
112-5 The Neutron Spectrum of a Standard Ra-Be Photo Source	
Charles Egger	69
114-3 Development of a Recoil-Type Neutron Spectrometer	
Gilbert J. Perlow	69
120-5 Calibration of a Ra-Be Neutron Source	
Willard C. Jordan	71
133-5 Design Study of a Multi-Bev Proton Synchrotron	
John J. Livingood	71

6

TABLE OF CONTENTS CONTINUED

	Page
135-4 Electron-Neutron Interaction Roy Ringo	72
140-1 A Gaseous Scintillation Counter Charles M. Huddleston	73
 II. <u>MASS SPECTROSCOPY</u>	
1-5 Mass Spectrometric Techniques Mark G. Inghram	75
2-5 Construction and Operation of MA-17 Henry E. Stanton	76
10-5 Search for Rare Naturally Occurring Isotopes David C. Hess	77
12-5 (Double Beta Disintegration of Te^{130}) Richard J. Hayden	77
30-5 The Heat of Vaporization of Carbon Mark G. Inghram	77
31-5 (Studies of Electron Impact) Richard J. Hayden	78
33-5 (Molecular States in Rare Gases) David C. Hess	78
34-5 Argon Age Determinations Richard J. Hayden	79
35-1 Studies of Negative Ion Emission Henry E. Stanton	79

TABLE OF CONTENTS CONTINUED

		Page
 III. <u>CRYSTALLOGRAPHY</u>		
1-5	(Crystal Studies of Technetium Compounds) William H. Zachariasen	80
2-5	Structural Studies of Boric Acids William H. Zachariasen	80
 IV. <u>EXPERIMENTAL REACTOR PHYSICS</u> (Covered in ANL-5274, Program C IV)		
 V. <u>THEORETICAL PHYSICS, GENERAL</u>		
1-5	Interpretation of the Energy States of Light Nuclei David R. Inglis	81
2-5	Energy States of Light Nuclei Dieter Kurath	81
4-5	Investigation of Nuclear Structure Maria Goeppert Mayer	84
5-5	Book on "Elementary Theory of Nuclear Shell Structure" Maria Goeppert Mayer	84
7-5	Collective Description of Nucleon Interactions Melvin I. Ferentz	85
8-5	Monoenergetic Neutrons from Charged Particle Reactions Alexander S. Langsdorf	86
9-3	Investigations on the "Cloudy Crystal Ball" for Heavy Nuclei Bernard I. Spinrad	86
10-1	The Effect of Inelastic Scattering in the Analysis of Scattering Resonances James Monahan	94

TABLE OF CONTENTS CONTINUED

		Page
29-4	Internal Conversion in the L and M Sub-Shells Eugene L. Church	95
31-5	(Configuration Interaction in Iron Group Elements) Norbert Rosenzweig	99
34-5	Quantized Space Time Katsumi Tanaka	99
37-4	On the Relation of the Schrodinger and Boltzmann Equation Katsumi Tanaka	100
39-3	Applications of the Theory of Angular Correlation Norbert Rosenzweig	100
41-2	Solutions of the Dirac Equation for a Free Particle Katsumi Tanaka	101
42-1	Second-Order Focussing for Magnetic Spectrometer Roland F. Herbst	102
43-1	The S Matrix Katsumi Tanaka	102

VI. REACTOR THEORY (Covered in ANL-5274, Program C VI)

VII. ELECTRONIC DIGITAL COMPUTERS

0-3	Report on the Digital Computer Symposium J. C. Chu	104
1-5	(Report on the Design of the AVIDAC) Raymond F. Kramer	104
2-5	Improvements of the AVIDAC David H. Jacobsohn	104
3-5	Operation and Maintenance of the AVIDAC Carl J. Bergstrom	104

TABLE OF CONTENTS CONTINUED

		Page
4-5	(Test Routines for the AVIDAC) Jean F. Hall	105
5-5	(Sub-Routine Library for the AVIDAC) Jean F. Hall	105
6-5	(Coding Manual for the AVIDAC) Donald A. Flanders	105
7-5	The Auxiliary Memory for the AVIDAC and ORACLE Leslie C. Merrill	105
10-5	(Report on the Control of the AVIDAC) Donald A. Flanders	106
13-2	New Memory for the AVIDAC J. C. Chu	106
20-4	Report on Research, Development, and Design of the ORACLE J. C. Chu	107

VIII. APPLIED MATHEMATICS AND COMPUTATION, GENERAL

1-5	IBM Methods and Procedures N. Frank Morehouse	108
2-5	Report on Technical Details of General Purpose Boards N. Frank Morehouse	108
10-4	Three-Group Calculation of Critical Mass and Flux Plots Bernard I. Spinrad	109
12-3	(Computation of Traces of Gamma Matrices) Donald A. Flanders	109

I. EXPERIMENTAL NUCLEAR PHYSICS

1-5 The Argonne Fast Neutron Velocity Selector (5211-01, 5261-01)

Lowell M. Bollinger and Duane A. Dahlberg
Reported by Lowell M. Bollinger

The velocity selector has been disassembled for modification before being reinstalled at CP-5.

2-5 Liquid Scintillation Neutron Detector (5211-01, 5261-01)

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

The development of a simple and reproducible liquid scintillation counting unit of general usefulness has been completed. A detecting system of large area can be formed by the parallel operation of several of these units.

Mechanical Properties

- a) Counting area - 2" x 6"
- b) Outside dimensions - 2-3/4" x 6-3/4"
- c) Counter thickness - 1"
- d) Two independent DuMont 6292 photomultipliers immersed in the counting liquid.

Optical Properties

- a) The added pulse height of the photomultipliers has a maximum difference of $\pm 10\%$, depending upon where the light is formed in the cell.

b) The pulse height in any one photomultiplier varies by a factor of five, depending on whether the light in the cell is formed in front of the photomultiplier or at the extreme end.

c) The pulse-height distribution is approximately triangular with a width at half maximum that is 85% of the value at maximum.

d) The light formed by neutrons entering the counter at random gives a coincidence count about 85% of the time.

e) No essential difference was found between a unit using a porcelain reflector and one using an aluminum oxide reflector.

3-5 Transmission Measurements with the Fast Neutron Velocity Selector
(5211-01, 5261-01)

Lowell M. Bollinger and Duane A. Dahlberg
Reported by Duane A. Dahlberg

Neutron transmission measurements have been completed on normal zinc and its four main isotopes within the energy region from 200 ev - 10 kev. Values of Γ obtained by comparing the areas above the calculated and experimental transmission curves and the isotopic assignments of the resonances are tabulated as follows:

E_0	Isotopic Assignment	g (Assumed)	Γ
225 ev	67	1/2	1.5 ev
455	67	1/2	13
530	68	1	10
1620	67	1/2	20
2300	67	1/2	30
2750	64	1	75
4600	64	1	60

No resonances were observed in Zn^{66} below 10 kev.

A weighted average of Γ_γ was calculated to be 0.5 ev.

5-4 The Absorption and Scattering of Neutrons by Hafnium (5211-01,
5261-02)

Lowell M. Bollinger, Sigmund P. Harris,
Carl T. Hibdon, Carl O. Muehlhause
Reported by Lowell M. Bollinger

The results obtained were reported in Phys. Rev. 92, 1527,
(1953).

6-4 Spiral Velocity Selector for Slow Neutrons (5211-01)

Roy Ringo

This apparatus is being finished on a very low priority basis
by the central shops. The principal work remaining is the balancing of
the rotor and testing.

11-5 Installation and Operation of the Van de Graaff Generator
(5211-01, 5261-02)

Ronald L. Amrein, Alexander S. Langsdorf, Merle T.
Burgy, William F. Evans, Robert E. Holland, F. Paul
Mooring, Jack R. Wallace, R. Ray Weeks
Reported by Alexander S. Langsdorf, F. Paul Mooring,
Jack R. Wallace, R. Ray Weeks

1. Instability of the Position of the Ion Beam - Reported by F. Paul Mooring

Since the installation of the aluminum shield rings in the
accelerator tube, the position of the ion beam on the target varies
critically with focus voltage and the voltage distribution down the acceler-
ator tube. New rings, which should align their centers more nearly along

the axis of the accelerator tube, are being built and will be installed in the near future.

2. Control Circuits - Reported by R. Ray Weeks

Tests on the stability of the high voltage power supply for the electrostatic analyzers have been made. These tests were made with an external oil-filled high voltage divider resistor, a bucking voltage of 67.5 V delivered by dry cells, and a DC scope with a sensitivity of 0.005 V/cm. Large surges on the 60-cycle line, such as the ones caused by starting the motor that drives the Van de Graaff machine's belt, caused voltage fluctuations as large as 1:1000. Starting and stopping of small control motors caused some variation in the high voltage. These variations appear to be due to stray coupling into the control-galvanometer circuit. Somewhat erratic drift variations as high as 1:2000 per minute were observed. The line surges have been corrected by applying mechanical filtering to the line through the use of a 400-cycle motor-generator followed by a Sorensen 400-cycle, 0.1% voltage regulator. Starting the belt motor now causes changes that are almost unobservable. The wiring of the galvanometer circuit has been shielded, with some small improvement. Shielding the wiring of the control motor is indicated. The Rubicon potentiometer used as the secondary standard against which the high voltage is compared has been returned to the factory for a complete overhaul. A replacement potentiometer shows considerable smoother operation. High voltage

fluctuations have been reduced to better than 1:20,000. All these measurements check the short-time stability. No long time tests have been made. Preliminary tests on the equality of plus and minus high voltages indicate that further work is required.

3. Safety Circuits - Reported by R. Ray Weeks

An electrically triggered air piston has been installed on the high vacuum valve which isolates the Van de Graaff machine proper from the auxiliary vacuum systems. This valve is actuated by ion gages upon indication of poor vacuum in the main system.

Protection has also been provided against pitting of the plates of the 90° - 40" electrostatic analyzer. An ion gage circuit removes the analyzer high voltage and the spray voltage upon indication of poor vacuum in the analyzer.

As an adjunct to the analyzer protection, a fail-safe shunting relay has been installed across the analyzer's galvanometer which controls the high voltage. If the power fails accidentally or is removed by one of the protective circuits, the galvanometer is shorted and stays shorted until reset manually.

4. The 90° Electrostatic Analyzer - Reported by R. Ray Weeks

Installation of the 90° electrostatic analyzer has been essentially completed with the addition of the proper 4-inch diffusion pump, 4-inch valve,

insides of the cold trap and vacuum protective circuits. The protective circuit shuts off the diffusion pump in case of cooling failure or when the spark gap fires on poor vacuum. An ion gage circuit is self protecting and shuts off the filament at 1.5 times full scale and actuates the high voltage shut off. The following check on the analyzer has been made.

After the Argonne 90° - 40" electrostatic analyzer, which is mounted in a horizontal plane, had been in use for several months, a scheme for checking the mechanical alignment of the object and image slits was devised. Since for short periods the beam energy may be held to about 1:5000 at 2 Mev with the analyzing magnet and associated feedback amplifiers, it is possible to make horizontal adjustments to allow a beam leaving the electrostatic analyzer's entrance slit with large divergence to pass through the analyzer without hitting the plates.

The Argonne analyzer is constructed after the pattern of the Wisconsin 90° analyzer¹ but with spherical plates and field-forming blocks.² The various components are indicated in Figure 1. The beam is bent through the analyzer magnet and focussed on the entrance cam slit with movable and insulated jaws. Differential beam current impinging on the halves of the entrance slit is used to control the Van de Graaff voltage. Auxiliary equipment for this experiment is shown inside the dotted lines.

¹ R. G. Herb, S. C. Snowdon, and O. Sala, Phys. Rev. 75, 246 (1949).

² J. E. Monahan, J. Applied Phys. 24, 434 (1953).

16

Figure 1

SCHEMATIC DIAGRAM FOR ALIGNMENT OF E. S. ANALYSER

PHG-620
4-1-54
26

The trimmer magnet corrects the entrance angle of the beam and also modulates the beam laterally to increase the entrance divergence as required. As the modulation is increased, portions of the beam hitting the field-forming blocks of the entrance will be displayed in the first scope, whose time axis is synchronized with the modulation. Reduction of the modulation and adjustment of the DC field allows the beam to be centered between the entrance field-forming blocks as indicated by vanishingly small equal pips on the first scope. The exit cam slit is opened wide so as to be ineffective. The beam is observed on a wide target which sees all the beam that leaves the analyzer. A small amount of modulation is applied while the high voltage supply is varied to observe the emergent beam as indicated on the third scope. Since the DC components of the beam are blocked from the scope, pips of absence-of-beam will be observed. The high voltage supply and modulation amplitude are now varied to show pips hitting both the inner and outer plates or exit blocks. Inner or outer hitting may be determined by the position on the synchronous time axis. Since the beam has some inherent jitter in energy, the pips will jitter more in amplitude as the point of contact proceeds toward the exit. Indeed, at the exit extremum (the field-forming blocks), a maximum of jitter will be observed in the third scope and verified by the presence of beam current pips in the second scope. It may now be deduced whether the beam hits the inside early and the outside late or vice versa. The entrance cam slit

18

assembly may now be translated a small amount and the whole procedure repeated until the beam may be shown to graze both analyzer plates with the same jitter at a maximum value of modulation at which all the beam enters the entrance blocks. A lateral departure of a few thousandths of an inch from the optimum position of the entrance slit may be observed in the scope patterns described above. The output slit may now be closed to the operating value and translated to the proper position by equalizing the average DC beam components impinging on the two halves of the slit.

The above adjustments permit the addition of a focussing lens (not shown) in front of the entrance slit so that good resolution and high intensity may be achieved. The beam divergence associated with focussing to small image size on the slit may be allowed to increase up to full use of the aperture of the analyzer.

5. Targets - Reported by R. Ray Weeks

Work is in progress on an additional target post, rotating target and shutter-viewer assembly. The rotating target for protons on lithium is a duplicate of the one used on the west target line with some small improvements. The tantalum disc has been replaced by an O-ring sealed tantalum cup, as was done on the west target line. The oil seal plate is fastened to the rotating tube with a radial O-ring joint instead of an axial one. This provides greater ease of handling since loose pieces do not fall out when changing targets. This assembly has been planned to

use the water-cooled shutter-viewer designed and built by A. Langsdorf. This target post assembly is to be installed at the output of the $90^\circ - 40''$ electrostatic analyzer on the nominal mass two beam line at 17.5° east with provision for shifting the whole target assembly to the nominal mass one beam line at 25° east.

6. Operational Experience - Reported by Jack R. Wallace

During this quarter (November 21 to March 4 inclusive) the Van de Graaff generator has been operating successfully up to 3.3 Mev with protons and up to 2.5 Mev with deuterons. These conditions fulfilled the requirements of the experiments scheduled for this period.

The time distribution for the various experiments was as follows:

1. Proportional counter checking - Gilbert J. Perlow	31.9
2. Total neutron cross sections - Carl T. Hibdon and R. Ray Weeks	18.9
3. Neutron irradiations - Stefan Kaufmann	11.1
4. Crystal counters - Robert E. Holland and F. Paul Mooring	71.6
5. Magnetic spectrometer - David R. Inglis, Robert E. Malm, Lillian Darlington	241.4
6. Self detection experiment - William A. Reardon	10.8
7. Checking and testing	32.2
8. Inelastic scattering proportional counter - Perlow, Holland, Mooring	<u>40.6</u>
Total machine time	458.5 hrs

Time available: 74 days x 8 hours	592 hours
Night time (outside of normal work day)	33.1
Start-up time and daily maintenance	38.0
Machine out of operation	71.0
Setup time and experimental equipment break down	57.6

The out-of-operation time was caused by the following:

- 1) Changing of the bottle of the ion source
- 2) Removing of gas switch
- 3) Replacement of R. F. oscillator tube
- 4) Vacuum trouble -- beam lines outside of machine
- 5) Changing of charging belt.

We removed the ion source bottle that had been in operation 453.1 hours. This one was replaced and ran for 180.1 hours and was accidentally broken while work was being done on the H. V. platform. This time a new source was installed that has a 2S aluminum probe piece. The source is supposed to have a longer beam life with this type of probe piece.

The gas switch which was originally installed to make it possible to change from one gas to another in the ion source without opening the machine has been removed, and we now connect directly to desired gas. There was some doubt as to whether the switch was operating properly. The high radiation backgrounds caused by deuterons when one was supposed

to be using hydrogen indicated that both deuterium and hydrogen might be getting into the ion source at the same time.

In the past we have had trouble with the short life of our 35TG R. F. oscillator tubes. We felt the cause might possibly be overheating that produced cracks in the filament press or grid lead-throughs in the tube. A blower was installed, and there have been no tube failures in the past 6 weeks. It is not certain, however, that this is the complete solution of our problem.

We had some vacuum troubles in our beam lines that caused some loss of time. We also had further trouble with the rotating lithium target. This has been corrected by a change in design that is now in use.

Our cotton charging belt deteriorated chemically and had to be changed. Past experience with rubberized belts at Site A showed that their shelf life is short. We now have some specially treated impregnated belts on order from Arthur S. Brown (Tilton, 4-ply, endless cotton belts, HT-30 impregnated). These treatments make the belts resist moisture and ozone, and they are supposed to have a good shelf life. A tentative report from the Chemistry Division on the cause of the deterioration of the belt showed nitrate and chloride present in the belt, perhaps accounting for the short life of our belt.

7. Design of a Fast Rotating Target for Lithium and Tritium - Reported by
Alexander S. Langsdorf

The problem of obtaining larger fluxes of neutrons from the Van de Graaff machine continues to be a key one in performing many difficult

experiments. There is little doubt that beam currents of resolved protons now available, of 5 to 20 microamperes, can be increased from 5 to 10 times by great attention to the behavior of the ion source. In anticipation of this step toward obtaining increased neutron yields, further work is necessary in order that the ion beam handling system can withstand the correspondingly greater energy dissipation. Suitable slit and shutter devices are already built. The more difficult problem of devising suitable targets remains. Designs of various sorts have been considered in some detail for the past several years.

A conservative design involving no departure from prior successful designs of rotating targets is being worked on. In this design the actual vacuum seal remains the lapped metal-to-metal type sealed by oil. Changes in design to permit increased rotational speed involve a technique for adjusting the thrust between the moving and stationary plates of the seal to minimal value consistent with a desirably small rate of leakage of the oil, and positive means of removing heat generated in the seal. These changes complicate the construction considerably. It is expected that a new design will be completed in the next quarter, and can be under test soon thereafter.

Robert E. Holland

15-1 Cross Sections for Stopping of Heavy Ions (5211-05)

During the past quarter, an experiment has been started with the purpose of measuring the stopping cross section of the gases hydrogen, helium, air, and argon for nitrogen and neon ions. The energy range to be covered is that which is possible with the electrostatic generator accelerating singly and doubly charged ions.

In the arrangement planned, the accelerated ions will be deflected magnetically into the 90° electrostatic analyzer, which will measure the energy of the incident ions, after which they will pass through a cell containing the stopping gas and enter a 25° electrostatic analyzer, which will measure their final energy.

In order to achieve magnetic deflection into the 90° analyzer, iron or cobalt-iron shims will be used to reduce the magnet's gap from one-half inch to one-quarter inch, and doubly charged ions will be used over some of the energy region available with singly charged ions. Thus the use of singly and doubly charged ions for acceleration will correspond to the two halves of the momentum range to be covered instead of the two halves of the energy range. Measurements of the field strengths attainable

with such iron shims have been made. A field strength of 22 kilogauss can be obtained, while one of 20 kilogauss is sufficient.

A cell to contain the stopping gas has been obtained from Professor Samuel K. Allison of the University of Chicago. Differential pumping on two intermediate sections at each end of the gas cell proper allow the ion beam to enter and leave the stopping gas without passing through foils.

The 25° electrostatic analyzer to be used is one formerly used for voltage control of the electrostatic generator.

Detection of the ions will be done at the end of the 25° analyzer with zinc sulfide as a scintillator and a photomultiplier tube.

At present, most of the equipment needed has been obtained. The principal things remaining to be done in preparation for the experiment are the construction of a radio frequency high voltage supply for the 25° analyzer and some shop work on vacuum plumbing parts. Also some work is planned with a test-bench ion source to find the optimum conditions for nitrogen and neon ion production as well as proton production.

20-5

Energy States of Light Nuclei from Charged Particle Reactions
(5211-01)

David R. Inglis, Robert E. Malm, Lillian Darlington
Reported by David R. Inglis

A long run in December and January was the first period of accelerator time that has been available to this program since the proton (and deuteron) beam ceased to jump.

The magnetic spectrograph was set up for observation, the voltage being controlled by the new 90° electrostatic analyzer using the diatomic beam. The control was found to be satisfactory when the beam-separating magnet was controlled from the entrance slits to the target chamber so as to maximize the target current. Work was continued on the reaction $B^{11}(p, \alpha) Be^8$, with a view to improving the statistics of our earlier investigation¹ of the excited states of Be^8 , but was abandoned because the evaporated targets employed this time vanished after a short bombardment. Targets prepared from diborane will be used on the next try.

The reaction $Be^9(p, \alpha) Li^6$ was extensively investigated, following up some preliminary results obtained in 1952 just before the move from Palos Park. The reaction shows a pronounced resonance at 2.56 Mev for gamma-rays resulting from the reaction going to the 3.58-Mev state of Li^6 . This is the second excited state and is presumed to have isobaric spin $T = 1$. It was shown by carefully following the excitation curves past this energy that the reaction going to the ground state and first excited state of Li^6 shows no trace of this resonance behavior. This behavior may be explained as a result of conservation of isobaric spin, the resonant state of the compound nucleus being assumed to be a quite pure $T = 1$ state, and the two low states of Li^6 to be ones for which $T = 0$.

¹ R. Malm and D. R. Inglis, Phys. Rev. 92, 1326 (1953).

A more complete report on this work is in preparation for publication. From the sharp peaks arising from protons scattered from Be, C, and O during this work it was learned that the magnetic spectrometer has so much in common with optical spectrographs that it even produces "ghosts". These minor peaks close to the main scattering peaks could be eliminated by stopping down the aperture to prevent the particles from grazing the inner edge of the deflection chamber, and are interpreted as arising from a loss of energy during outward scattering from this surface. They appear in spite of precautions taken in the construction of the instrument to minimize such internal scattering.

With the intention of investigating the properties of the first two excited states of N^{15} , which form a surprisingly narrow double level with a splitting of only 30 kev in spite of an excitation energy of over 5 Mev, the reaction $N^{14}(d,p)N^{15}$ was observed. Nylon targets and targets prepared by heating thick tantalum in an atmosphere of nitrogen (of questionable purity) were found unsatisfactory, the former because they burned out or carbonized with quite weak beams and the latter because they showed no nitrogen. A gas cell was made to insert into the available target chamber, the gas target being confined by a cylindrical nickel foil 2×10^{-5} cm thick. This had just too much straggling to permit resolution of the double peak. Other target arrangements will be tried.

This was the first work with a deuteron beam since moving to the new site. It was found possible, after having operated with protons, to focus and adjust the beam without viewing it, thus avoiding exposure to neutrons. Some difficulty was encountered with corrosion of the proton-deuteron change-over valve (because of the use of freon).

The new generating fluxmeter, designed to minimize the effects of temperature variation, has been installed, and revised magnet-control circuits employing it have been brought into regulation.

30-5 Scintillation Coincidence Spectrometer (5211-01)

S. Bradley Burson and Willard C. Jordan
Reported by S. Bradley Burson

The resolution of the scintillation spectrometer has been greatly improved by installing larger NaI (Tl) crystals and different photomultipliers. The crystals were procured by B. Hamermesh and kindly loaned to us pending the arrival of our own order. They are nearly cubic, measuring approximately $2\frac{1}{4}'' \times 2\frac{1}{4}'' \times 2\frac{1}{8}''$. The crystals were packaged and adapted to DuMont photomultipliers by R. Swank and J. Moenich. For the 662-kev gamma-ray of Cs¹³⁷, a resolution of about 8% is obtained. In addition to the higher resolving power, the Compton distribution usually associated with higher energy gamma-rays is greatly attenuated and the photopeaks much enhanced. This fact, together with the higher detection efficiency due to the greater thickness of the crystals, has greatly improved

the work in the energy region above about 300 kev.

In an attempt to obviate the energy drift previously reported in the instrument, a constant temperature oven has been constructed and is now in operation. All eight of the type 5651 voltage standards have been included in the oven. Since the operation of this change has not been specifically tested as yet, more detailed discussion will be postponed until the results can be included. It is intended to determine the amount of drift observed in the calibration when the room temperature is allowed to undergo wide variations.

Publication of the report on this apparatus was also postponed until the defect could be remedied.

31-5 (The 1.42 min Isomeric State in $_{77}\text{Ir}^{192}$) (5211-01)

S. Bradley Burson, Bernard Hamermesh,
Virginia Hummel, Willard C. Jordan
Reported by S. Bradley Burson

A small amount of work has been done on this study using the large NaI crystal detectors. No new information has been obtained, however.

Eugene L. Church

The collective model of nuclear structure proposed by Bohr and Mottelson predicts excitation levels of even-even nuclei having energies of the form¹

$$E_I = A I(I+1) \left[1 - 16 \left(\frac{A}{E} \right)^2 I(I+1) \right]$$

where $I = 0+, 2+, 4+, \dots$ are the spins and parities of the successive excited states, and the quantities A and E are nuclear parameters. Levels of this type are characterized by the electric-quadrupole decay cascades so predicted.

Relevant data on the low-energy transitions in a number of even-even Sm, Gd, and Dy isotopes have been collected in Table I.

Table I

Transitions Energies in Kev		
Nucleus	$E_2 - E_0$	$E_4 - E_2$
$^{150}_{62}\text{Sm}_{88}$	336.7 *	440.2 *
$^{152}_{64}\text{Gd}_{88}$	343.8	(412.2)
$^{152}_{62}\text{Sm}_{90}$	121.8	244.4
$^{154}_{64}\text{Gd}_{90}$	123.4	247.7
$^{156}_{64}\text{Gd}_{92}$	88.8 *	(198.7) *
$^{158}_{64}\text{Gd}_{94}$	79.1 *	(181.7) *
$^{160}_{66}\text{Dy}_{94}$	86.3	(196.1) *

1. A. Bohr and B. R. Mottelson, Det Kongelige Danske Videnskabernes Selskab, 27, 16, 90.

Those values denoted by an asterisk have been obtained by observing the conversion electrons accompanying neutron capture,² while the remaining were observed following beta decay.³ Those values^{2,4} in parentheses have not been previously interpreted as Bohr-Mottelson transitions, and are included on a speculative basis.

The data in Table I have been used to compute the values of the parameters A and E in the preceding formula. The results obtained are presented graphically in Figure 2. Between 88 and 94 neutrons, at least, both of these quantities are strict and smoothly varying functions of N. This behavior lends strong support to the consistent interpretation of the data in Table I.

The parameter A, which is essentially the reciprocal of the nuclear deformation, is seen to fall rapidly as one moves away from the closed neutron shell at $N = 82$, to a broad minimum beyond $N = 94$. The mean nuclear vibrational energy E, on the other hand, is relatively constant over the same region, although showing a definite minimum at 90 neutrons and a general increase thereafter. Rasmussen⁵ has recently noted a similar increase with mass in the region beyond doubly-magic lead 208. This behavior is contrary to theoretical expectations, which indicate that E should decrease with increasing mass.

-
2. C. T. Hibdon and C. O. Muehlhause, Phys. Rev. 88, 943 (1952); E. L. Church (unpublished).
 3. G. Scharff-Goldhaber, Phys. Rev. 90, 587 (1953); E. L. Church, ANL-5174.
 4. J. M. Cork et al, Phys. Rev. 77, 848 (1950); S. B. Burson et al, Phys. Rev. (to be published).
 5. J. O. Rasmussen (private communication).

Figure 2

The decay schemes of the adjacent odd-mass nuclei ${}_{63}\text{Eu}^{153}_{90}$ and ${}_{64}\text{Gd}^{155}_{91}$ are currently under investigation,⁶ where there is evidence for the existence of low-lying electric-dipole transitions.

In conjunction with M. Goldhaber of Brookhaven, a paper covering this work was presented at the spring meeting of the American Physical Society to be held in Washington, D. C.

38-3 The Radiations from ${}_{65}\text{Tb}^{160}$ (5211-01)

S. Bradley Burson, Willard C. Jordan, James M. LeBlanc
Reported by S. Bradley Burson

This study has been completed, and no further reports will be made on this topic. The results have appeared in *Physical Review*, 94, 103 (1954) of which the following is an abstract.

No further reports will be made on this topic.

Decay of ${}_{65}\text{Tb}^{160}$ (71 day)

Abstract

By means of 180° internal conversion electron spectrometers and the scintillation coincidence spectrometer, the radiations of ${}_{65}\text{Tb}^{160}$ (71 day) have been studied. In addition to many of the previously reported transitions in Dy^{160} , three new gamma-rays of 0.759, 1.17, and

6. E. L. Church, ANL-5031.

and 1.26 Mev are observed. By using the energy values determined from the internal conversion studies, together with beta-gamma and gamma-gamma coincidence results, a decay scheme is deduced which is consistent with the experiments discussed.

40-3 The Decay Scheme of $^{52}_{23}\text{V}$ (5211-01)

S. Bradley Burson, James M. Cork (University of Michigan), Willard C. Jordan, James M. LeBlanc
Reported by James M. LeBlanc

In order to determine whether the 15-hr activity which was observed in our V sources was due to Na contamination, the Na was chemically separated from the V after irradiation in CP-3'. Both the Na and V fractions were then counted with the scintillation spectrometer. It was found that the activity of the Na fraction was more than 100 times that of the V fraction, and that the activity of the V fraction was only two times the background. The small residual activity in the V fraction is probably due to incomplete separation of the Na, and possibly to other contaminants. Since a spectroscopic analysis of our sources established that Na was an impurity with an abundance of only 0.05%, it is concluded that the 15-hr activity previously assigned to $^{52}_{23}\text{V}$ was probably due to Na impurity in the sources. A report on this study appeared in Physical Review, 93, 1124 (1954) as a Letter to the Editor.

1. J. M. Cork, et al, Phys. Rev. 76, 575 (1949), and T. Wielding, Phys. Rev. 91, 767 (1953).

5/12/52

41-3 The Decay Scheme of $_{48}\text{Cd}^{117}$ and $_{49}\text{In}^{117}$ (5211-01)

S. Bradley Burson, James M. Cork (University of Michigan), James M. LeBlanc
Reported by James M. LeBlanc

No work has been done on this study during the past quarter.

43-2 The Decay of the 3.5-min Metastable State of Sb^{122} (5211-01)

S. Bradley Burson, James M. Cork (University of Michigan), James M. LeBlanc
Reported by James M. LeBlanc

In order to observe internal conversion electrons of the 60-kev gamma-ray which was observed with the scintillation spectrometer, long exposures were made in the 180° spectrometers. Four conversion electron lines were observed which are interpreted as K, L_1 , and L_3 lines of a 75.3-kev gamma-ray and a K line for a 60.7-kev gamma-ray. The energy of 60 kev obtained with the scintillation spectrometer is in good agreement.

44-1 The 49-sec Isomeric State in $_{32}\text{Ge}^{75}$ (5211-01)

S. Bradley Burson, Willard C. Jordan, James M. LeBlanc
Reported by S. Bradley Burson

The metastable state in Ge^{75} is formed by neutron capture in Ge^{74} . Flammersfeld¹ produced this activity by irradiation of Ge with fast and slow neutrons and by irradiation of As with fast neutrons. He found that the half-life to be 42 seconds and measured the energy of the transition to be 150 kev by absorption measurements on the internal conversion

1. A. Flammersfeld, Z. Naturforsch. 7a, 295 (1952).

electrons. Smith et al,² report the half-life to be 48 ± 2 seconds and the energy of the isomeric transition to be 175 kev.

Using the 180° electron spectrograph, a plate was exposed 50 times to an activated source of enriched Ge^{74} . K and L lines were detected from which we assign an energy of 138.5 ± 1.0 kev to the transition. Since the L line was too weak to warrant densitometer measurements of the plate, the K/L ratio could only be estimated visually to be greater than 3.

The scintillation spectrometer with the ten-channel analyzer yielded a value of 142 ± 3 kev for the transition (using the 159-kev gamma-ray from Te^{123} for calibration). By following the decay of the peak, the half-life was found to be 49 ± 2 seconds. A search was made, but no other gamma-rays was observed. Using the anthracene crystal beta-detector, the single-channel analyzer was biased to reject pulses caused by the internal conversion electrons, and a search was made for beta-rays of energy greater than 175 kev; none were found.

45-2 The Short-Lived Activities of Zn (5211-01)

S. Bradley Burson, James M. Cork (University of Michigan), James M. LeBlanc
Reported by James M. LeBlanc

A report on this study was made at the Michigan meeting of the American Physical Society on March 20, 1954.

2. Smith, Caird, and Mitchell, Phys. Rev. 88, 150 (1952).

46-2 The Decay of $_{32}\text{Ge}^{77}$ (12 hours) and $_{32}\text{Ge}^{77\text{m}}$ (52 sec) (5211-01)

S. Bradley Burson, Willard C. Jordan, James M. LeBlanc
Reported by S. Bradley Burson

Analysis of the gamma-ray spectrum of $\text{Ge}^{77\text{m}}$ shows the presence of two radiations, instead of only one as previously reported in the literature. Using the 159-keV gamma-ray of Te^{123} and the 214-keV gamma-ray of Hf^{180} for calibration, these radiations are assigned energies of 160 ± 5 and 215 ± 5 keV, respectively.

The two peaks are of nearly equal intensity and the half-life is found to be 52 ± 2 seconds by following the decay of the 215-keV peak. Although the source used was enriched in Ge^{76} , the 138.5-keV gamma-ray associated with $\text{Ge}^{75\text{m}}$ is still found present in sufficient intensity to make both half-life and energy measurements on the 160-keV peak somewhat less reliable than those made on the 215-keV peak.

Gamma-gamma coincidence measurements show the two radiations not to be in coincidence. Beta-gamma coincidence measurements show the 160-keV gamma-ray is not in coincidence with beta-rays, but do show coincidences between the 215-keV gamma-ray and beta-rays. Absorption measurements in aluminum show the beta-ray in coincidence with the 215-keV gamma-ray to have a half thickness of approximately 170 mg/cm^2 of Al, corresponding to an endpoint energy of about 2.7 MeV.

From these experiments, it is concluded that the isomeric

state of Ge^{77} decays by two branches: an isomeric transition of 160 kev to the ground state of Ge^{77} and a 2.7-Mev beta-ray to a 215-kev excited state of As^{77} .

Investigation of the internal conversion electron spectrum of Ge^{77} (12 hr) definitely showed lines for two of the gamma-rays, the 210 and 265-kev radiations. A weak line at about 204-kev may be interpreted as the K line of a transition of approximately 215 kev.

Further studies with the scintillation coincidence spectrometer show the presence of many more gamma-rays in the higher energy region. These are weak in intensity and were at first erroneously attributed to a small amount of 15-hour Na^{24} activity present in the source material. The larger crystals, however, so improved the detection efficiency and resolution of the apparatus that we have been able to resolve many gamma-rays previously undetected.

The existence of sixteen gamma-rays has definitely been established. Referring to the study of the beta spectrum by Smith it is possible to rationalize the decay scheme proposed with the three branches reported by assuming that several of the beta groups lie so close to one another in energy as to preclude their resolution. For instance, the two branches with the highest energy differ by only 140 kev out of about 2.2 Mev.

The decay scheme is in practically complete disagreement with that published by Smith. This is not surprising, considering the fact that we have found no trace of six out of a total of thirteen gamma transitions reported by him. In addition we have resolved at least nine transitions not previously reported.

Analysis of the numerous experiments has led to the decay scheme proposed in Figure 3. The experiments will not be described here, but the interpreted results are summarized in Table II. The letter "A" designates a conclusive result in which the existence of the coincidence as well as the interpretation is certain. The letter "B" indicates that the coincidences exist but that there is some doubt or ambiguity concerning the interpretation.

Data are still being analyzed, and those gamma-rays whose placement in the scheme is still unknown or considered doubtful have been omitted.

Figure 3

PROPOSED DECAY SCHEME OF $^{77m}_{32}\text{Ge}$ (52 sec) & $^{77}_{32}\text{Ge}$ (12 hr)

PHG-616
3-23-54
B. G.

Table II

Beta-Gamma and Gamma-Gamma Coincidences Ge^{77} (12 hr)

		Gamma															
Beta		0.210	0.215	0.265	0.365	0.410	0.560	0.625	0.71	0.80	0.91	1.10	1.19	1.36	1.75	2.0	2.3
	0.7									B							
	1.4	- B	-	B	B	B	A					B					
	2.2	- B	-	A	A	A											
Gamma	2.3																
	2.0																
	1.75	- B	-	A	B	B		B									
	1.36	- B	-	A	A	A		B									
	1.19			A													
	1.10																
	0.91			A	B	B											
	0.80	- B	-	A	A	A	A										
	0.71																
	0.625						A										
	0.560		B	A	A	A											
	0.410		A														
	0.365			A													
	0.265	A															
	0.215																

47-1

The Decay of 30-min Pt¹⁹⁹

S. Bradley Burson, James M. Cork (University of Michigan), James M. LeBlanc
Reported by James M. LeBlanc

Although the 30-min activity in Pt¹⁹⁹ has been produced by many investigators,¹ the beta and gamma radiations emitted in its decay have not been studied intensively. Absorption experiments have shown the presence of a beta-ray with a maximum energy of 1.8 Mev, but the gamma-rays associated with this activity have not been investigated.

Sources of this activity were obtained by the irradiation of normal PtO in CP-3'. They were then studied with the 180° photographic spectrometer and the 10-channel scintillation spectrometer. Gamma-rays of energy 0.070, 0.197, 0.246, 0.318, 0.48, 0.53, 0.71, 0.87, and 0.96 Mev were found to decay with a half-life of 30 min and are therefore assigned to this activity. By measuring the attenuation in Al of the beta-rays in coincidence with the various gamma-rays it is found that the 0.197 and 0.53-Mev gamma transitions follow a 1.1 ± 0.1 -Mev beta-ray, the 0.246 and 0.318-Mev transitions follow a 1.3 ± 0.1 -Mev beta-ray, and the 0.71 and 0.78-Mev transitions follow a 0.8 ± 0.1 -Mev beta-ray. In addition a beta-ray of energy 1.7 ± 0.2 Mev was observed and found not to be in coincidence with gamma-rays. The results of gamma-gamma coincidence measurements are shown in Table III. The gamma-rays are listed in the first row and column. Where coincidences are observed

1. R. S. Krishman and T. E. Banks, Proc. Cambridge Phil Soc. 37, 317 (1941), and R. Sherr, K. T. Bainbridge, and H. H. Anderson, Phys. Rev. 60, 473 (1941).

42

between two gamma-rays, an x is placed at the intersection of the appropriate row and column. Gamma-rays not in coincidence are indicated by an 0 and the spaces are blank where no data are available.

Table III

	960	780	710	530	480	318	246	197	70
70		0	X	0	X	0	X	X	
197				X	X	X	X	X	X
246				0	X	0	0	X	X
318		0	0	0	X	0	0	X	0
480		0	0	0	0	X	X	X	X
530		0	0	0	0	0	0	X	0
710				0	0	0			X
780				0	0	0			0
960									

A report on this study was given at the Washington meeting of the American Physical Society.

50-5 Internal Conversion of Capture Gamma-Rays Associated with Gd
(5211-01)

Carl T. Hibdon

No further work has been done. Reports on this topic will be discontinued until further work has been done.

of 5

51-5 Characteristics of a Scintillation Counter Spectrometer (5211-01)

Bernard Hamermesh and Arthur Recksiedler
Reported by Arthur Recksiedler

The large NaI(Tl) crystal has been moved to a horizontal position to obtain better geometry in the coincident capture gamma-ray study. A sacrifice in shielding was necessary, and increased background was found, so that the crystal was most effective in the high energy range. A 2-inch cube has been substituted for the smaller crystal previously used in the lower energy regions being studied.

The resolving time of the twenty-channel pulse-height analyzer's coincident circuit will be shortened from its present value of 5 microseconds.

52-5 Capture Gamma-Ray Spectra (5261-02)

Bernard Hamermesh and Arthur Recksiedler
Reported by Arthur Recksiedler

Chlorine and cadmium have been studied for coincident capture gamma-ray emission. Repeated trials have been made to assure statistical accuracy of the data obtained through the scintillation spectrometer.

So far it has been found that the 0.558-Mev and 8.5-Mev gamma-rays previously reported in cadmium form a coincident cascade branch. In chlorine the 0.784 - 7.77 Mev, 1.15 - 6.98 Mev, and 1.59 - 6.62-Mev gamma-rays also form two-step cascade branches. There appears to be a gamma-ray in chlorine at 0.735 Mev whose significance is not yet known.

The study will be continued at CP-5.

gamma-ray and a 370-kev gamma-ray. The intermediate half-life is 3×10^{-7} sec and so Pb^{204} was deemed suitable for such a study.

Delayed coincidences between the 905-kev gamma-ray and the 370-kev gamma-ray were measured at angles of 135° and 225° between the two counters. With no magnetic field these angles are symmetrical and no difference in the coincidence rate should be observed. Upon application of a magnetic field perpendicularly to the plane of the two counters the correlation pattern is shifted because of precession about the applied magnetic field resulting from the interaction of the magnetic moment of the intermediate state with the field. The ratio of the coincidence rates at the two angles as a function of applied magnetic field will yield the moment of the intermediate state.

A true angular correlation is given by a formula of the type

$$W(\theta) = \sum_{k=0} B_k P_k(\cos \theta) \quad (1)$$

It cannot be assumed that the true correlation of the Pb^{204} cascade is obtained here. The source is dissolved in concentrated nitric acid and there are indications that the rapidly fluctuating local electric fields have decreased the correlation.² Abragam and Pound conclude that the effect of such time varying fields is to attenuate the B_k 's in (1) by a factor $e^{-\lambda_k t}$. Therefore, at any instant the angular distribution in liquid

2. Abragam and Pound, Phys. Rev. 92, 943, (1953).

media is given by:

$$W(\theta, t) = \sum_{k=0} B_k e^{-\lambda_k t} P_k(\cos \theta) \quad (2)$$

Here the λ_k 's depend on the medium. To get an observed correlation, (2) is integrated over the times of the experiment and the decay of the nucleus.

$$W(\theta) = \int_{t_1}^{t_2} B_k e^{-\lambda_k t} P_k(\cos \theta) e^{-\lambda_n t} dt \quad (3)$$

λ_n is the reciprocal life time of the intermediate excited state. In this experiment a delay of $0.37 \mu\text{sec}$ was used and the coincidence resolution time was $0.132 \mu\text{sec}$. The limits of integration are, therefore, 0.24 and $0.50 \mu\text{sec}$. It was assumed that the highest power of $\cos \theta$ present in $W(\theta)$ is the second power. The true anisotropy, i. e., the ratio of coincidences at 180° to those at 90° , is assumed to be 1.47 as obtained by Frauenfelder in the liquid melt.³ Our value of 1.27 for concentrated nitric acid is then used to get λ_2 for nitric acid by solving equation (3).

The result is

$$\lambda_2 = 1.4 / \mu\text{sec}$$

The effect of the magnetic field is to precess the pattern, and at time t the correlation function is given by:

$$W(\theta, H, t) = \sum B_k e^{-\lambda_k t} P_k[\cos(\theta - \omega t)] \quad (4)$$

which upon integration gives the experimentally observed result

3. Frauenfelder, Lawson, Jentschke, and DePasquali, Phys. Rev. 92, 1241 (1953).

$$W(\theta, H) = \int_{t_1}^{t_2} B_k e^{-\lambda_k t} P_k [\cos(\theta - \omega t)] e^{-\lambda_n t} dt \quad (5)$$

where ω is the Larmor precession velocity of the intermediate state.

Normalization factors have been omitted in equations (1) thru (5) for we are interested only in ratios of the type $\frac{W(135^\circ, H)}{W(225^\circ, H)}$.

The points obtained experimentally are fitted to a curve calculated from (5). The result obtained to date is: $g = +.04 \pm .02$.

This experiment was reported to the Washington meeting of the American Physical Society.

It is desirable to repeat this experiment with better electronics. This will be done in the next quarter. In addition a quantitative measure on the Cd^{111} cascade is contemplated.

71-5 Angular Correlation of β -Rays and Delayed Neutrons from Br^{87}
(5211-01)

Leonard S. Goodman and Andrew Stehney (Radiological Physics)
Reported by Leonard S. Goodman

We are waiting for electronic equipment. No progress has been made during the past quarter.

80-5 Molecular Beam Studies (5211-01)

John A. Dalman, Leonard S. Goodman, Sol Wexler
Reported by Leonard S. Goodman

We were unable to reproduce the resonance in Cs^{134m} reported in the last quarterly report, although much time was spent in

searching for some. Subsequent tests demonstrated that the difficulty was not due to re-evaporation of the activity from the collectors or uncertainties in the decay scheme of $\text{Cs}^{134\text{m}}$ (see Burson, et al, this report).

It was then decided to spend some time improving the apparatus so as to increase its sensitivity. To this end an extra pump was added to the collector compartment, new ovens and a new oven movement were constructed, a vertical beam stop was added, a water-cooled baffle was installed in the oven chamber, the surface ionization detector was revamped mechanically, and the entire system was re-aligned optically. Tests on a sodium beam are now under way to improve the line-up. In addition, several samples of cesium metal have been sealed under vacuum in quartz tubes for future use as sources of $\text{Cs}^{134\text{m}}$ in place of $\text{CsCl} + \text{Na}$ mixtures used in most previous work.

When the line-up is completed, radioactive Na^{24} will be run to test the collection system, and then measurements on $\text{Cs}^{134\text{m}}$ will be resumed.

90-5 Cross Sections for 14-Mev Neutrons (5211-01)

Harvey Casson, Leonard S. Goodman, Jack Haugsnes
Reported by Harvey Casson

The R-F ion source which was constructed during the last quarter has been successfully bench tested. The electronic circuits used

in these tests will be retained for future testing of R-F ion source bottles. New circuits have been constructed and mounted on an assembly for installation in the pressure tank. The new circuit assembly is being tested at present.

The old Zinn-type ion source which has given us so much trouble in the past, has been reconditioned and appears to be in good working order at the present time.

It is hoped that experimental work on neutron scattering will get under way in the very near future.

91-5 Angular Distribution of Scattered Neutrons (5261-02)

Carl T. Hibdon, Raymond O. Lane, Alexander S. Langsdorf
Reported by Raymond O. Lane

This experiment is currently in the stage of construction, assembly, and testing of component parts. During the past quarter, the grate floor in the Van de Graaff accelerator room has been extended; the shield tanks and most of their accessories have been received and tested; the BF_3 counters have been received and tested; and the design of the electronic circuits for use with these counters has been started. A mock-up of a typical oil-immersed BF_3 counter assembly is now being tested. A preliminary experiment is planned which will use the Van de Graaff accelerator as a source of monoenergetic neutrons to determine the energy response of the oil-immersed BF_3 counter assembly as compared with that of the long counter. Following this, the main angular distribution experiment will be begun as soon as availability of equipment and accelerator time permits.

92-5 Neutron Scattering Cross Sections by Use of the Scattering Chamber (5261-02)

Arthur H. Jaffey, Robert G. Scott, Ruth Sjoblom (Chemistry Division), Carl T. Hibdon
Reported by Carl T. Hibdon

Data for the measurement of ν for Pu^{241} were taken by use of the annular scattering chamber. A complete report is to appear in the quarterly report of the Chemistry Division.

96-5 (Pile Absorption Cross Sections) (5261-01)

David Rose

No work has been done on this program during the past quarter.

98-4 Total Cross Sections in the kev Region (5211-01, 5261-02)

1. Analysis of Cross Section Data - Carl T. Hibdon

The single level Breit-Wigner formula¹ for scattering of neutrons by nuclei reduces at maximum of the resonance to the expression

$$\sigma_{\max} \approx 4\pi \lambda^2 \left[A_J \cos^2 \delta_l + \sin^2 \delta_0 \right] \quad (1)$$

in which

$$A_J = \frac{2J+1}{(2I+1)(2S+1)}$$

and

$$\begin{aligned} \delta_0 &\approx -x, & \delta_1 &\approx -x + \pi/2 - \cot^{-1} x \\ \delta_2 &\approx -x, + \pi - \cot^{-1} (x^2 - 3)/3x \end{aligned}$$

x is the quantity a/λ or ka in which a is the radius of the nucleus. The other symbols have their customary meanings. A more exact expression

1. R. K. Adair, Rev. Mod. Phys. 22, 249 (1950), equation 5.

includes a sum of terms $\sum (2\ell + 1) \sin^2 \delta_\ell$, rising from the potential scattering but only the one for $\ell = 0$, $\sin^2 \delta_0$, has been retained since those for $\ell > 0$ become negligibly small for the small values of x involved in the data to which the expression is to be applied. In making the calculations the nuclear radius, a , has been taken to be $1.4 \cdot A^{1/3} \cdot 10^{-13}$ cm. None of the calculated quantities from which conclusions are reached are sensitive to the exact value of this assumed nuclear radius. The values of the δ 's, the phase shifts, are small enough that the squares of their sines are small compared to the quantities to which they are added and their exact values are not important. The cosines are close enough to unity to be but little affected by sizeable percentage errors in the assumed effective nuclear radii. For all of the resonances considered the term $A_J \cos^2 \delta_\ell$ is so much larger than $\sin^2 \delta_0$ that it is convenient to take the former term to give the height of the peak above the general level of cross section in the neighborhood of the peak. This general level includes both the potential scattering and minor contributions from other peaks at some distance away. In this way peak cross sections for various values of the energy (X), J and ℓ have been calculated and plotted with the experimental curves of cross section vs energy, as in Figure 4 for fluorine. For each value of J there is a family of curves, one for each possible value of ℓ . The curves for given J 's but different ℓ 's, however, differ but slightly for the small δ_ℓ 's and corresponding values of $\cos \delta_\ell$ all close to unity.

With adequate experimental resolution every measured peak cross section for a resonance at which elastic scattering is the only nuclear process occurring should lie on one or another of the curves. With peaks as actually measured the observed maximum cross section is less than the true one, even for thin samples, by an amount that depends on the resolution. If enough is known about the latter a correction can be made to the observed maximum value. For making this correction one can use the following approximate form for the resonance peak

$$\sigma = \sigma_0 \cdot \frac{\Gamma^2/4}{(E-E_r)^2 + \Gamma^2/4} \quad (2)$$

(this expression being reasonably accurate when

$$2 |E - E_r| \sin 2\delta \ll \Gamma).$$

From this it can be shown by simple averaging that if the neutrons range uniformly over a spread of energies of amount ΔE centered on the peak of the resonance the average cross section $\bar{\sigma}$ will be given by

$$\bar{\sigma} / \sigma_0 = \frac{\Gamma}{\Delta E} \cdot \tan^{-1} (\Delta E / \Gamma) \quad (3)$$

Furthermore, if $\Delta E \ll \Gamma$ and the mean neutron energy is the value for which $\sigma = \sigma_0/2$ the observed average value will also be $\sigma_0/2$. This means that widths measured at half height will give correct values of Γ regardless of the energy spread of neutrons provided that $\Delta E \ll \Gamma$. This is valid for any distribution of energy of the neutrons in the interval ΔE that is symmetrical about the mean value.

Also, it can be shown for a uniform distribution of neutrons in the range ΔE centered at an energy Γ from the center of the peak that σ/σ_0 has a value of 0.20 for $\Delta E \ll \Gamma$, of 0.23 for $\Delta E = \Gamma$ and 0.28 for $\Delta E = 3/2 \Gamma$. Thus for resonances for which ΔE and Γ are comparable the width of the peak at $0.25 \sigma_0$ is close to 2Γ .

The integral of σ over the whole range of energy from 0 to ∞ is $\pi \Gamma \sigma_0 / 2$ if $\Gamma \ll E_r$. It is readily shown that this is also the value of the area under the experimental curve (after subtraction of background) even with poor resolution, provided that the value of the true integral is practically independent of the limits of integration and the experimental cross sections were obtained with truly thin samples. In general one would expect to find the experimental value to be somewhat too low. The integral of σ over the range from $E_r - \Gamma/2$ to $E_r + \Gamma/2$ is $\pi \Gamma \sigma_0 / 4$. The determination of this half area from an experimental curve is less sensitive to assumptions about the background cross sections being subtracted off than the determination of the area over the whole energy range so that it would be expected to give better agreement with the calculated value if the effective resolution width is well below $\Gamma/2$, and truly thin samples have been used.

If one knows enough about the resolution to correct a measured $\bar{\sigma}$ to the true value it should then lie sufficiently close to one of the curves to give an unambiguous indication of the J for the resonance. It is hardly

possible to get sufficient accuracy to distinguish between the different $\mathcal{L}$ values that are possible for the given J. If, however, the true half width can be determined the reduced width can be calculated from the expression²

$$\gamma_n^2 = \frac{\Gamma_n \lambda}{2 T_{\mathcal{L}}} \quad (4)$$

Γ_n is the measured width at half maximum and

$$T_0 = 1, T_1 = x^2/(1 + x^2), T_2 = x^4/(9 + 3x^2 + x^4), \text{ etc.}$$

The quantity γ_n^2 is not expected to exceed the Wigner limit, $3\hbar^2/2ma$, by any large factor. An upper limit to $\mathcal{L}$ can thus be set by finding the greatest $\mathcal{L}$ for which this condition is satisfied. It is also to be expected that the values of γ_n^2 for different resonances of the same nucleus will be of nearly the same magnitude.

The above considerations will now be applied to experimental results.

Fluorine

As shown in Figure 4, there are three prominent resonances in fluorine at energies of 28.2, 49.7, and 99.5 kev. These resonances were known previously (AECU-20+0) but the resolution is much better in the present experiments. The measured peak cross sections are 28, 33, and 25 barns, respectively, and the widths at half of the measured peak height are 1.5, 2.3, and 13.6 kev, respectively. (Erroneous values of the widths were given previously in report I-98-3). None of these resonances

2. Reference 1, equation 8.

Figure 4

shows any marked dip on the low energy side or asymmetry about the center as would be expected if any of them corresponded to S-wave neutrons ($\ell = 0$).

The spread of energies in the neutron beam is believed to be between 1 and 2 kev, so the broadest resonance at 99 kev, whose half width is 13.6 kev, might be expected to give a measured value of the peak cross section closest to the true value. If one assumes $\Delta E = 2$ kev and calculates $\bar{\sigma}$ by expression (2) one gets $\bar{\sigma} = 0.99 \sigma_0$ so the measured values of the peak cross section should be reasonably accurate. As is apparent in Figure 4 this peak lies very close to the lines for $J = 1, \ell = 0, 1$, and 2. $\ell = 0$ is excluded by absence of an anti-resonance dip. The values of γ_n^2 corresponding to $\ell = 1$ and $\ell = 2$ are found to be 1.0×10^{-12} and 7.5×10^{-9} kev cm, respectively, whereas the Wigner limit is 1.16×10^{-9} kev cm. Neither value of ℓ can be ruled out with certainty.

The area under the experimental curve from $E_r - \Gamma/2$ to $E_r + \Gamma/2$ is 214-kev barns and the value of $\pi \sigma_0 \Gamma/4$ is 225-kev barns, values in as good agreement with each other as could be expected in view of possible errors in the values of σ_0 and Γ . An attempt to find the total area under the curve yields a value considerably under 2×214 , but the value obtained is highly dependent upon assumptions as to the background cross sections.

The peak at 49 kev rises above the lines for $J = 0$. If we assume that with sufficient resolution it would reach the next higher line for $J = 1$ the true peak value should be 45 b instead of 33 b. Thus, we would have $\bar{\sigma} / \sigma_0 = (33-4) / (45-4) = 0.71$. Since the measured value of 33 is likely to be low because of the sample being too thick, this indicates that $\bar{\sigma} / \sigma_0$ should be somewhat greater than 0.71. From equation (3) we can conclude that $\Delta E / \Gamma < 1.3$. Since ΔE is less than Γ the width of the peak should be 2Γ for a value of σ between $0.20 \sigma_0$ and $0.23 \sigma_0$, probably closer to the latter position. The width at $0.22 \sigma_0$ is 3.4 kev giving a value of 1.7 kev for Γ . The corresponding ΔE is ≤ 1.3 kev, close to the value inferred from measurements made at the threshold of the (p,n) reaction on the Li target. If one assumes $J = 2$, the true peak should be at 74 barns and $\bar{\sigma} / \sigma_0 = (33-4) / (74-4) = 0.44$. From this $\Delta E / \Gamma < 3$, and Γ from the width at $0.25 \sigma_0$ is ~ 1.0 kev. This would give $\Delta E \leq 3.0$ kev. The area under the measured peak is ~ 90 -kev barns. The values of $\pi \sigma_0 \Gamma / 2$ for $J = 1$ and $J = 2$ are both 110-kev barns. The lack of agreement is as expected, since the measured cross sections are likely to be low for such a narrow peak. The foregoing considerations afford us firm basis for a choice between $J = 1$ and $J = 2$.

The cross section in between 49 and 99 kev drops to the value of 3.8 barns that it has over a considerable region below 20 kev. This dropping to a value indistinguishable from the expectable background suggests

that there may be interference between the 49 and 99-kev resonances. It is of interest, therefore, to see what values of the cross section would be expected in this intermediate region without interference occurring. One takes the expression for the cross section that includes contributions from both resonances, with due regard to the variation of the f 's with the one-half power of the energy, differentiates it to find the position of the minimum, and calculates the value of the cross section at that minimum. Assuming the constants appropriate to $J = 1$ for the 49-kev level the cross section is calculated to have the minimum value of 0.89 b above background at 60 kev; using the constants for $\sigma = 2$ one gets a minimum value of 0.79 b at 58 kev. Thus, the predicted values throughout the region should lie above $3.8 + 0.8 = 4.6$ barns. The experimentally measured ones lie well below this over a considerable region of energy.

It would seem that the two peaks must be interfering. This possibility has been explored further, however, by developing the theory, using equation (5) of Adair's paper with two resonance amplitudes included, and calculating expected cross sections. The interference that would account for the low cross sections observed would lead to a reduction of the cross sections of the 49-kev peak on its high energy side incompatible with the observations. The peaks evidently are not interfering, so one is at a loss to account for the observed low cross sections in the intermediate region.

- 7

The calculated values of γ_n^2 are 3.3×10^{-11} and 5.2×10^{-9} kev cm for $\ell = 1$ and $\ell = 2$, respectively, using the value of 1.7 kev for Γ_n . The Wigner limit is 1.16×10^{-9} kev cm so that here also neither value can be ruled out with certainty. The expectation that γ_n^2 should be of nearly the same magnitude for both resonances would also require that both of them should have the same ℓ value.

The resonance at 28 kev is even narrower than the one at 49 kev so that little can be concluded except that the true peak cross section should lie well above the observed one, thus giving $J \geq 1$. The area under the measured curve is roughly 43-kev barns. This can be corrected by the factor found for the 49-kev peak to give $43 \times 110/90 = 52$, probably still too low. Setting this equal to $\pi \Gamma \sigma_0 / 2$ one gets a value of 0.47 kev for Γ if σ is taken as 70 b above background ($J = 1$) and of 0.30 kev if σ_0 is taken as 120 b above background ($J = 2$). For the γ_n^2 calculated from either of these widths to be of the same order of magnitude as for the other two resonances the same value of ℓ as for the other two would be required.

The values of the cross section between the 28 and 49-kev peaks also lies somewhat below the expectable background but, lacking any understanding of the same result for the cross sections between the 49 and 99-kev peaks where the constants are better known, one is at a loss to account for this.

Summarizing, the results for F are:

Resonance energy (kev)	Firm conclusions		Indicated values	
	J	ℓ	J	ℓ
28.2	1	1 or 2	1	1
49.7	≥ 1	1 or 2	2	1
99.5	≥ 1	1 or 2	1	1

Titanium

The prominent features of the cross section curve for titanium are a high peak at 18 kev with an unresolved lesser one at 23 kev and two peaks at 38 and 53 kev.

The peaks at 38 and 53 kev are both accompanied by a low dip on the low energy side and show the characteristic asymmetry - steeper slope on the low energy side - characteristic of S-wave peaks interfering with the S-wave poriton of the potential scattering. They must thus both have a J value of $1/2$, the only one possible for $\ell = 0$. As indicated by Adair¹ the peak lies at an energy given by $\tan^{-1} \rho/2 (E_r - E) = \pi/2 - \delta_0$ and the preceding minimum at the energy given by $\tan^{-1} \rho/2 (E_r - E) = -\delta_0$. To the accuracy of the measurements the separation between those two positions is given by $E_r - E_0 = -\rho/2 \delta_0 = \rho/2 ka$. ρ , therefore, equals $2 ka (E_r - E)_0$. $(E_r - E)_0 = 3.0$ and 5.3 kev, and $ka = 0.20$ and 0.24 for the 38 and 53 kev peaks, respectively, thus giving corresponding values for ρ of 1.2 and 2.5 kev. The respective peak heights are 38 and 30 barns, whereas the ones calculated for $J = 1/2$, $\ell = 0$ are 52 and 37 barns on the assumption that they are to be attributed to the Ti^{48} isotope, whose

abundance is 73.4%. The peak at 53 kev rises to a greater percentage of its calculated height, as would be expected because of its greater width. The calculated values of γ_n^2 for the two peaks based on the values of $\int$ obtained above are 3.6×10^{-12} and 5.4×10^{-12} kev cm.

Since the two peaks at 18 kev and 23 kev are not resolved it is difficult to get accurate information about either of them. Apparently they do not interfere with each other and are thus to be attributed to levels of the same nucleus having different quantum numbers, or to nuclei of different isotopes. There is no indication of S interference or asymmetrical shape of the 18 kev peak. Assuming that it is approximately symmetrical the actual peak value for the 23-kev resonance is only about 30 barns, to be compared with a lowest possible calculated value of 85 barns for Ti^{48} , ($J = 1/2$). Since the peak does not appear to be exceedingly narrow it is probably to be ascribed to one of the less abundant isotopes of Ti. If this is correct the true isotope peak value would be at least about 300 barns, a reasonable value at this energy. The 18 kev peak, however, should not be grossly distorted by this lesser one at 23 kev. The peak value of 105 barns equals that calculated for Ti^{48} , $J = 1/2$. The apparent half width, as judged by the shape on the low energy side, is ~ 8 kev. The corresponding γ_n^2 values are 1.43×10^{-11} and 7.8×10^{-10} for the two possible ℓ values, 0 and 1, respectively, the Wigner limit being 1.17×10^{-9} kev cm. The only basis for choice is the one of having the γ_n^2 for this resonance be more nearly that of the other two resonances, thus suggesting

62

$\ell = 0$. This seems to be contrary to the lack of asymmetry of the peak even though a dip in the low energy side might be masked by the presence of lesser resonances that are to be ascribed to less abundant isotopes

Summarizing, the results for Ti are as follows:

Resonance Energy (kev)	Isotope	J	ℓ
18	Ti ⁴⁸	1/2	0 or 1
23	not Ti ⁴⁸	?	?
38	Ti ⁴⁸	1/2	0
53	Ti ⁴⁸	1/2	0

Nickel

The data for nickel are complicated, there being resonance peaks at 4.6, 5.2, 13, 16, 29, 65, 99, 111, 126, 144, and 160 kev. Of these the ones at 16, 65, 111, 144, and 160 kev are the most prominent. Analysis is further complicated by the isotopic composition of Ni, the isotopes of masses 58, 60, and 62 having abundances of 67.4, 26.7, and 3.8%, Ni⁶¹ and Ni⁶⁴ accounting for the slight remainder.

The peak at 16 kev has a measured peak height of 90 barns and an apparent half width of ~ 3 kev. The calculated peak heights for it are as follows: Ni⁵⁸, J = 1/2, 102 b; Ni⁶⁰, J = 1/2, 46 b; Ni⁶⁰, J = 3/2, 90 b. Taking ΔE for the energy spread to be 1.8 kev and $\Gamma = 3$ kev, $\bar{\sigma}/\sigma_0 = \frac{\Gamma}{\Delta E} \tan^{-1} \frac{\Delta E}{\Gamma}$ gives $\bar{\sigma}/\sigma_0 = 0.90$; with $E = 1.2$ kev one gets $\bar{\sigma}/\sigma_0 = 0.95$. Ni⁵⁸, J = 1/2 seems like the most probable identification. There is no way to decide between $\ell = 0$ and $\ell = 1$. There

is some lesser structure to mask the possible resonance dip for $\ell = 0$; there is, however, no indication of an asymmetrical shape of the peak. The values of γ_n^2 are 5.4×10^{-12} and 2.4×10^{-10} kev cm for $\ell = 0$ and $\ell = 1$, respectively.

The 65 kev peak shows asymmetrical structure and the dip to lower energies ahead of its characteristic of $\ell = 0$. The peak value is very close to the calculated one for Ni^{58} , $J = 1/2$ of 28 b and well above the value of 10 b for Ni^{60} , $J = 1/2$. The distance from minimum to maximum is ~ 5 kev and $k a$ is 0.29, giving a value of ~ 2.9 kev for Γ . It seems reasonably certain that an assignment to $J = 1/2$, $\ell = 0$ for Ni^{58} is correct. γ_n^2 is computed to be 2.6×10^{-12} .

The resonance at 111 kev has the asymmetry characteristic of S-wave scattering. The peak value is well above the value predictable for Ni^{60} and somewhat below that for Ni^{58} . Provisionally it is to be attributed to Ni^{58} , $J = 1/2$, $\ell = 0$. A paper on these results for possible publication in the Physical Review is being prepared in collaboration with A. Langsdorf.

The peaks at 144 and 160 kev are both preceded by dips to such low cross sections that they are scarcely to be accounted for except as $\ell = 0$, $J = 1/2$ peaks for Ni^{58} . The maximum cross section at 144 kev is 12 b, the calculated value for Ni^{58} , $\ell = 0$, $J = 1/2$ being 12.5 b. The half width is ~ 4 kev and there is no pronounced asymmetry. The 160-kev peak was not followed completely through its maximum but it rises up to the Ni^{58} , $\ell = 0$, $J = 1/2$ line.

64

In summary:

<u>Resonance energy (kev)</u>	<u>Isotope</u>	<u>J</u>	<u><i>ℓ</i></u>
16	58	1/2	0 or 1
65	58	1/2	0
111	58	1/2	0
144	58	1/2	0
160	58	1/2	0

2. Resonances of Li^6 and Li^7 near 250 kev - Carl T. Hibdon and R. Ray Weeks

An examination of the literature, (AEC-2040), shows that natural Li and Li^6 have neutron resonances of nearly the same peak cross section close to 250 kev. Since natural Li consists principally of Li^7 this must mean that each isotope has a resonance peak of about the same peak cross section at nearly the same energy value. A sample of Li enriched in Li^6 being available, thanks to the courtesy of the Los Alamos Scientific Laboratory, it was decided to explore this energy region carefully to determine the location of the peaks and the cross sections more accurately.

The cross section measurements were made using neutrons produced by protons from the Van de Graaff generator impinging on a Li target 1.4 to 1.8 kev thick. All measurements were made with forward neutrons at an angle of 0° with respect to the direction of the proton beam. A long counter was used as a monitor at an angle of 30° with the proton beam.

The energy region was covered twice, the statistics being poor, however, because of a low beam current. Both coverages of the energy region gave the same results. From the measured cross sections and the known isotopic abundance of each sample the cross section of each isotope, Li^6 and Li^7 , was calculated. The results indicate that Li^7 has a resonance at about 257 kev, peaking at a height of 11.8 barns. The highest cross section for Li^6 was almost 12 barns at 247 kev. These measurements also indicate that a second peak exists in Li^6 located near the Li^7 peak. However, sufficient experiments have not been performed to date to make it certain that this second peak exists.

The width of the Li^7 peak at half maximum is 27 kev and that of Li^6 is 89 kev.

The Li^7 resonance was analyzed according to the method described in Part 1 of this report. No marked dip in the cross section was observed at energies below the Li^7 resonance, which indicates that it is not due to S-neutron interaction. The maximum of the Li^7 resonance is near the peak line for $J = 3$ ($\ell = 1, 2, \text{ or } 3$), too high for possible S-neutron interaction. The reduced width for a P-neutron interaction is smaller than the Wigner limit, but it is several times greater than the Wigner limit for assumed D-neutron interaction. Assuming P-neutron interaction, a single level Breit-Wigner expression fits the resonance on the low energy side and at the peak but deviates some in the wing of the resonance on the high

energy side, the measured cross sections being higher than the computed values. The $\sin^2 ka$ term plus the resonance contribution is approximately equal to the measured cross section at energies below the resonance.

There is little that can be said concerning the Li^6 peak until it is determined definitely whether it is a single broad peak or the superposition of two at nearly the same energy.

These experiments will be repeated in order to get more accurate results.

99-3 Standards for Measurements of Thermal Neutron Absorption
Cross Section (5261-01)

Henry R. Hoekstra (Chemistry Division), Roy Ringo,
 Sol Wexler
 Reported by Roy Ringo

There are still disagreements between the standards (for measurements of absorption cross sections of thermal neutrons) in use by various laboratories. One possibility of explaining these disagreements lies in the measurement of the amount of boron in a solution since all the standards are boron solutions. These measurements are usually based on the assumption that ignited boric acid produces B_2O_3 . Hitherto it has not been possible to check this, but recently an oxygen analysis has been made of some B_2O_3 prepared just as our standards were. The proportion of oxygen was found to be as expected within 0.2%. This gives further support to this reliability of the Argonne-Brookhaven value of 752 ± 3 barns for absorption cross section of boron.

101-2

A Method for Measuring Radiative Capture Cross Sections

(5211-01)

Robert E. Holland and F. Paul Mooring

Reported by F. Paul Mooring

Preliminary experiments designed to test the method have been conducted. The counter assembly consisted of sixteen two-inch cubes of sodium iodide arranged to surround the gamma source almost completely. The outputs of the sixteen photomultipliers were connected in parallel and fed into a ten-channel pulse-height analyzer. The resolution of the counter assembly for the 662 kev Cs¹³⁷ gamma-ray line was of the order of ten percent.

Due to the large gamma sensitive volume of sodium iodide, backgrounds were troublesome. This background arose from two sources. First, a large natural background, natural to the Van de Graaff room at least, is to be blamed primarily on the radium spill of two summers ago. Second, the Van de Graaff generator itself is a source of low energy gamma-rays. Only after completely surrounding the counting assembly with two inches of lead was the background reduced to a tolerable level.

Two types of experiments have been performed. In the first type, designed to get a measure of the summing efficiency of the counter assembly, pulse-height analyses were taken using Na²⁴ and Co⁶⁰ as gamma-ray sources. Both of these sources emit two gamma-rays in cascade. The summing ability of the assembly was not as great as had been anticipated.

65

In order to test directly the feasibility of using the method for measuring capture cross sections, the assembly was set up at the Van de Graaff generator. To make the measured results as simple as possible, proton capture gamma-rays from various elements were looked for. Protons with energies of about 2.5 Mev were used to bombard targets consisting of 50 microgram layers of the capturing material evaporated onto 10 mil tantalum backings. At various times copper, cobalt, iron, and magnesium were used as the capturing element. Though pulse height analysis showed the presence of capture gamma-rays, in no case was a capture sum peak evident..

The data have been accumulated only recently and, though they are somewhat disappointing, it is too early to draw definite conclusions from them. A statement concerning the practicality of using very large crystals for measuring radiative capture cross sections can be made only after a more thorough study of the data.

102-2 (Neutron Cross Sections by Self Detection) (5211-01)

William A. Reardon

The theoretical treatment of the results obtained in these experiments is still being developed as the deadline for reporting is reached. It seems desirable to postpone their discussion until the next quarterly report.

R. W. Holmes (Central Shops), Roy Ringo,
Surain Sidhu (Metallurgy Division)
Reported by Roy Ringo

Sol Raboy and Roy Ringo Reported by Sol Raboy

Charles Eggler

Gilbert J. Perlow

The coincidence spectrometer described in the preceding two quarterly reports was tried early during the past quarter. Since

70

tritium-free deuterio-methane was not available, ordinary methane was used in the proportional counter. The scattered neutrons were detected at angles near 90° in a bank of BF_3 counters embedded in Lucite. Pulse-height distributions of the proportional counter pulses were obtained by measurements on oscilloscope pips photographed by a continuous film camera. The desired peak in the distribution was apparent, but the large background of accidentals showed the scheme to be impractical in the form used. It is clear that to make it work, the efficiency and shielding of the Lucite block must be increased and the lifetime of neutrons in it must be decreased. The required effort would be considerable; the method has been at least temporarily abandoned in favor of another described below, which is expected to be tried this quarter.

The new attempt consists of two proportional counters fastened side by side with a common gas filling. The counter interiors communicate through a collimator plate consisting of a multiplicity of stacked narrow channels. The axes of the channels are orientated so that for neutrons incident broadside on one counter, the forward proton recoils may pass from one counter into the second. A coincidence signals a useful event, and the sum of the pulses from the two counters is the desired pulse height. The path length of the recoils in the collimator is quite small compared to the counter diameters, so that at an appropriate gas pressure, the fluctuation will be small due to the ionization lost in

the collimator for recoils originating at different distances from it.

The device may be considered to be like the much-used hydrogenous-film-plus-collimator systems, with the exception that the film is now made thick, and the ionization in it is accounted for.

120-5 Calibration of a Ra-Be Neutron Source (5211-01)

Willard C. Jordan

Little progress has been made on this program during the past quarter.

More data confirm the undersirability of the G. M. tube as the beta detector. It is planned to test the feasibility of using an anthracene scintillator by using the existing ten-channel scintillation equipment.

133-5 Design Study of a Multi-Bev Proton Synchrotron (5211-01)

Edwin A. Crosbie, Melvin I. Ferentz,
Morton Hamermesh, John J. Livingood
Reported by John J. Livingood

The lectures on conventional and alternating gradient accelerators are still continuing, with over 200 pages of mimeographed notes already issued covering the theory of phase stability and orbit stability in the betatron, cyclotron, synchrocyclotron and synchrotron, and the theory of the linear and non-linear alternating gradient device already issued. Emphasis has been placed on the various approximations involved in each development. Possibly a dozen more lectures remain, covering

the proton linear accelerator and synchrotron oscillations in the alternating gradient machine.

The accuracy of the REAC, in integrating the linear equation for betatron oscillations in the alternating gradient synchrotron, has been checked by observing the reproducibility of calculated eigen-values. A program is now under way to study the effects of non-linearities; comparison will be made with the results obtained, for the same problem, by Courant and Kerst using digital computers.

135-4

Electron-Neutron Interaction

(5211-01)

Roy Ringo

The electron-neutron interaction has been measured at Argonne by the anistropy of the neutron scattering of krypton and xenon. The coherent neutron scattering amplitude of krypton and xenon are directly involved in the calculations of the interaction. It was intended to measure these by neutron diffraction from frozen krypton and xenon powder. However in the course of some preliminaries to these measurements it was found to be relatively easy to obtain liquid krypton and keep it liquid in spite of the small range (5° C) in which it is liquid at atmospheric pressure. Accordingly it is now proposed to measure these coherent amplitudes by the intensity of reflection from a mirror of liquified gas. This scheme is much less subject to difficult corrections for incoherent effects than is the powder diffraction nethod when used for an absolute measurement.

15

Apparatus for this mirror reflection experiment has been designed and built and is now in the leak-hunting stage.

140-1 A Gaseous Scintillation Counter (5211-05)

Charles Egger and Charles M. Huddleston
Reported by Charles M. Huddleston

A gaseous scintillation counter has been used to detect α -particles. The gas-filled cell is an aluminum cylinder 2 inches in diameter and 2 inches deep. It is filled to a pressure of about four atmospheres of argon. An α -source is located at one end, and a Lucite window covers the other end. The inside of the window is coated with a thin film of 2.6% tetraphenylbutadiene in polystyrene.¹ The window coating acts as a color-shifter, converting the far ultra-violet emission lines of argon, which are excited by the α -particles, into the visible region. These pulses of visible light are measured with a DuMont photomultiplier tube and a differential discriminator.

It should be noted that no large pulses could be obtained without the color-shifter. Other color-shifters which appeared to be satisfactory were fluorescein and a mixture of 2-5 diphenyloxazole and diphenylhexatriene in phenylcyclohexane.²

The counter has been observed to operate with He as well as

-
1. Contributed by Warren Buck and Robert Swank of the Instrument and Research Division.
 2. Kindly supplied by Mr. George Thomas.

with A. However, mixtures of A and He have not yet been made to count.

In preliminary tests the counter efficiency is found to be essentially 100%, and the resolution of the counter is better than 50%. The order of 100 photo-cathode electrons are ejected by the light from a single α -particle when argon is used as the counter gas. Still larger pulses are obtained with helium. The overall pulse width, including electronic effects, is $5 \mu\text{sec}$.

Efforts are being made to improve the resolution of the counter, and to obtain larger light pulses by reflection from the walls of the cell.

It is hoped that the gas cell can be filled, completely or partially, with He^3 and that it can act as a neutron spectrometer by measuring the total energy of the proton and triton released when a neutron is captured in the gas.

An abstract was presented at the April meeting of the American Physical Society.

II. MASS SPECTROSCOPY

1-5

Mass Spectrometric Techniques

(5211-08)

Robert Gomer (University of Chicago) and Mark G. Inghram
Reported by Mark G. Inghram

A study has been started of the emission of ions from surfaces due to very high electrostatic fields 10^8 volts/cm, Field Emission. This study has the dual purpose of (1) studying surface chemistry and (2) testing the feasibility of the method as an ion source for isotopic analysis of micro samples. Since a great deal of work is necessary on the subject before it can become "a tool", (item 2), it will be reported in this quarterly henceforth under "Field Emission Studies".

The technique involves the use of a Mueller microscope, i. e. , a needle with a tip radius of 10^{-5} cm surrounded by a hemispherical conducting shell on which is usually placed a phosphor. When a high potential (~ 5000 volts) is placed between the shell and the tip, with the tip negative, electrons are drawn from that point by field emission. When the potential is reversed and increased about 6 times, i. e. $\sim 30,000$ volts, positive ions are drawn from the tip. It was known at the start of this work that such ion currents existed but no study had ever been made as to their masses.

We have started preliminary studies of the emission of hydrogen ions from the tip when the gas around the tip is hydrogen. We

find that at low fields both H^+ and H_2 ions come from the tip and that the H_2 predominates by a factor of about 10. This is evidence that at room temperature part of the hydrogen absorbed on a tungsten tip is absorbed as H_2 and not in the atomic form. As the voltage is increased the intensity ratios shift toward more complete dissociation and at very high potentials $\sim 10^8$ volts/cm other phenomena take over in which ionization occurs up to 300 Å away from the surface, which seems to keep all gas from striking the surface at all. The explanation of this ionization is not clear. In addition to these voltage effects, there is a hysteresis effect; i. e., the intensity ratios are not the same as one goes up and down in voltage. This is clearly due to the fact that the chemistry of the surface is changing. It is clear that a number of phenomena are involved in this work and that it will take some time to unravel them and make the source a useful tool for surface chemistry.

2-5

Construction and Operation of MA-17

(5211-08)

Henry E. Stanton

After cleaning and assembly the background in the machine was found to be reduced to a tolerable level.

The machine is not yet complete nor suitable for appearance potential work except very crudely. An emission regulator and source control panel have been ordered from electronics after preliminary experiments with battery supplies indicated the requirements of these

two units. Delivery has been promised during the next quarter.

10-5 Search for Rare Naturally Occurring Isotopes (5211-08)

David C. Hess

The double magnetic analyzer, MA-16, has been reassembled and is in process of readjustment. An electron bombardment source has been installed so that a persistent ion beam is obtainable.

Attempts are being made to increase the ion intensity and resolution.

No materials have been "searched" during the past quarter, as most of the measurements have been made on the mass 44 and 45 peaks of carbon dioxide.

Some re-design and installation of gold gaskets may be necessary before the machine can be baked to clean it out.

12-5 (Double Beta Disintegration of Te^{130}) (5211-08)

Richard J. Hayden and Mark G. Inghram
Reported by Richard J. Hayden

No progress has been made on this problem during the past quarter.

30-5 The Heat of Vaporization of Carbon (5211-08)

William A. Chupka (Harvard University) and
Mark G. Inghram
Reported by Mark G. Inghram

The Knudsen cell furnace for use in the mass spectrometer

for thermodynamic equilibrium studies has been completed. The cell was loaded with graphite and studies of the effusion from the small exit hole made (area of hole $1/2000$ of the area of the inner surface). The furnace operated successfully up to 2500°K , at which point one of the insulators gave out. A minor change has been made to enable us to reach 2800°K .

At 2400°K we were not able to measure the C , C_2 , or C_3 . The instrument was calibrated by using a known mass of silver in the furnace. With the calibration so obtained the carbon evaporation should have been three times the limit set, if the low heat of evaporation (141 Kcal/mole) is correct. Since the calibration is uncertain to about this factor it is clear that no conclusions can be reached. It is also clear, however, that there is nothing wrong with the equipment and that one of the next few attempts should give the answer to this fundamental problem.

31-5 (Studies of Electron Impact) (5211-08)

William A. Chupka (Harvard University) and
Richard J. Hayden
Reported by Richard J. Hayden

There are no results to report at the present time.

33-5 (Molecular States in Rare Gases) (5211-08)

David C. Hess

No work was done specifically on this problem during the past quarter.

19

34-5

Argon Age Determinations

(5211-08)

Richard J. Hayden and Gerald J. Wasserburg
(University of Chicago)
Reported by Richard J. Hayden

A program is under way to relate argon-potassium ages to lead uranium and lead-lead ages by making both types of determinations on the same mineral. Several argon analyses have been made of samples which come from regions previously lead-uranium dated by other investigators. However, the ages of these samples cannot be determined until their potassium analyses are received from the analytical chemistry section. We intend to check the lead-uranium and lead-lead ages by chemical analysis and by isotopic dilution.

35-1

Studies of Negative Ion Emission

(5211-08)

Henry E. Stanton

Since MA-17 has been in operation, its usefulness for measuring energies of molecular fragments produced in the process of ionization has been demonstrated for both positive and negative ions.

In the case of negative ions, however, intensities have been very near the threshold for their detection and reliable information has not been obtainable. The studies have been concerned with O^- and C^- ions and the intensities of the latter are particularly low. The reasons for these intensities being so low have not as yet been determined.

80

III. CRYSTALLOGRAPHY

1-5 (Crystal Studies of Technetium Compounds) (5211-11)

William H. Zachariasen

There are no further results to report

2-5 Structural Studies of Boric Acids (5211-11)

William H. Zachariasen

Further experimental data have been taken on the cubic
form of metaboric acid, HBO_2 .

31

V. THEORETICAL PHYSICS, GENERAL

1-5 Interpretation of the Energy States of Light Nuclei (5211-07)

David R. Inglis

The non-spherical, three-dimensional-oscillator treatment of the collective properties of closed shell nuclei as described in the last report has been extended to include further analysis of the rotational properties of a distorted nucleus, in an attempt to understand the success of the assumption used elsewhere that nuclear matter behaves dynamically as a classical irrotational fluid.

2-5 Energy States of Light Nuclei (5211-07)

Dieter Kurath

The calculation of the level scheme for mass number $A = 13$ with intermediate coupling has been completed. The level order resulting from solution of the secular equations is shown in Figure 5 in a manner which exhibits the shifting of the levels from the values of the diagonal energy matrix elements (which would be the result of first order perturbation theory).

In column (a) of Figure 5 are the levels from calculated diagonal matrix elements with the number of nucleons in the $1p_{1/2}$ -shell indicated on the left. Column (b) has levels resulting from solution of the secular equations; on the right is the identification $(J, T)^{\text{parity}}$. Column (c) has

52

experimental levels for C^{13} as taken from Ajzenberg and Lauritsen.¹ Only the ten lowest levels are given, and the experimental order is given for comparison. The interesting point is that the calculation indicates that only one of the many levels between 3.68 and 7.67 Mev should be contributed by the $1p$ -shell excitations. Since the next shells are $2s$ and $1d$, one would expect these levels to have positive parity unless two nucleons are excited out of the $1p$ -shell. Experimental determination of the parity will therefore provide clarification of this point.

The calculated value of the magnetic moment of the ground state is reasonable. ($\mu = 0.72$ n.m. compared to an experimental value of 0.70 n.m) The squares of the amplitudes of configurations which are mixed with the unperturbed configurations which provided the diagonal elements, are given for the first three states in Table IV.

Table IV

Amount of excited configuration in the resultant wave functions of the low states (square of the amplitude)

$(1p_{3/2})^m (1p_{1/2})^n$ (J, T)	$(m, n) = (8, 1)$	$(7, 2)$	$(6, 3)$	$(5, 4)$
$(1/2, 1/2)$	.789	.0006	.195	.015
$(3/2, 1/2)$	---	.747	.148	.105
$(5/2, 1/2)$	---	.832	.150	.018

There is considerable mixing, and the feature that $(1p_{3/2})^{m-2} (1p_{1/2})^{n+2}$ provides most of the admixture for the ground state is not carried over

1. F. Ajzenberg and T. Lauritsen, Revs. Mod. Phys. 24, 321 (1952).

PHG-627
3-31-54
B.G.

Figure 5

to the excited states.

Therefore there seems to be no valid way to select the states that interact most strongly with the lowest state of a given (J, T) for the more complicated nuclei. However, since the difficulty of the problem is due chiefly to the quantity of labor, it is planned to set up the problem for machine computation. In preparation for this, wave functions are being calculated for all the 1p-states, and this step is nearly completed. The setting up of the calculation will be done in conjunction with J. M. Cook.

4-5 Investigation of Nuclear Structure (5211-07)

Maria Goeppert Mayer

An article on beta-ray systematics for a book on "Beta and Gamma-Ray Spectroscopy", being edited by Kai Siegbahn, has been prepared and submitted to the publisher, the North Holland Publishing Company.

Extensions of the Bohr-Mottelson theory of nuclear deformations are being worked on, but no essential results have been obtained so far.

5-5 Book on "Elementary Theory of Nuclear Shell Structure" (5211-07)

J. H. D. Jensen (Institute für Theoretische Physik, Heidelberg, Germany), and Maria Goeppert Mayer
Reported by Maria Goeppert Mayer

The book is completed and has been forwarded to the publishers (Wiley).

7-5

Collective Description of Nucleon Interactions

(5211-07)

Melvin I. Ferentz, Murray Gell-Mann (University of Chicago), David Pines (University of Illinois)
Reported by Melvin I. Ferentz

The fact that the first dipole level in our theory completely exhausts the Bethe-Levinger sum rules¹ leads us to believe that this is the only level in real nuclei that is collective in nature. Assuming this to be so, the canonical transformation may be considerably simplified and the effects of exchange forces estimated in a more convincing manner. After performing the canonical transformation one may rotate coordinates so that the wave-vector of the oscillator is along the preferred axis in isotopic-spin space. Then, since only τ_z appears in the equations of motion, one need deal only with commuting quantities in the unperturbed case. In this new coordinate system coulomb forces involve τ_x and τ_y as well as τ_z , but these terms may be handled by straight-forward perturbation theory.

Our predictions for the elastic gamma-ray resonance cross sections¹ are in extremely good agreement with the recent measurements by Fuller and Hayward.² Since the N. B. S. group plans on doing differential cross section measurements for both electrons and gamma-rays, explicit cross section calculations are underway in an attempt to predict their results.

1. Ferentz, Gell-Mann, and Pines, Phys. Rev. 92, 836 (1953).

2. E. G. Fuller and Evans Hayward, N. B. S. Report 3129 and Phys. Rev. in press.

8-5

7

Monoenergetic Neutrons from Charged Particle Reactions
(5211-07)

Alexander S. Langsdorf, James Monahan, William A. Reardon
Reported by Alexander S. Langsdorf

A full report, issued as ANL-5219, has been prepared by the information division.

It contains an 18 page mathematical introduction and analysis followed by 30 pages of tables of neutron energies versus bombarding proton energy for production of neutrons in a lithium target.

This is the final report on this project. It will be reopened if we should later decide to make similar tabulations for neutrons bombarding other targets.

9-3

Investigations on the "Cloudy Crystal Ball" for Heavy Nuclei
(5211-07)

Bernard I. Spinrad

Method

The "cloudy crystal ball" formalism for neutron scattering problems is one in which the problem of quantum mechanical scattering is solved by considering that the neutron is traveling in free space outside the nucleus; that the nucleus is a sphere of radius "a"; and that inside the sphere, the neutron moves in a potential well given by $V_0 (1 + i S)$. The imaginary part of the complex potential is intended to account for all processes which remove the neutron from its initial state; it leads to a decay of the neutron wave function into the nucleus which is interpretable as a net probability for loss of the neutron by formation of a compound nucleus.

The same scheme with $\mathcal{S} = 0$ gives the formula for diffraction scattering by nuclei; this diffraction scattering shows a resonance structure with very sharp peaks. The effect of the "absorptive" term in the potential is to diminish and spread these peaks. It may then be expected that the technique is not only physically reasonable, but may yield reasonable approximations to the observed neutron cross section curves, which show slowly varying rises and dips when individual compound nuclear resonances are smoothed out. Moreover, the theory may predict believable angular distributions.

Equations and Formulae

Units

$x^2 = k^2 a^2$, where a is the nuclear radius and k is the wave number of the neutron in free space.

$X_0^2 = (K^2 + k^2) a^2$, where K is the (complex) wave number of a neutron whose kinetic energy is $V(1 + i\mathcal{S})$; $\sqrt{K^2 + k^2}$ is then the wave number of the neutron inside the nucleus.

Functions

$$V_0 = X \cot X$$

$$V_{n+1} = \frac{x^2}{2n+1 - V_n}$$

$$W_0 = -X \tan X$$

$$W_{n+1} = \frac{x^2}{2n+1 - W_n}$$

$$U_0 = X_0 \cot X_0$$

$$U_{n+1} = \frac{X_0^2}{2n+1 - U_n}$$

$$Z_0 = -\tan X$$

$$Z_n = (-)^{n+1} \frac{J_{n+1/2}(x)}{J_{-n-1/2}(x)}$$

$$Z_{n+1} = Z_n \left[\frac{2n+1 - V_n}{2n+1 - W_n} \right]$$

Of these functions, all are real except the U_n ; the U_n are complex with negative imaginary parts, X_0 being complex.

$$\beta_n = Z_n \left[\frac{U_n - V_n}{U_n - W_n} \right]$$

$$\frac{\sigma_s}{4\pi a^2} = \sum_{n=0}^{\infty} \sigma_{sn} ; \sigma_{sn} = \frac{2n+1}{X^2} \frac{|\beta_n|^2}{|1 - \epsilon' \beta_n|^2}$$

$$\frac{\sigma_a}{4\pi a^2} = \sum_{n=0}^{\infty} \sigma_{an} ; \sigma_{an} = \frac{2n+1}{X^2} \frac{I(\beta_n)}{|1 - \epsilon' \beta_n|^2}$$

where $I(\beta_n)$ is the imaginary part of β_n .

$$\frac{\sigma_s(\theta)}{4\pi a^2} = \frac{1}{2X^2} \sum_n \sum_m (2n+1)(2m+1) \frac{\beta_n^* \beta_m}{(1 + \epsilon' \beta_n^*)(1 - \epsilon' \beta_m)}$$

$$P_n(\mu) P_m(\mu),$$

where $\mu = \cos \theta$.

Series for V

Of the functions in the preceding section the recurrence relation on V is the only one which loses precision rapidly as n increases. Hence, we present the series for V in power form:

$$V_n = 2n+1 - \frac{X^2}{2n+3} - \frac{X^4}{(2n+3)(2n+5)} - \frac{X^6}{2(2n+3)^3(2n+5)(2n+7)}$$

The four terms converge to better than .001 absolute error for $X \leq X_0(n)$ of the following table:

<u>n</u>	<u>$X_0(n)$</u>
0	1.22
1	1.73
2	2.22
3	2.69
4	3.14
5	3.57
6	3.98

Low Energy Cross Sections

At low energy, the cross sections are the following:

$$\lim_{X \rightarrow 0} \frac{\sigma_s}{4\pi a^2} = \left| \frac{U_0(Ka) - 1}{U_0(Ka)} \right|^2$$

$$\lim_{X \rightarrow 0} \frac{\sigma_a}{4\pi a^2} = \frac{1}{ka} \operatorname{Im} \left[\frac{1}{U_0(Ka)} \right]$$

where I is the imaginary part.

Selection of Parameters

For a given isotope, these limits may be interpreted as

follows: $\lim_{X \rightarrow 0} \sigma_s$ = epithermal, inter-resonance, scattering cross section, (or scattering cross section of the free atom at thermal energy).

$\lim_{X \rightarrow 0} \sigma_a$ = difference between "poor resolution" total cross section in the epithermal range, and σ_s

(or, $\frac{1}{ka} \lim_{E \rightarrow 0} \left\{ \sigma_{act} \left[1 + \frac{r_n}{r_y} \right] ka \right\}$ for poor resolution experiments on activators).

For selected isotopes, these are reasonably well known.

We first examine $\lim_{X \rightarrow 0} \sigma_a$ for approximate behavior.

$$U_0(Ka) = Ka \cot Ka; \text{ let } Ka = u + i'v$$

$$\frac{1}{U_0(Ka)} = \frac{\tan(u + i'v)}{u + i'v} = \frac{\tan u + i' \operatorname{th} v}{(1 - i' \tan u \operatorname{th} v)(u + i'v)}$$

$$= \frac{(\tan u + i' \operatorname{th} v)(1 + i' \tan u \operatorname{th} v)(u - i'v)}{(1 + \tan^2 u \operatorname{th}^2 v)(u^2 + v^2)}$$

$$I \left[\frac{1}{U_0(Ka)} \right] = \frac{u \operatorname{th} v \sec^2 u - v \tan u \operatorname{sch}^2 v}{(u^2 + v^2)(1 + \tan^2 u \operatorname{th}^2 v)}$$

$$= \frac{u \operatorname{sh} 2v - v \sin 2u}{(u^2 + v^2)(\operatorname{ch} 2v + \cos 2u)}$$

This function is then known for a choice of "a". Now the order of magnitude of u may be estimated by taking reasonable values of a (say $1.5 \times 10^{-13} \text{ A}^{1/3} \text{ cm}$) and of K', the wave number of the most energetic neutron in the nucleus. For heavy nuclei, this makes $u = O(10)$, within a factor of 3. Furthermore, we may expect $v \ll u$, since the imaginary part of the potential is treated as a perturbing fraction of the real part. Hence, v^2 may be almost neglected compared with u^2 ; $\sin 2u$ is small compared with u; v is certainly less than $\operatorname{sh} 2v$; $\operatorname{sh} 2v$ may be approximated in a one term expansion; and

$$I \left(\frac{1}{U_0(Ka)} \right) \doteq 2 \frac{v}{u(1 + \cos 2u)} \doteq \frac{v}{u \cos^2 u}$$

The available data indicate that I is small, so that $\frac{v}{u}$ must be small and, moreover, $\cos u$ must not be too close to zero (i.e., u must

not be near $(n + 1/2) \pi$. Since we expect $\cos u$ to have many periods in passing through the periodic table, we then ought to get regions where compound nucleus formation is highly favored at low energies.

$$\text{If } u = (n + 1/2) \pi,$$

$$I \doteq \frac{1}{u v} \doteq \frac{u}{v} \left(\frac{1}{u^2} \right)$$

$$\text{If } u = n \pi,$$

$$I \doteq \frac{v}{u}$$

Hence, if we are not to expect too much variation in compound nucleus formation in traversing the region of heavy elements ($A > 150$), v must be of $O(1)$.

It is clear that, without these simplifications, the fixing of the low energy limit for compound nucleus formation determines v for a nucleus uniquely from a choice of u .

$$\text{We now examine } \sigma_s(0). \text{ We need } 1 - R \left(\frac{1}{U_o(Ka)} \right)$$

$$1 - R = 1 - \frac{u (\tan u \operatorname{sch}^2 v) + v \operatorname{tanh} v \operatorname{sic}^2 u}{(u^2 + v^2) (1 + \operatorname{ta}^2 u \operatorname{th}^2 v)}$$

$$= 1 - \frac{u \sin 2u + v \operatorname{sh} 2v}{(u^2 + v^2) (\operatorname{ch} 2v + \cos 2u)}$$

Then,

$$\begin{aligned} \frac{\sigma_s(0)}{4 \pi a^2} &= 1 - \frac{2(u \sin 2u + v \operatorname{sh} 2v)}{(u^2 + v^2) (\operatorname{ch} 2v + \cos 2u)} + \frac{(\operatorname{sh}^2 2v + \sin^2 2u)}{(u^2 + v^2) (\operatorname{ch} 2v + \cos 2u)^2} \\ &\doteq 1 - \frac{2 \sin 2u}{u (1 + \cos 2u)} + \frac{4 v^2 + \sin^2 2u}{(\operatorname{ch} + \cos 2u)^2 u^2} \end{aligned}$$

This is near 1 for u large and not near $(n + 1/2) \pi$.

For u near $(n + 1/2) \pi$,

$$\begin{aligned} \frac{\sigma_s(0)}{4\pi a^2} &\approx 1 - \frac{4v^2}{2u^2 v^2} + \frac{4v^2}{4u^2 v^4} \\ &\approx 1 + \frac{1}{u^2 v^2} \end{aligned}$$

Again $v = 0$ (1) prevents fluctuations from being extreme.

If we take $v = 0$ (1)

$$u = 0 \text{ (10),}$$

we get the ratio $0 \left(\frac{u}{v}\right) = \frac{1}{10}$, which is what is used by Weisskopf (.04).

For a , we may use

$$\frac{\sigma_s(0)}{4\pi a^2} \approx 1, \text{ and expect to get an approximate answer.}$$

To pin u down, let us assume $v = 0$ for the moment. Then we may solve the diffraction scattering problem, looking for the broad, low l , resonance peaks and dips, which occur at varying energies for varying u . Values of u which give resonances at the same energies will be approximately spaced at intervals of π . There is very little to choose between one value and the next, the closest criterion being that the potential should be $O(20 \text{ Mev})$.

General Observations

The probability of compound nucleus formation seems to vary with neighboring elements (U^{238} vs Th^{232} , for example) by large amounts

without materially changing the total cross section curve; either this indicates u near $(n + 1/2)\pi$ in this region, or more probably indicates that " v " is characteristic of an element and that the damping effect of $\mathcal{S}(\rho)$ is initially large but saturates at rather small values as far as flattening resonances out is concerned.

U_n is in general large compared to V_n, W_n ; for this reason, $\beta_n \approx Z_n$. When $\beta_n = Z_n$, however, the scattering has the characteristics of scattering from a hard sphere. Hence, we may expect to find regions of energy where hard sphere, diffraction, and "clouded" scattering have very similar angular distributions.

Program for Computation

Diffraction scattering plots for x^2 vs X_0^2 are needed to fix approximate values of " u " by ρ vs E curve shape.

For selected elements, $\lim_{E \rightarrow 0} \left\{ ka \sigma_{act} \left[1 + \frac{\Gamma_n}{\Gamma} \right] \right\}$ or $\lim_{x \rightarrow 0} x \sigma_a$ are to be determined, so that approximate values of v may be computed.

"Clouded" computations should then be performed, varying u, v , and a to fit total cross section curves. Here, variation of parameters should be performed first on u , then on v , finally on a , in order.

Note: AVIDAC is a sufficient vehicle for these computations, but it should be possible to use CPC, either by special purpose wiring, or by doing the problem in stages, making use of function tables for V, W, Z .

10-1

The Effect of Inelastic Scattering in the Analysis of
Scattering Resonances

Morton Hamermesh and James Monahan
Reported by James Monahan

Stelson and Preston (P. H. Stelson and W. M. Preston, Phys.

Rev. 88, 1354 (1952)), have measured the total neutron cross section of Na^{23} with good resolution (2.5 to 5 kev) over the energy range 120 to 1000 kev. In their analysis of the data, however, they have neglected inelastic scattering to the first excited (430 kev) level of Na^{23} . Calculations based on the statistical model of nuclear reactions show that such a procedure is not always correct. For example, a total cross section of 2.1 barns is measured for the 542 kev resonance (see the above reference for the definition of "total cross section" for an S-resonance); the calculated cross sections, neglecting inelastic scattering, are 1.70 barns (assuming the spin and relative parity of the excited virtual level to be $J = 1+$) and 2.80 barns for $J = 2+$. This led to the assignment $J = 1+$ to this level. When the possibility of inelastic scattering is taken into account, however, these cross sections are reduced to 1.69 barns for $J = 1+$ and 1.94 barns for $J = 2+$, indicating that the level is probably a $2+$ level. It might be noted that this level is only 100 kev above the inelastic threshold.

Within the energy range considered, the calculated inelastic cross section reaches a maximum of about 0.6 barns for a parity-favored S-resonance. This decreases to less than 0.01 barn for a parity-unfavored

D-resonance.

In addition to extending the calculations described above, we plan to consider the effect of inelastic neutron scattering on the shape of resonance curves and on the angular distribution of elastically scattered neutrons.

29-4 Internal Conversion in the L and M Sub-Shells (5211-07)

Eugene L. Church and James E. Monahan
Reported by Eugene L. Church

1. Relative Internal Conversion in the L Sub-Shells

Non-relativistic internal-conversion coefficients for magnetic radiations have been computed for the three L sub-shells in the Pauli approximation, paralleling the calculations of Drell¹ for the K shell. The relative internal conversion coefficients have been evaluated for multipole orders 1 through 5 with the aid of hypergeometric functions computed by the Mathematics Branch of Frankford Arsenal.² The results obtained are presented in Figures 6 and 7 as functions of the parameter $Z^2/\hbar\omega$, where Z is the atomic number of the nucleus involved, and $\hbar\omega$ is the transition energy in kev. The present results constitute an extension of the work of Tralli and Lowen³ to higher values of $Z^2/\hbar\omega$.

1. S. D. Drell, Phys. Rev. 75, 132 (1949).

2. The generous assistance of Mr. Sylvan Eisman of Frankford Arsenal is gratefully acknowledged.

3. N. Tralli and I. S. Lowen, Phys. Rev. 76, 1541 (1949); N. Tralli (private communication).

The comparison of the above with the analogous results for electric transitions⁴ has already been discussed.⁵

The individual points indicated in Figure 7 are the results of the relativistic calculations of Gellman et al,⁶ for M1 transitions. The corresponding points for Figure 6 are generally an order of magnitude less than the non-relativistic predictions, and have not been included. In the case of the 46.7-kev M1 transition in Bi²¹⁰, the experimental value⁷ of the relative conversion in the L₁₁₁ sub-shell falls between the relativistic and non-relativistic estimates.

The possible effects of screening have been neglected in all cases. If, as in previous work,^{3,8} screening is taken into account by replacing Z by $Z_{\text{eff.}} = Z - \sigma$, where $\sigma = 4.15$ is Slater's screening constant for the L shell,⁹ agreement with experimental data on M4 transitions¹⁰ is improved.

2. Non-Relativistic Calculation of Internal Conversion Coefficients

It is possible to compute non-relativistic internal conversion coefficients using the existing screened electronic wave

-
4. E. L. Church, ANL-5141.
 5. E. L. Church and J. E. Monahan, Bull. Amer. Phys. Soc., 29, 1, 1A6; also privately circulated notes.
 6. H. Gellman et al, Phys. Rev. 85, 944 (1952).
 7. C. S. Wu et al, Phys. Rev. 91, 319 (1953).
 8. M. H. Hebb and E. Nelson, Phys. Rev. 58, 486 (1940).
 9. J. C. Slater, Phys. Rev. 36, 57 (1930).
 10. J. W. Mihelich, Phys. Rev. 87, 646 (1952); J. W. Mihelich and A. de-Shalit, Phys. Rev. 93, 135 (1954).

Figure 6 - L_{III}/L_I Conversion of
Magnetic Radiations

Figure 7 - L_1/L_{11} Conversion of
Magnetic Radiations

17

functions of Meyerott.¹¹ The results obtained would differ from previous non-relativistic calculations^{1,8} by the inclusion of the first-order effects of screening and the use of the complete radial expansion of the multipole field.

The evaluation of these quantities is being considered for the K-shell for low multipole orders and several values of energy and atomic number. In conjunction with the relativistic calculations of Reitz,¹² such data would fill an existing need for low-energy internal-conversion coefficients.

31-5 (Configuration Interaction in Iron Group Elements) (5211-14)

Jean F. Hall and Norbert Rosenzweig
Reported by Norbert Rosenzweig

Work on this project will be resumed when the AVIDAC becomes available for computations.

34-5 Quantized Space Time (5211-14)

Emil J. Hellund and Katsumi Tanaka
Reported by Katsumi Tanaka

An article with this title has been published in Physical Review, 94, 192 (1954).

It was decided not to submit the originally planned letter on the time localized solutions until more results are available.

11. R. E. Meyerott, ANL-5008.

12. J. R. Reitz, Phys. Rev. 77, 10 (1950).

37-4

On the Relation of the Schrodinger and Boltzmann Equation

(5211-14)

Emil J. Hellund and Katsumi Tanaka

Reported by Katsumi Tanaka

As described in the last quarterly we are attempting to include the collision term in the Boltzmann representation, which we will then transform in order to see what it corresponds to in the usual Schrodinger representation.

The collision term can be given only when the nature of interaction between particles at collision is known. Since it is impossible to describe the details of the process of collision, we must assume some law of interaction. It appears simpler to treat Maxwellian particles (inverse 5th power law of force) and find the form of the collision term in the Schrodinger representation before considering the case when the force between two particles is a general inverse power law.

39-3

Applications of the Theory of Angular Correlation (5211-07)

Melvin I. Ferentz and Norbert Rosenzweig

Reported by Norbert Rosenzweig

In our last report we gave the numerical values of the coefficients A_{γ} , B_{γ} and C_{γ} for five γ - γ angular correlation functions which are pertinent to the study of the decay of Pb^{204} . Currently, these functions are being evaluated and plotted as a function of the angle θ and the multipole mixture δ . L. C. Renick's assistance is gratefully acknowledged.

101

41-2 Solutions of the Dirac Equation for a Free Particle (5211-14)

Emil J. Hellund and Katsumi Tanaka
Reported by Katsumi Tanaka

Tomonaga (1950) has shown that the problem of fermions in an enclosure is reducible to the treatment of bosons. His treatment is confined to the consideration of a one dimensional system, and employs the calculus of second quantization. The essential part of the analysis is that one can, with the variables which obey the commutation relations consistent with Fermi-Dirac statistics, find new variables which obey commutation relations pertaining to Bose-Einstein statistics.

According to Fock (1932), it is possible to consider the configuration representation and the system of second quantization, interchangeably. It should therefore be possible to show this correspondence in the configuration representation. This was described briefly in the preceding report.

Although the correspondence which was shown directly relates the boson field with the fermion field it does not follow that the solution of the problem of fermions in an enclosure is necessarily more simple when first solved for the boson field. The boundary conditions are necessarily different for the two kinds of particles. Thus the treatment of Feshbach and Colgston (1941) of the problem of perturbation of boundaries of an enclosure containing a system of phonons requires the additional labor of interpretation of the proper boundary conditions before it is easily transcribed

into a treatment of fermions.

A short paper entitled "Relativistic Behavior of Free Particles" has been submitted to the Physical Review.

42-1 Second-Order Focussing for Magnetic Spectrometer (5211-14)

Roland F. Herbst

Hintenberger¹ and Kerwin² have calculated the second-order focussing effect of curved boundaries for sector type spectrometers. These calculations ignore fringing field effects. An attempt is being made to incorporate the fringing field into these calculations using a method due to Coggeshall.³

43-1 The S Matrix (5211-14)

Katsumi Tanaka

It is possible that in the future theory the S matrix will take over the role played by the Hamiltonian in quantum theory.

Definitions of the S matrices have been given in the interaction representation and the Schrodinger representation, is as follows

$$S = \sum_{n=0}^{\infty} S_n \quad S_0 = I \quad (1)$$

$$S_n = \frac{(-i)^n}{n!} \int_{-\infty}^{\infty} \dots \int_{-\infty}^{\infty} dT_n \dots dT_1 P(H(T_n) \dots H(T_1))$$

-
1. H. Hintenberger, Z. Naturforsch, 3a, 125 (1948).
 2. L. Kerwin, Rev. Sci. Instr. 20, 36 (1949).
 3. N. D. Coggeshall, J. Appl. Phys. 18, 855 (1947).

and

$$S = \Omega_-^* \Omega_+$$

where

$$\Omega_+ = \lim_{\epsilon \rightarrow +0} \epsilon \int_{-\infty}^0 e^{i(H_0+H)T} e^{-iH_0T + \epsilon T} dT \quad (2)$$

$$\Omega_- = \lim_{\epsilon \rightarrow +0} \epsilon \int_0^{\infty} e^{i(H_0+H)T} e^{-iH_0T - \epsilon T} dT$$

H_0 = energy for free system

H = interaction energy in the Schrodinger representation

$H(T)$ = interaction energy in the interaction representation

$$\begin{aligned} H(T) &= e^{iH_0T} H e^{-iH_0T} \\ &= i e \int_{\phi(T)} \psi(x) \not{d} \psi(x) d\phi \end{aligned} \quad (3)$$

The former is related to the time-dependent (non stationary) and the latter to the time-independent (stationary) formulation of the theory of scattering and reaction processes. A necessary condition for the equivalence of the two definitions is that the eigenvalue spectrum of $H_0 + H$ be the same as that of H . If one uses definition (1) one can obtain the diagrams including divergent vacuum graphs for the matrix elements using the ordering theorem given by Dyson Wick and Jauch. As suggested by Jauch, the problem of developing a similar procedure for the definition (2) is being investigated. Since the two definitions of the S matrix are not in general equivalent, not all the diagrams can occur in (2).

The relation and properties of the two formalisms are being studied.

VII. ELECTRONIC DIGITAL COMPUTERS

0-3 Report on the Digital Computer Symposium (4520-02)

J. C. Chu

This report has appeared as ANL-5181.

There will be no further reports.

1-5 (Report on the Design of the AVIDAC) (4520-02)

Raymond F. Kramer

Writing of this report has been deferred until completion of numerous minor changes of the machine.

2-5 Improvements of the AVIDAC (4520-02)

Carl J. Bergstrom, J. C. Chu, Raymond F. Kramer,
David H. Jacobsohn
Reported by David H. Jacobsohn

During this period, the Ferranti photo-electric reader and teletype high-speed punch and associated circuits were installed on the AVIDAC. The tape reperforator was constructed and is available for use.

3-5 Operation and Maintenance of the AVIDAC (4520-02)

Carl J. Bergstrom

Maintenance schedules previously set up are being used.

A tube checker, adequate for testing tubes to the standards required by the AVIDAC, has been built and is now in operation.

105

4-5 (Test Routines for the AVIDAC) (4520-02)

Jean F. Hall

No new work has been completed since the AVIDAC was unavailable during the quarter.

5-5 (Sub-Routine Library for the AVIDAC) (4520-02)

Jean F. Hall

No new work has been completed since the AVIDAC was unavailable during the quarter.

6-5 (Coding Manual for the AVIDAC) (4520-02)

Donald A. Flanders

No work has been done on this project since July 1.

7-5 The Auxiliary Memory for the AVIDAC and ORACLE (4520-02)

Raymond F. Kramer and Leslie C. Merrill
Reported by Leslie C. Merrill

Centerpieces for the recording heads are complete insofar as the shop is concerned. Chrome plating of the recording gaps is 20% done and proceeding at a rate of 20% per week. Assembly of the recording head bodies has begun. Approximately 50% of the wound pole pieces have been received from the coil-winding subcontractor. The head holders are now finished.

106

The tape drive units are 50% complete.

The main frame for the ORACLE auxiliary memory is now in Building 203, Room R-170, where installation and testing will take place.

The prototype windup reel and basket is installed and ready for testing.

A subcontract for construction of the electronic reading/writing chassis has been initiated.

Logical design of the auxiliary memory control was completed after consultation with the computer group at Oak Ridge.

10-5 (Report on the Control of the AVIDAC) (4520-02)

James H. Alexander
Reported by Donald A. Flanders

So far no draft of this report has been received from Mr. Alexander, now on leave of absence from the Laboratory. He is still working on it.

13-2 New Memory for the AVIDAC (4520-02)

J. C. Chu

At the present time the Laboratory is considering acquiring a 4096-work magnetic core memory* for the AVIDAC. No definite decision has been made as yet.

* See page 84 of ANL-5181.

20-4

Report on Research, Development, and Design of the ORACLE

(4520-02)

J. C. Chu

This report is divided into two parts. Part I describes the logical structure of the ORACLE and Part II describes the engineering design. Inasmuch as this report is not intended to be an operational or maintenance manual of the ORACLE, much of the construction details will be omitted therefrom.

Part I of the report has been completed.

1029

VIII. APPLIED MATHEMATICS AND COMPUTATION, GENERAL

1-5 IBM Methods and Procedures (5211-14)

N. Frank Morehouse

(a) Tables of the opacity, $\Delta s/D$, were run off for various mixtures to determine what elements contribute most to the total opacity. The results will be reported by R. Meyerott.

(b) Several more flux distributions were run for D. Okrent (Reactor Engineering Division). The results will be reported by him.

(c) A few "Wilson-Serber condition flux problems" were run for H. Hummel, who will report on this work.

(d) The zone melting problem which was reported on last quarter by D. Flanders and N. F. Morehouse is being run on the IBM machines. This work which is for the PBR will be reported on by C. Stockman (Chemical Engineering Division).

(e) More computations of transmissions were done for L. Bollinger. (See section of this report by L. Bollinger).

(f) Correlation coefficients were run on some blood data for the Biological and Medical Research Division.

2-5 Report on Technical Details of General Purpose Boards
(4520-02)

N. Frank Morehouse

The reports on the technical details of the IBM general purpose boards have been completed. General distribution is not

/ 3 /

contemplated since these boards can be used only with a CPC, model I, a machine which has currently been replaced with model II's in most laboratories.

10-4 Three-Group Calculation of Critical Mass and Flux Plots
(4520-01)

Bernard I. Spinrad and Katsumi Tanaka
Reported by Bernard I. Spinrad

Multigroup Parameters and Critical Calculation in D₂O-Moderated System

The following is an abstract of an article submitted to
Reactor Science and Technology.

For systems with heavy water moderation, critical masses calculated on the two-group picture disagree with experimental results. Since the slowing down kernel may be approximated better by a three-group picture, it is desirable to do three-group calculations using, so far as possible, information obtained from two-group calculations. We exhibit a way of converting from two-group to three-group constants and outline an iterative process which leads to rapid convergence of the critical concentration of fuel.

12-3 (Computation of Traces of Gamma Matrices) (5211-12)

Donald A. Flanders and Joseph M. Cook
Reported by Donald A. Flanders

No progress has been made during the quarter.