1

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TABLE OF CONTENTS

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

	Page
 I. <u>EXPERIMENTAL NUCLEAR PHYSICS</u>	
1-3 The Argonne Fast Neutron Velocity Selector L. Bollinger	12
2-3 Liquid Scintillation Neutron Detector G. Thomas	14
3-3 Transmission Measurements with the Fast Neutron Velocity Selector R. Palmer	16
4-3 (Resonances in Separated Mo Isotopes) S. Harris	19
5-2 The Absorption and Scattering of Neutrons by Hafnium S. Harris	19
6-2 (Special Velocity Selector for Slow Neutrons) R. Ringo	19
11-3 Installation and Operation of the Van de Graaff Generator	
1. General Remarks A. Langsdorf	19
2. The Corona System P. Mooring	20
3. Control Circuits A. Langsdorf	20

TABLE OF CONTENTS CONTINUED

		Page
	4. System for Handling Large Proton Beams	
	A. Langsdorf	21
	5. Instability in the Ion Beam Position	
	F. Mooring	21
	6. Increase of Voltage	
	F. Mooring	24
12-3	R. F. Ion Source for the Argonne Van de Graaff Generator	
	F. Mooring	24
14-2	Pulsed Neutron Beams from Van de Graaff Generator	
	R. Holland	25
20-3	Energy States of Light Nuclei From Charged Particle Reactions	
	R. Malm	25
30-3	Scintillation Coincidence Spectrometer	
	B. Burson	26
31-3	The 1.42-Min Isomeric State in $^{192}_{77}\text{Ir}$	
	B. Burson	27
32-3	Decay Scheme of $^{165\text{m}}_{66}\text{Dy}$ (1.2 min) and $^{165}_{66}\text{Dy}$ (2.3 hr)	
	W. Jordan	28
33-3	Decay Schemes of $^{159}_{64}\text{Gd}$ (18 hr) and $^{161}_{64}\text{Gd}$ (3.7 min)	
	W. Jordan	28
35-3	(Decay Schemes of Long-Lived Rare-Earth Isotopes)	
	E. Church	30
36-3	The Decay Schemes of Mass 48 Nuclei	
	H. Casson	30
38-1	The Radiations From $^{160}_{65}\text{Tb}$	
	B. Burson	30

TABLE OF CONTENTS CONTINUED

		Page
39-1	Decay Scheme of $_{80}\text{Hg}^{205}$ (5.2 min) W. Jordan	36
40-1	The Decay Scheme of $_{23}\text{V}^{52}$ J. LeBlanc	38
41-1	The Decay Schemes of $_{48}\text{Cd}^{117}$ and $_{49}\text{In}^{117}$ J. LeBlanc	40
42-1	Gamma Radiations of Various Radioactivities Induced by Neutron Capture W. Jordan	42
50-3	(Internal Conversion of Capture Gamma-Rays Associated with Gd) C. Hibdon	44
51-3	Characteristics of a Scintillation Counter Spectro- meter R. Culp	44
52-3	Neutron Capture Gamma-Ray Studies with the Scintillation Spectrometer R. Culp	44
60-3	Eight-Meter Bent Crystal Spectrometer B. Hamermesh	47
70-3	Measurement of Nuclear Moments by Angular Correlation S. Raboy	47
71-3	The Angular Correlation of β -rays and Delayed Neutrons from Br^{87} L. Goodman	50
80-3	Molecular Beam Studies L. Goodman	51

TABLE OF CONTENTS CONTINUED

		Page
90-3	Cross Sections for 14-Mev Neutrons H. Casson	52
91-3	Neutron Transport Cross Sections A. Langsdorf	53
92-3	(Neutron Scattering Cross Sections by Use of the Scattering Chamber) C. Hibdon	53
96-3	(Pile Absorption Cross Sections) D. Rose	53
98-2	Total Neutron Cross Sections in the kev Region C. Hibdon	54
99-1	Standards for Measurement of Thermal Neutron Absorption Cross Sections R. Ringo	55
109-2	Neutron Diffraction Apparatus R. Ringo	56
110-3	Crystal Spectrometer for 0.1 to 100 ev Neutrons S. Raboy	56
112-3	(The Neutron Spectrum of a Standard Ra-Be Photo- source) C. Egger	58
114-1	Development of a Recoil Type Neutron Spectrometer G. Perlow	58
115-1	Neutron Counters Containing Boron Trimethyl A. Langsdorf	59
120-3	Calibration of a Ra-Be Neutron Source S. Harris	60

TABLE OF CONTENTS CONTINUED

		Page
131-3	Average Charge of Daughter Atoms After Nuclear Transitions S. Wexler	62
132-3	Chemical Service Work S. Wexler	62
133-3	Design Study of a Multi-Bev Proton Synchrotron J. Livingood	62
134-2	Optical Excitation Spectra of He ³ Species After β^- Decay of T ₂ S. Wexler	63
135-2	(Electron-Neutron Interaction) R. Ringo	65

II. MASS SPECTROSCOPY

1-3	Mass Spectrometric Techniques M. Inghram	66
2-3	Construction of MA-17 H. Stanton	66
9-1	Normal Isotopic Constitution of Hafnium R. Hayden	67
10-3	Search for Rare Naturally-Occurring Isotopes D. Hess	68
11-3	Technetium in Nature M. Inghram	69
12-3	Double Beta Disintegration of Te ¹³⁰ R. Hayden	69

TABLE OF CONTENTS CONTINUED

		Page
31-3	Studies of Electron Impact W. Chupka	70
32-3	Complex Ion Studies M. Inghram	70
33-3	(Molecular States in Rare Gases) D. Hess	71
34-3	Argon Age Determinations R. Hayden	71
III. <u>CRYSTALLOGRAPHY</u>		
1-3	Crystal Structure of Technetium Compounds W. Zachariasen	72
2-3	Structural Studies of Boric Acids W. Zachariasen	72
20-1	Table of Squared Sines A. Plettinger	74
IV. <u>EXPERIMENTAL REACTOR PHYSICS</u> (Covered in ANL- 5141, Program C-IV)		
V. <u>THEORETICAL PHYSICS, GENERAL</u>		
1-3	The Interpretation of the Energy States of Light Nuclei D. Inglis	75
2-3	Excited States of Light Nuclei D. Kurath	76
3-3	The Sequence of γ Emission in Triple Correlations J. Jauch	76

TABLE OF CONTENTS CONTINUED

		Page
4-3	Investigation of Nuclear Shell Structure M. Mayer	80
5-3	Book on Nuclear Shell Structure M. Mayer	80
7-3	Collective Description of Nucleon Interactions M. Ferentz	80
8-3	(Monoenergetic Neutrons from Charged Particle Reactions) W. Reardon	81
28-3	(Angular Distribution of Elastically Scattered Neutrons) M. Hamermesh	81
29-2	Internal Conversion in Subshells M. Hamermesh	81
30-3	(Consultation on Miscellaneous Theoretical Problems) M. Hamermesh	82
31-3	Configuration Interaction in Iron Group Elements N. Rosenzweig	82
32-3	Plural Scattering of Electrons at Oblique Incidence J. Monahan	82
33-3	Geometry for Maximum Scattering and Minimum Dis- persion J. Monahan	82
34-3	Quantized Space Time K. Tanaka	83
35-3	(Scattering of Photons by Atoms)	84
37-2	On the Relation of the Schrodinger and Boltzman Equation E. Hellund	84

TABLE OF CONTENTS CONTINUED

		Page
38-1	Cerenkov Radiation K. Tanaka	84
39-1	Applications of the Theory of Angular Correlation N. Rosenzweig	85
40-1	Compton Scattering K. Tanaka	86

VI. REACTOR THEORY (Covered in ANL-5141, Program C-VI.)

VII. ELECTRONIC DIGITAL COMPUTERS

0-1	Report on the Digital Computer Symposium R. Kramer	89
1-3	(Report on the Design of the AVIDAC) R. Kramer	91
2-3	Improvement of the AVIDAC C. Bergstrom	91
3-3	Operational Maintenance of the AVIDAC C. Bergstrom	92
4-3	Test Routines for the AVIDAC J. Alexander	93
5-3	Subroutine Library for the AVIDAC J. Hall	94
6-3	Coding Manual for the AVIDAC D. Flanders	95
7-3	The Auxiliary Memory for the AVIDAC and ORACLE L. Merrill	95

TABLE OF CONTENTS CONTINUED

		Page
8-3	(A Problem in Partitions) D. Flanders	96
10-2	Report on the Control of the AVIDAC J. Alexander	96
11-1	Automatic Stabilization of the Beam Currents in Williams Tube Memories R. Klein	96
12-1	Comparison of Inspection Systems for Williams Memory Tubes D. Jacobsohn	97
20-2	(Report on Research, Development, and Design of the ORACLE) J. Chu	98
21-3	Operation of the ORACLE J. Chu	98

VIII. APPLIED MATHEMATICS AND COMPUTATION, GENERAL

1-3	(IBM Methods and Procedures) F. Morehouse, Jr.	101
2-3	Report on Technical Details of General Purpose IBM Boards F. Morehouse, Jr.	101
5-3	IBM Floating-Point Subroutines E. Dershem	101
9-2	Monte Carlo Calculations on Liquid Neutron Counters F. Morehouse, Jr.	102

TABLE OF CONTENTS CONTINUED

		Page
10-2	Three-Group Calculation of Critical Mass and Flux Plots	
	K. Tanaka	102
11-1	Computations of the Absorption of β -Rays in Air	
	W. Feurzeig	102
12-1	Computation of Traces of Gamma-Matrices	
	J. Jauch	102

I. EXPERIMENTAL NUCLEAR PHYSICS

1-3 The Argonne Fast Neutron Velocity Selector (5211-01, 5261-01)

L. M. Bollinger, H. Jackson, R. Palmer, G. Thomas
Reported by L. Bollinger

Neutron Detection System

A new liquid scintillation neutron detector containing enriched methyl borate (counter No. 7 of Table I, report I-1-2), has been installed at the 40-meter detection station and has been in use for about two months. The higher neutron counting efficiency and narrower pulse-height distribution of counter No. 7 as compared with counter No. 6 have increased the signal to background ratio of neutron transmission data by a factor of two; the counting rates for neutrons of energy greater than 100 ev have also increased by a factor of two. The counting rate of the 40-meter detection station is now about 1.5 counts per min per μ sec channel width, with a signal to background ratio of 2, for neutrons of 1000 ev energy. The properties of counter No. 7 have not changed measurably during the two months it has been in operation.

Monte Carlo Calculation

The Monte Carlo calculation of the neutron capturing efficiency of an infinite slab liquid scintillation neutron counter has been completed. For each of the energies studied, the histories of 100 neutrons were

followed in an infinite counting medium until the neutrons were captured.

Table I gives the results of a statistical analysis of the number of neutrons captured as a function of counter thickness. The capture probabilities listed for 40 and 250 kev are somewhat too high for thin counters and too low for thick counters, because the energy variation of the hydrogen scattering cross section was neglected in the calculation.

Table I

The Neutron Capturing Efficiency
of a 50% Methyl Borate -- 50%
Phenolcyclohexane Medium.

Counter Thickness (cm)	Neutron Energy				
	10 ev	173 ev	2000 ev	40,000 ev	250,000 ev
0.5	31	9	3	1	0
1.0	67	28	12	4	3
1.5	79	40	24	8	6
2.0	86	50	36	20	10
2.5	90	60	43	31	20
3.0	96	69	52	41	26
3.5	96	79	56	47	35
4.0	96	81	61	54	39
4.5	96	86	68	59	45
5.0	96	86	69	62	49
5.5	96	87	72	63	52
6.0	97	87	76	67	54
6.5	97	89	76	69	56
7.0	97	89	77	72	59
∞	97	89	77	74	60
Reflected	3	11	23	26	40
Total	100	100	100	100	100

For neutron time-of-flight experiments, the capture time of the detector used is of primary importance. The results of a statistical analysis of the mean capture times of those neutrons that are captured in a liquid counter of 2 cm thickness are given in Table II. It is seen that the capture times of a thin counter are not much smaller than those of an infinite medium.

Table II
The Mean Capture Time in a 2 cm
Thick Liquid Neutron Counter.

Neutron Energy (ev)	Mean Capture Time (μ sec)	Fraction Captured
10	$0.32 \pm .03$	.86
173	$0.27 \pm .06$	.50
2000	$0.28 \pm .08$	.36
40,000	$0.11 \pm .05$	.20
250,000	$0.16 \pm .08$	.10
Infinite medium	0.46	1.00

2-3 Liquid Scintillation Neutron Detector (5211-01, 5261-01)

L. Bollinger and G. Thomas
Reported by G. Thomas

A new liquid scintillation neutron counter which has the same basic design as counter No. 6 has been constructed and tested and is now in use with the fast chopper. The new counter (No. 7) differs from

all previous models in that photomultipliers of the highest cathode photo-sensitivity (DuMont 6292) are used, and the neutron absorbing material is enriched methyl borate. The improved photomultipliers result in an increased counting efficiency and a narrower pulse-height distribution for thermal neutrons. The use of enriched methyl borate increases the neutron capturing efficiency of the counter without affecting its response to γ -rays.

The properties of counter No. 7 are as follows:

- A) Cross section - 2" x 4".
- B) Mean neutron capture time - 0.4 μ sec.
- C) Optical efficiency - greater than 95%.
- D) Over-all neutron counting efficiency - roughly 90% at 10 ev and 40% at 1000 ev.
- E) Pulse-height distribution - approximately triangular with a width at half maximum that is 65% of the value at the maximum.
- F) Stability of all the above properties.

A liquid neutron counter (counter No. 8) of larger cross section area has been designed and is being constructed. The counting medium, with an area of 4-1/2" x 4-1/2" and a thickness of 3 cm, will be viewed by four photomultipliers. The properties of counter No. 8 are expected to be similar to those of counter No. 7, except that its greater area should increase the neutron capturing efficiency.

Our program for the future includes:

- A) Completion of measurements of the efficiency of counter No. 7.

B) Completion of construction of counter No. 8.

C) Design of a counter of large area to be used with velocity selector at CP-5.

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

L. Bollinger and R. Palmer
Reported by R. Palmer

<u>Sample</u>	<u>Thickness</u> (gm/cm ²)	<u>Total Cross Section Data</u>		<u>Resonances and Comments</u>
		<u>Resolution</u> μ s/m	<u>Energy Range</u> (ev)	
Gallium-71	1.13	0.13	70-4000	Confirmed that resonances at 96, 290, and 390 ev are due to Ga-71.
	1.13	0.13	100-30,000	Transmission dips observed earlier in natural gallium at $\sim$ 1800 and 7000 ev can not be assigned with certainty to either Ga-69 or Ga-71.
Gallium-69		0.13	70-30,000	A resonance observed at 330 ev may be due to Mn impurity.
Germanium	3.72	1.5	9-600	Cross section $\sim$ 9.5b below 80 ev.
	3.72	0.13	60-30,000	In addition to the well known resonance at 103 ev, other transmission dips were observed at 205, 225, 490, 1140, and 5200 ev. Resonance previously reported at 330 ev and one observed at 2800 probably due to Mn impurity.

<u>Sample</u>	<u>Thickness (gm/cm²)</u>	<u>Resolution μs/m</u>	<u>Energy Range (ev)</u>	<u>Resonances and Com- ments</u>
Niobium	21.6	2.0	2-600	Cross section ~5.5b up to ~500 ev save for small transmission dips near 4 and 35 ev possibly due to a slight Ta impurity.
	21.6	0.5	6-1000	
	21.6	0.13	250-30,000	Small transmission dips at 380, 1000, and 2600 ev. It is possible that some of these dips are due to impurities. Average cross section increases steadily up to at least 25 kev.
Titanium	10.78	2.0	1-200	Cross section decreases steadily over this range and has the approximate value $\sigma = 5.0 \text{ E}^{-.043}$ up to ~100 ev.
	10.78	0.13	250-30,000	Prominent transmission dips at 3.3 kev and 16.7 kev. The 3.3-kev dip is probably caused by 2 or more resonances.
	2.72	0.13	250-30,000	
Zirconium	16.8	2.0	2-600	Cross section ~6.2b over this range with small transmission dips at ~2.5 and 8 ev probably due to impurities.
	16.8	0.13	60-30,000	Fairly prominent transmission dip at 300 ev. Others at 700, 1600, 2700, 4000, and 7000 ev.

<u>Sample</u>	<u>Thickness (gm/cm²)</u>	<u>Resolution μs/m</u>	<u>Energy Range (ev)</u>	<u>Resonances and Com- ments</u>
Zinc	3.08	0.13	100-30,000	The previously reported transmission dip at 500 ev has been separated into 2 distinct dips - at 450 and 520 ev.
Antimony- 123	1.27	0.3	18-1000	It was definitely established that the 22-ev resonance in Sb is due to Sb ¹²³ and the 30-ev resonance is due to Sb ¹²¹ . Sb ¹²³ will be run in the low energy range.
Mercury-199	0.29	0.6	15-1000	The 33 ev resonance in Hg may now be definitely assigned to Hg ¹⁹⁹ .
Mercury-201	0.64	0.3	15-5000	No transmission dips were observed that could be attributed to Hg ²⁰¹ .
Selenium	10.8	0.13	100-30,000	Prominent transmission dips at 212, 270, 2070, and 5670 ev. Lesser dips at 384, 685, 865, and 980 ev. The 212, 270, and 384-ev dips appear to be caused by single resonances.

It is planned to investigate the following substances in the near future, concentrating on energies greater than 100 ev: Bi, Cl, Mn, V, and Zn isotopes.

4-3 (Resonances in Separated Mo Isotopes) (5211-01)

S. Harris

These results have been written up and will soon be submitted for publication.

5-2 The Absorption and Scattering of Neutrons by Hafnium (5211-01,
5261-02)

L. Bollinger, S. Harris, C. Hibdon, C. Muehlhause
Reported by S. Harris

The article submitted for publication is being revised somewhat in accord with editorial suggestions.

6-2 (Special Velocity Selector for Slow Neutrons) (5211-01)

R. Ringo

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

11-3 Installation and Operation of the Van de Graaff Generator
(5211-01, 5261-02)1. General Remarks - Reported by A. Langsdorf

a) The machine has been operated as high as 3.5 Mev with no difficulties that would indicate it could not operate to considerably above four million volts.

b) Considerable effort has been expended in trying to eliminate jumping of the beam. (See Section 5)

2. The Corona System - Reported by P. Mooring

To investigate belt charging under operating conditions, a generating voltmeter was installed in the Van de Graaff machine. The voltmeter, which looks alternately at the upper and lower halves of the belt, allows the operator to adjust for equal and opposite charges on the belt.

The voltmeter showed that at relative humidities above 10% the belt charge leaked rapidly to the ground end of the Van de Graaff. A pulsation of the charge carried by the belt to the high voltage shell was evident at the higher humidities. This pulsation, which was in synchronism with the belt frequency, disappeared below 10% relative humidity.

The voltmeter is constructed of brass with the stator insulated from the rotor by Lucite spacers. The signal is fed into an amplifier which has a 10^9 ohm input resistance. Because Freon attacks brass and forms a conducting scum, the Lucite insulator shorted out, and the generator ceased functioning. At present the parts are being nickel-plated in the hope that this will remedy the difficulty.

3. Control Circuits - Reported by A. Langsdorf

The precision beam current integrator built several years ago (See ANL-4798, p. 12) has been put back into service. Considerable effort was expended in making an accurate circuit diagram and in making several improvements found desirable during the earlier use of the instrument. A description of the device and instructions for its use, based on an outline

by A. Langsdorf, has been written by Frank Fishman in the form of an instruction manual.

4. System for Handling Large Proton Beams - Reported by A. Langsdorf

No further work has been done. Slits and viewers already built are in regular use.

5. Instability in the Ion Beam Position - Reported by P. Mooring

Not long after the Van de Graaff machine was put into operation in Building 203, it was noticed that the position of the proton beam on the target would occasionally shift suddenly. The frequency of these jumps, which at first were no more than one or two per day, gradually increased until it became as large as several times per hour. Though for a long time only a vertical motion was noticed, it is now known that the beam can move in any direction. The magnitude of the jumps can be as great as $3/8$ inch. The beam can move suddenly in any direction or drift slowly. Usually after a jump it remains in its new path for many minutes, then moves as suddenly to another one.

The jumping beam is particularly annoying for several reasons. The motion is large enough for the beam to be intercepted by defining apertures, thus requiring the use of external beam benders and re-positioning of the beam lines. After jumping, the beam illuminates a new target spot, thus changing reaction yields. The electrostatic analyzer is designed to

focus a beam coming from an infinite source. After a jump, the beam enters the analyzer from a new direction, causing the calibration of the analyzer to change as much as 0.1% to 0.2%. For these reasons considerable effort has been spent to locate and eliminate the cause of the jumping.

Three kinds of possible causes were considered: (1) mechanical motion of some part of the machine, particularly at the high voltage end; (2) stray magnetic fields; and (3) electrostatic forces. The tests made will be discussed in order.

A thorough check was made to find and tighten all loose nuts and bolts. A few were found and tightened, but no effect on the jumping of the beam was observed. A transit was sighted on the high voltage end, but no motion was visible at the time the beam jumped, even though a motion as small as 1/32 inch could have been detected. The parts of the ion source were checked for tightness. All these mechanical tests were negative.

The magnet was removed from the ion source with no effect. A new magnet housing designed to insure axial symmetry to the field was installed. It produced no effect. No external field could be located.

All needle gaps, high voltage circuitry, and associated components were thoroughly checked and proved not responsible for the trouble. Unbalanced belt changes were shown not to affect the beam. Grounds were installed on parts not heretofore grounded, with no apparent change in the jumping of the beam. New parts were inserted in the ion source with no

effect. The pressure in the accelerator tube was varied by bleeding in air with no apparent effect. The ion source was carefully re-aligned.

None of these tests is inconsistent with the possibility of charges collecting on the glass insulators inside the accelerator tube and deflecting the beam sidewise. The fact that the jumping was shown to decrease in frequency and magnitude with increasing accelerator voltage is entirely consistent with this hypothesis. However, none of the similar tubes at Oak Ridge, Duke University, and Rice Institute, all built by High Voltage Engineering Corporation, who also built the Argonne tube, have shown this difficulty, though the beams do not emerge from the tube along the same path from day to day. Of those mentioned, the tube at Rice Institute is most like the Argonne tube, the essential difference being that at Rice Institute mercury vapor pumps are used, while at Argonne oil diffusion pumps are used.

The focussing assembly is constructed so that a 1/4-inch aperture can be inserted to prevent a diverging beam from striking the electrodes of the accelerator tube. At the suggestion of Mr. E. Alfred Burrill, the High Voltage Engineering representative, the aperture was removed from the focussing assembly. The beam jumped so badly that it was completely unusable. The aperture was then reinserted in a different place so as to collimate the beam much more. The increased collimation has greatly reduced the beam-jumping problem, though it has not entirely eliminated it.

At present the hypothesis that charges are collecting on the interior

walls of the accelerator tube seems to be the most plausible one.

Aluminum ring inserts to increase the shielding of the beam from the glass walls of the accelerator tube have been designed and are now being constructed. A new beam-limiting aperture designed to give still better beam collimation is also under construction. In case the jumping beam problem can not be entirely eliminated, new beam lines and mountings for the electrostatic analyzer are being designed so that one can operate with a minimum of trouble despite the jumping beam. It is hoped that it will not be necessary to construct them.

6. Increase of Voltage - Reported by P. Mooring

As planned, an additional set of needle gaps has been installed in the Van de Graaff generator. This new set of gaps permits quite adequate currents to flow down the corona column and has increased the voltage stability of the generator. A maximum voltage of 3.55 Mev has been reached. This is the highest voltage yet attained with the Argonne Van de Graaff machine. Attempts to reach a still higher voltage were not made because of breakdown in the high voltage cable connectors to the electrostatic analyzer which is used to determine the particle energy relative to the Li(p,n) threshold.

12-3

R. F. Ion Source for the Argonne Van de Graaff Generator

P. Mooring

(5211-01, 5261-02)

The r. f. oscillator has been rewired so that the loading of the two HK-24G tubes which are used in push-pull is now the same for both.

A new magnet mount which has additional soft iron pole pieces has been constructed and tested. When large beams are desired, the magnet can be installed, but for modest beams (~ 20 microamps) the magnet is not used.

The r. f. ion source is easy to use, produces a well focussed beam at moderate focussing voltages, and uses very little gas. It has proved itself entirely satisfactory.

14-2 Pulsed Neutron Beams from Van de Graaff Generator (5211-01)

R. Holland

A test set-up for operating a radio frequency ion source with provisions for pulsing it has been constructed. No tests on the ion source, or on methods of pulsing it, have been made thus far.

20-3 Energy States of Light Nuclei From Charged Particle Reactions
(5211-01)

R. Malm and D. R. Inglis
Reported by R. Malm

Energy Levels of Be⁸

From recent investigations of the $B^{11}(\gamma, t)Be^8$ and $B^{10}(\gamma, d)Be^8$ reactions and the $B^{11}(p, \alpha)Be^8$ reaction, Erdos, Scherrer, and Stoll¹ have reported the existence of levels of the Be^8 nucleus at 2.2, 2.9, 3.4, 4.0, 4.9, and 6.8 Mev. The 2.2, 3.4, and 6.8-Mev levels have not been reported

¹ Erdos, Scherrer, and Stoll, *Helv. Phys. Acta.* 26, 207 (1953).

previously.

An attempt has been made to confirm the existence of these levels by observing the alpha-particle groups from the $B^{11}(p,\alpha)Be^8$ reaction in the 16-inch proton spectrometer. Natural boron evaporated on platinum was used as the target, and the angle of observation was 90° . A proportional counter was used for the detection of the alpha particles.

The excitation function for the ground state alpha particles was measured, and resonances were found for proton energies of 1.98 and 2.61 Mev corresponding to excited states of the C^{12} nucleus at 17.94 and 18.56 Mev. Subsequently, for each of these proton energies, the energy region from 0 to 7 Mev excitation of the Be^8 nucleus was investigated.

Only two groups of alpha-particles were observed in each case, the group corresponding to the ground state transition and the group corresponding to the transition to the well-known broad level at 2.9 Mev. It is believed that any groups having a peak height greater than 15% of the ground state group would have been observed.

30-3 Scintillation Coincidence Spectrometer (5211-01)

S. B. Burson and W. C. Jordan
Reported by S. B. Burson

Along with a number of studies being conducted on short-lived activities, a study of the complex gamma spectrum of $_{65}Tb^{160}$ was begun (see I-38-1). This instrument was constructed mainly for the study of such

complex gamma emitters. Within the first few hours of investigation, the observation of an unreported radiation at 1.18 Mev upset all of the previously published decay schemes, including the one proposed as a consequence of the study made at this laboratory in 1950.

As a result of operations to date, several minor alterations have been made in the instrument, but all are directed toward ease of operation, rather than fundamental circuit modifications. The only serious defect experienced so far is a rather pronounced drift in the calibration, apparently correlated with room temperature. Tests were made, heating and cooling the photomultiplier probe through a rather severe temperature cycle, and although effects were apparent, the results of the test could hardly account for the observed drift. The high voltage supplies are suspected, and an effort is being made to ascertain whether this is the seat of the trouble.

A comprehensive description of the instrument is now in rough draft form and will shortly be submitted for publication in the Review of Scientific Instruments.

31-3 The 1.42-Min Isomeric State in $_{77}\text{Ir}^{192}$ (5211-01)

B. Burson, B. Hamermesh, V. Hummel, W. Jordan
Reported by B. Burson

During the past quarter, no further experiments were conducted. It is intended to re-run the critical absorption measurements more carefully and with better normalization techniques, and, unless more suggestive results are obtained, the study will be dropped.

32-3 Decay Scheme of ${}_{66}\text{Dy}^{165\text{m}}$ (1.2 min) and ${}_{66}\text{Dy}^{165}$ (2.3 hr) (5211-01)

B. Burson, J. Cork (University of Michigan), W. Jordan
Reported by W. Jordan

The results of this study have been submitted for publication in The Physical Review. A brief summary is given below.

The activities induced by neutron capture in Dy^{164} have been studied with the 180° photographic internal conversion electron spectrometers and the scintillation coincidence spectrometer. The metastable transition energy is found to be 108.0 ± 0.2 kev. Other gamma-rays of approximately 160, 360, and 515 kev are associated with the 1.2-min activity and appear to follow beta decay from the metastable level. Gamma-rays of 94.4 ± 0.2 , 279.4 ± 0.8 , 361.2 ± 1.0 , 634 ± 3 , 710 ± 20 , and 1020 ± 30 kev follow the 2.3-hr beta decay of the ground state. Coincidences are observed between members of the pairs 279-710 and 361-634. The 94-kev gamma-ray is coincident with a beta transition of about 1.2 Mev, while the other gamma radiations are coincident with a softer beta component (~ 0.3 Mev).

33-3 Decay Schemes of ${}_{64}\text{Gd}^{159}$ (18 hr) and ${}_{64}\text{Gd}^{161}$ (3.7 min) (5211-01)

B. Burson, J. Cork (University of Michigan), W. Jordan
Reported by W. Jordan

The results of this study have been submitted for publication in The Physical Review and are scheduled to appear in the issue of October 15, 1953. (This is the last of the reports on this topic.) These results,

as obtained with the 180° photographic electron spectrometers and the scintillation coincidence spectrometer, are summarized below.

${}_{64}\text{Gd}^{159}$ (18 hr): Internal conversion lines corresponding to gamma transitions of 57.5 ± 0.3 and 364 ± 3 kev are observed. Peaks due to the K x-ray and 364-kev gamma-ray are observed in the NaI pulse-height distribution. The results of coincidence measurements indicate that the two gamma transitions are not in cascade, but that the 57-kev gamma-ray is preceded by a beta transition of ~ 1.1 Mev while the 364-kev gamma-ray is preceded by a beta transition of ~ 0.9 Mev.

${}_{64}\text{Gd}^{161}$ (3.7 min): The half-life of this activity is found to be 3.73 ± 0.10 min. Aluminum absorption measurements indicate an energy of ~ 1.6 Mev for the beta transition. Peaks are observed in the pulse-height distribution which correspond to transitions of 44 ± 1 (Tb K x-ray), 102 ± 3 , ~ 165 , and ~ 360 kev. The high-energy peak is resolved into two peaks in coincidence distributions, showing a ~ 360 -kev transition to be coincident with the x-ray, and a transition of ~ 320 kev to be coincident with the 102-kev gamma-ray. The K internal conversion line for a 316-kev transition is the only readily observed line in the internal conversion electron spectrum. All of the electromagnetic radiation appears to be coincident with a beta transition of ~ 1.6 Mev. The possible existence of a gamma transition of ~ 60 kev is suggested.

35-3 (Decay Schemes of Long-Lived Rare-Earth Isotopes) (5211-01)

E. Church

No progress has been made on this project during the last quarter.

36-3 The Decay Schemes of Mass 48 Nuclei (5211-01)

H. Casson, L. Goodman, V. Krohn
Reported by H. Casson

Although other investigators have claimed that the 2.2-Mev gamma-ray of V^{48} is in coincidence with positron annihilation radiation, it has been considered worthwhile to re-investigate this point. Using the 10-channel coincidence pulse-height analyzer, it has been found that the 2.2-Mev gamma-ray is in coincidence, not with annihilation radiation, but with the 0.99-Mev gamma-ray.

It has been possible to propose decay schemes for both Sc^{48} and V^{48} which are consistent with the available data and permit spin assignments which are in agreement with the predictions of the shell model.

A paper based on this, and earlier work, has been sent to The Physical Review for publication.

38-1 The Radiations From ${}_{65}Tb^{160}$ (5211-01)

B. Burson, W. Jordan, J. LeBlanc
Reported by B. Burson

The reasons for undertaking the study of the radiations from

72-d ${}_{65}\text{Tb}^{160}$ were two-fold. Investigations made at other laboratories subsequent to our study of the beta spectrum in 1950 yielded results inconsistent with our findings in some respects. Also, it appeared to be desirable to use the scintillation coincidence spectrometer with a relatively long-lived activity in order to develop techniques and skill in its use and to investigate its stability and reliability without the additional complications present when one is dealing with activities of very short half-life.

Introduction

Neutron capture in terbium produces a long-lived activity first observed by Bothe,¹ who assigned a half-life of 72 d. His absorption measurements indicated the presence of a beta-ray of about 600 kev in addition to gamma-rays. From the fact that terbium exists in nature only as stable Tb^{159} , it was deduced that the activity belonged to Tb^{160} . The activity has also been produced by the irradiation of Gd with deuterons.² The assignment of the activity to Tb^{160} was confirmed by mass-spectrometer measurements.³ The beta spectrum was resolved by Cork et al⁴ into two components of 546 and 882 kev, and the presence of numerous gamma-rays was ascertained from internal conversion electron measurements. At this

¹ W. Bothe, Naturwiss, 31, 551 (1943); Z. Naturforsch 1, 173-179 (1946).

² N. L. Krisberg, M. L. Pool, and C. T. Hibdon, Phys. Rev. 74, 44 (1946).

³ M. G. Inghram, R. J. Hayden, D. C. Hess, Phys. Rev. 71, 643 (1947).

⁴ J. M. Cork, R. G. Shreffler, and C. M. Fowler, Phys. Rev. 74, 240(1948); J. M. Cork, C. E. Branyan, W. C. Rutledge, A. E. Stoddard, and J. M. LeBlanc, Phys. Rev. 78, 304 (1950).

laboratory, Burson et al⁵ resolved the beta spectrum into three components with end-point energies of 860, 521, and 396 kev. Internal conversion lines corresponding to five gamma-rays were also observed. Salmi's measurements⁶ of the beta spectrum with a double-focusing spectrometer indicated only two components with end-point energies of 886 and 546 kev. McGowan⁷ reports a metastable state, indicating that the gamma-ray of about 85 kev has a half-life of 1.8×10^{-9} sec. The delayed coincidence measurements indicate that this state follows the highest energy beta-ray of about 900 kev. The measured⁸ K-shell conversion coefficient is in agreement with the theoretical value for an E2 transition.

Internal Conversion Electron Studies

The most comprehensive measurements on the internal conversion electron groups are those reported by Cork et al.⁴ They report 26 conversion lines and 13 photo lines (using a lead radiator) and from these deduce the presence of 12 gamma-rays.

Our study of the internal conversion spectrum (not yet complete) indicates the presence of the gamma-rays tabulated in the first column below. For comparison the gammas found by Cork et al⁴ are also listed:

<u>Present Argonne Investigation</u>	<u>Cork, et al</u>
0.0863 Mev	0.0865 Mev
	0.0926
	0.1762

⁵ S. B. Burson, K. W. Blair, and D. Saxon, Phys. Rev. 77, 403 (1950).

⁶ E. Salmi, Thesis, Univ. of Michigan (1950).

⁷ F. K. McGowan, Phys. Rev. 85, 142 (1952).

⁸ F. K. McGowan, Phys. Rev. 85, 151 (1952).

<u>Present Argonne Investigation</u>	<u>Cork, et al</u>
0.197	0.1964
0.217	0.2147 0.2820
0.299	0.2978 0.3752 0.3910 0.4103
0.759	
0.873	0.876
0.960	0.962
1.17	
1.26	

The Normal Photon Spectrum

In examining the NaI(Tl) pulse-height distribution with the ten-channel analyzer, ten peaks are clearly resolved (see Figure 1). The peak with the highest energy represents two gamma-rays heretofore unreported. It is to be identified with the 1.17 and 1.26-Mev transitions observed in the internal conversion studies.

By comparison with other photo peaks in the same energy region, the peak located at about 900 kev is seen to be unnaturally broad and clearly due to two radiations close together in energy. These are to be associated with the two gamma-rays of 873 and 960 kev, respectively. The broad peak centered at about 650 kev can be assigned to the Compton distribution due to the two previously mentioned gamma-rays. A very

34

FIGURE 1

GAMMA RAY SPECTRUM OF $^{160}_{65}\text{Tb}$ (71 day)
(Na I PULSE HEIGHT DISTRIBUTION)

weak line appears at about 400 kev. Two very strong lines are resolved at about 300 and 200 kev. Using the 279-kev line of Hg^{203} , these are assigned energies of 296 and 206 kev, respectively. While the peak near 200 kev is not obviously complex, the fact that its energy lies between the 197 and 217-kev lines reported from the internal conversion data would indicate that the line probably represents this pair. The lowest energy gamma-ray which was detected is assigned an energy of 86 kev, using the 85-kev line of Tm^{170} for calibration. The two remaining peaks are attributable to the K x-ray of Dy and its associated escape peak.

Gamma-Gamma Coincidence Measurements

Using the coincidence spectrometer, the following information has been ascertained:

The 1.17-Mev gamma-ray is in coincidence with the 86.3-kev gamma-ray.

The 960-kev gamma-ray is in coincidence with the 217-kev gamma-ray and perhaps the 299-kev gamma-ray.

The 873-kev gamma-ray is in coincidence with the 299-kev and the 86.3-kev gamma-rays.

Coincidences may exist between the 299-kev and the 197-217-kev group, but have not as yet been clearly established.

Coincidences also seem to exist between the 217-kev and the 197-kev gamma-rays. Both seem to be coincident with the 86.3-kev gamma-ray.

Beta-Gamma Coincidence Measurements

With the anthracene crystal beta detector in the single-channel arm of the spectrometer, all of the observable gamma-rays are seen to be in coincidence with beta-rays. Aluminum absorptions were run, and the following half-thicknesses were observed: combined 1.17 and 1.26-Mev gamma-rays, 17 mg/cm²; combined 873 and 960-kev gamma-rays, 28-30 mg/cm² and a softer component; 299-kev gamma-ray, 20 mg/cm²; combined 197 and 217-kev gamma-rays, 18-20 mg/cm²; 86.3-kev gamma-ray, 22-24 mg/cm².

Summary

Although some definite relationships are apparent from the foregoing observations, there are certain anomalies. No decay scheme for ${}^{160}_{66}\text{Dy}$ can be proposed at this time. It is hoped that further investigation will make it possible to assign a unique array of energy levels for Dy^{160} .

39-1 Decay Scheme of ${}^{205}_{80}\text{Hg}$ (5.2 min) (5211-01)

B. Burson, J. M. Cork (University of Michigan), W. Jordan
Reported by W. Jordan

A 5.5-min beta activity in mercury irradiated with deuterons was observed by Krishnan and Nahum¹ in 1940. The beta energy was

¹ R. Krishnan and E. Nahum, Proc. Cambridge Phil. Soc. 36, 490 (1940).

found by absorption to be 1.62 Mev. The activity is also produced by neutron capture in Hg. By using separated isotopes Lyon² established that the activity belongs to Hg²⁰⁵. No gamma-rays have been previously reported to be associated with this decay.

The sources used in this investigation were prepared from mercuric oxide in which the mercury-204 was enriched to 89%. Several measurements of the half-life yield an average value of 5.2 ± 0.1 min, which is somewhat smaller than previously reported values.¹⁻²

Peaks are observed in the NaI pulse-height distribution corresponding to the K x-ray and a gamma-ray of about 200 kev. These two peaks individually decay with the 5.2-min half-life. Both the x-ray and the gamma-ray are coincident with beta radiation, and the coincidence rates are equally attenuated by aluminum absorbers. The attenuation of the beta single counting rate by the same amount of aluminum is not as great, indicating that the beta decay is complex. The absorption values are compatible with maximum energies of ~ 1.4 and ~ 1.6 Mev for the two components.

The presence of the x-ray peak in the pulse-height distribution shows that the gamma transition is partially internally converted. After many integrated exposures, two very weak conversion electron lines were detected with the photographic spectrometers. The energies of these

² W. Lyon, Phys. Rev. 82, 276 (1951).

lines correspond to K and L lines for a 203-kev transition, using the electron binding energies of thallium.

Apparently Hg^{205} decays by beta emission to either a 203-kev excited state or to the ground state of Tl^{205} . The spin of the ground state of Tl^{205} is $1/2^3$ in agreement with an orbital assignment of $s_{1/2}$ to the odd proton. According to shell theory the ground state of Hg^{205} should be $p_{1/2}$. This requires a first forbidden beta transition between these states. It has been noted⁴ that the $\log (ft)$ value (5.4) is unusually low for a first forbidden transition. Since this value does not take account of the branching, it must be regarded as a lower limit. However, the true value is probably not much larger, since most of the beta transitions appear to lead to the ground state.

No further work on this project is contemplated.

40-1 The Decay Scheme of $_{23}\text{V}^{52}$ (5211-01)

B. Burson, J. Cork (University of Michigan), J. LeBlanc
Reported by J. LeBlanc

Previous investigations of the decay of V^{52} have led to the assignment of three activities (16 hr, 3.7 min, and 2.5 min) to this isotope. The 16-hr and 3.7-min activities have been reported to be

³ H. Schuler and J. Keyston, Z. Physik 67, 433 (1931).

⁴ Conference on Nuclear Spectroscopy, Indiana University (1953).

associated with metastable states which decay by emission of 59 and 96-keV gamma-rays. The 2.5-min state was reported to decay by beta emission to excited states in Cr^{52} , which in turn emit gamma-rays of energy 0.539, 0.739, 0.850, 1.00, 1.40, 1.76, 2.36, and 3.2 MeV. Gamma-rays of 0.73, 0.94, and 1.46 MeV have been reported to be emitted by Cr^{52} after positron emission from Mn^{52} .

The present study has been concerned mainly with the 3.7-min activity, although some work has been done on the 16-hr decay. The 3.7-min activity produced no lines in the photographic spectrometers. When examined with the scintillation spectrometer, one strong gamma-ray of 1.41 MeV was measured. Any higher energy gamma-rays in this activity are very weak compared with the 1.41-MeV gamma.

The study of the 16-hr activity is made difficult by the presence of a sodium impurity in the vanadium sample. The sodium yields a 15-hr activity with gamma-rays of 1.37 and 2.75 MeV. So far only these gamma-rays have been detected in the $\sim$ 16-hr activity of the vanadium sample.

The present data are not consistent with the previously proposed decay scheme.¹ The investigation will continue.

¹ T. Wiedling, Phys. Rev. 91, 767 (1953).

41-1 The Decay Schemes of $_{48}\text{Cd}^{117}$ and $_{49}\text{In}^{117}$ (5211-01)

B. Burson, J. Cork (University of Michigan), J. LeBlanc
Reported by J. LeBlanc

The decay of Cd^{117} , produced by neutron capture in Cd^{116} , has been thought to be complex, involving a 3-hour metastable state and a 50-min ground state which decays by beta emission to In^{117} . A gamma-ray of 1.2 Mev has been measured by absorption and assigned to the 3-hr decay. Beta-rays of 1.6 and 3.0 Mev have been assigned to the 50-min activity by absorption measurements. The In^{117} daughter product is also thought to possess a metastable state of 70-min half-life and a ground state beta activity of about 2 hours. Two gamma-rays have been detected following the beta decay of In^{117} with energies of 161 and 558 kev, as measured by a scintillation spectrometer. Sn^{117} is known to have a metastable state whose half-life is 14 days. It decays by the emission of a 159-kev gamma-ray followed by a 160-kev gamma-ray. A beta-ray of 1.73 Mev has been measured in In^{117} by spectrometers.

The present investigation was begun in order to determine whether there are gamma-rays which are associated with the metastable states and to attempt to obtain a consistent decay scheme for these nuclei.

The Cd^{117} - In^{117} chain has been obtained by irradiation, in the "rabbit", of both ordinary Cd and enriched Cd^{116} . These samples have been studied in the 180° photographic spectrometers and the

10-channel coincidence scintillation spectrometer. So far 10 gamma-rays have been resolved which are assigned to the ^{117}In isotope. In an attempt to assign these transitions to the proper element, the In has been chemically separated from the Cd and the spectra of each fraction studied with the scintillation spectrometer. The half-life of each of the lines has also been measured, both in the Cd^{117} and In^{117} mixture and in the separated components. The gamma-rays which appear to go with the Cd^{117} fraction have energies of 0.27, 0.43, 0.84, 1.27, 1.56, and 2.00 Mev, while those in the In^{117} fraction appear to be 0.160, 0.312, 0.560, and 0.720 Mev. Of these gamma-rays only the 160, 270, and 312 kev have been observed in the photographic spectrometers. There is evidence from these spectrometers that in the 270-kev region there are actually two gamma-rays separated by about 15 kev. This would be in agreement with the fact that the 270 peak in the scintillation spectrum is considerably broader than the Hg^{203} calibration peak at 279 kev. This point will be investigated further.

The 160 and 560-kev gamma-rays are most certainly the ones previously reported in Sn^{117} following decay of In^{117} . Coincidence measurements show them to be strongly in coincidence with each other. The 720-kev gamma-ray is not in coincidence with either the 160 or 550-kev gamma-ray and is probably the crossover transition. No evidence is found for the formation of Sn^{117} nuclei in the 14-day metastable level at 319 kev.

42-1 Gamma Radiations of Various Radioactivities Induced by
Neutron Capture (5211-01)

B. Burson, J. Cork (University of Michigan), W. Jordan
Reported by W. Jordan

The energies of several gamma-rays have been measured by means of their associated internal conversion electrons and photoelectrons from lead radiators. All of these gamma-rays have been previously reported in the literature, but in most cases the energy values were not determined with the accuracy possible with the photographic spectrometers used in this investigation. The data on these gamma radiations are summarized in the accompanying table.

Internal conversion electrons from Ga^{70} (20 min) and Br^{80} (18 min) were searched for but not detected. Scintillation spectrometer studies of the 18-min Br radiations show the presence of annihilation radiation and a 620-kev gamma transition. The gamma-ray is of about the same intensity as the annihilation radiation, but coincidence measurements show that it follows the negative beta decay.

Table III

Internal Conversion Electrons and Photoelectrons
from Several Radioactive Isotopes.

<u>Radioactive Isotope</u>	<u>Electron Energy</u>	<u>Interpretation*</u>	<u>Energy Sum (kev)</u>	<u>Gamma Transition Energy (kev)</u>
Ga^{72} (14 hr)	618	K (Ge)	629	629 ± 3
	679	K (Ge)	690	690 ± 3
	689	L (Ge)	690	690 ± 3
	827	K (Ge)	838	838 ± 4

<u>Radioactive Isotope</u>	<u>Electron Energy</u>	<u>Interpretation*</u>	<u>Energy Sum (kev)</u>	<u>Gamma Transition Energy (kev)</u>
Br ^{80m} (4.5 hr)	23.3	K (Br)	36.8	36.8 ± 0.2
	35.1	L (Br)	36.8	
		K (Br)	48.6	48.5 ± 0.2
	46.7	L (Br)	48.4	
	48.2	M (Br)	48.4	
Br ⁸² (36 hr)	540	K (Kr)	554	554 ± 3
	550	L (Kr)	552	
	605	K (Kr)	619	619 ± 3
	685	K (Kr)	699	699 ± 3
	764	K (Kr)	778	778 ± 4
	815	K (Kr)	829	829 ± 4
	954	K (Pb radiator)	1042	1046 ± 10
	1035	K (Kr)	1049	
	1238	K (Pb radiator)	1326	1323 ± 10
	1306	K (Kr)	1320	
	1396	K (Pb radiator)	1484	1478 ± 15
	1458	K (Kr)	1472	
Sr ^{85m} (70 min)	136.0	K (Rb)	151.2	151.2 ± 1.0
	214.0	K (Sr)	230.1	230.1 ± 1.0
	221.4	K (Sr)	237.5	237.5 ± 1.0
Zr ⁹⁷ (17 hr)	568	K (Pb radiator)	656	657 ± 3
	638	K (Mo)	658	
	652	K (Pb radiator)	740	742 ± 3
	724	K (Nb)	743	
	740	L (Nb)	742	
Te ^{131m} (30 hr)	150.7	K (Te)	182.5	182.6 ± 0.6
	178.1	L (Te)	182.7	
Hg ^{199m} (44 min)	144.5	L (Hg)	159	159 ± 2
	289.5	K (Hg)	372.6	372.7 ± 1.0
	358.0	L ₁ (Hg)	372.8	

* Some of the interpretations are based on the work of other investigators.

Further study of these activities in the near future is not contemplated.

50-3 (Internal Conversion of Capture Gamma-Rays Associated with Gd) (5211-01)

C. T. Hibdon

No further progress has been made on this program.

51-3 Characteristics of a Scintillation Counter Spectrometer (5211-01)

R. Culp, B. Hamermesh, A. Reckseidler
Reported by R. Culp

Spectrum analysis using the 3-1/2" by 3-1/2" right cylinder of NaI in conjunction with three 5819 photomultipliers has continued during the last quarter. The improved resolution and Compton peak suppression of this combination has been demonstrated by the discovery of several new lines in the elements $Z = 17 - 30$. The results are enumerated in I-52-3.

A letter has been submitted to The Physical Review concerning the good resolving power of the spectrometer in the region about 2 Mev, as demonstrated on the 2.23-Mev capture gamma-ray in hydrogen (see ANL-5080).

The combination of large NaI crystal and three photomultipliers will be used unchanged for continued re-examination of the elements $Z = 17 - 30$ during the next quarter.

52-3 Neutron Capture Gamma-Ray Studies with the Scintillation Spectrometer (5261-02)

R. Culp, B. Hamermesh, A. Recksiedler
Reported by R. Culp

Studies of the neutron capture gamma-ray spectra of the elements

$Z = 17 - 30$ are in progress using a 3-1/2" by 3-1/2" right cylinder of NaI(Tl) and a bundle of three 5819 photomultipliers as a detector for the 20-channel pulse-height analyser.¹ Those elements already studied are: Cl, Ti, Cr, Mn, and Fe. Special studies also were made of Al, depleted U²³⁸, and H.

Chlorine

No lines other than those previously reported were discovered in chlorine. The results were not well correlated, and a further study of this element is planned.

Titanium

The spectrum of titanium contained previously unresolved lines at 0.331 Mev and 3.97 Mev. The line listed by Hamermesh and Hummel² as 6.5 - 7.0 Mev is probably 6.4 Mev. All other known lines were confirmed.

Chromium

The complex high energy region of chromium was not well resolved. The 0.880-Mev line was confirmed, and a line at 2.22 Mev was discovered, with a 1.72-Mev pair production peak providing confirmation of it.

Manganese

The 0.090, 0.190, 5.0, and 7.2-Mev lines were confirmed,

1. See Section I-51-3 of this report.

2. Hamermesh and Hummel, Phys. Rev. 88, 916 (1952).

but no additional lines were discovered in the spectrum for this element. No crossover was found for the 0.090 and 0.190-Mev lines, nor was a line found which corresponded to the difference between the 5.0 and 7.2-Mev lines.

Iron

The 6.0, 7.4, and 8.5-Mev lines were confirmed. The region below 5.0 Mev is to be studied in the near future.

Aluminum

A special effort was made to locate the 0.030-Mev line in this element as a test of the spectrometer in this low range. It was not possible to resolve the line.

Hydrogen

A very excellent representation of the 2.23-Mev line and its associated 1.73-Mev pair production peak was obtained. The complete spectrum curve, showing suppression of low energy background, was submitted in a letter to The Physical Review (see ANL-5080).

Those elements not yet studied in the group $Z = 17 - 30$ are K, Ca, Sc, V, Co, Ni, Cu, and Zn. As many as possible will be studied before CP-3' is shut down, and the remainder will be studied when a reactor port is again available.

60-3 Eight-Meter Bent Crystal Spectrometer (5261-02)

B. Hamermesh and D. Rose
Reported by B. Hamermesh

The mechanical design is virtually completed. The design consists of 11 sub-assemblies. Six of these are being constructed; the remaining ones are being detailed and should be ready for our shops within a month.

70-3 Measurement of Nuclear Moments by Angular Correlation
(5211-01)

V. Krohn and S. Raboy
Reported by S. Raboy

115
The isomer of Pb^{204} , which decays by the emissions of two gamma-rays with a half-life of 65 min, was selected as a suitable nucleus for determination of the magnetic moment of the excited state by an angular correlation experiment. The method involved doing an angular correlation experiment with and without a magnetic field. The magnetic field will interact with the magnetic moment of the intermediate state, if there is sufficient time, so as to reduce the angular anisotropy. The magnetic moment of the intermediate excited state can be determined from this reduction in anisotropy.

The two gamma-rays of $\text{Pb}^{204\text{m}}$ are a 900-kev and a 370-kev gamma, respectively. The intermediate state decays with the emission of the 370-kev gamma and has a half-life of 3×10^{-7} sec.

The Pb^{204} isomer was prepared by bombarding thallium foil with 20-Mev deuterons. A 55-hr activity with a 280-kev gamma-ray was also produced, and this is believed to be Pb^{203} . A 420-kev gamma-ray with a half-life of 5 to 9 hr was also observed. This cannot be the 420-kev line of Pb^{293} as assigned by Hollander, Perlman, and Seaborg.¹

The angular correlation experiment on the two gamma-rays of $\text{Pb}^{204\text{m}}$ was performed in the presence of the radiations mentioned above. However, their influence was reduced by:

1. Short bombardment intervals which gave more Pb^{204} production relative to the longer-lived activities.
2. Pulse-height selection for the 900-kev and 370-kev lines of $\text{Pb}^{204\text{m}}$.

The decay of the analyzed single counting rates was checked to insure that the experiment was actually performed on the two gamma-rays of interest. Only about the first three half-lives of 68 min each were used for the accumulation of data after each irradiation.

The first experiment consisted of studying the angular correlation of Pb^{204} in thallium foil. An asymmetry of $1.17 \pm .07$ was obtained.

¹

Hollander, Perlman, and Seaborg, Rev. of Mod. Phys. 25, 469 (1953).

By asymmetry is meant the ratio of true coincidences at 180° to the true coincidences at 90° . This number is not corrected for solid angle. It is the result of only about 500 coincidences at each angle and, therefore, is to be considered preliminary.

It was suspected, however, that electrical interactions with the quadrupole moment of the intermediate state reduced the expected correlation. Work on Cd^{111} by the Swiss group² indicated this possibility, and Abragam and Pound,³ Coester,⁴ and Alder⁵ have demonstrated such an effect theoretically. Hence, further measurements were made with liquid sources.

The bombarded thallium foil was dissolved in nitric acid. Two different concentrations, 6N and 16N, were used. An asymmetry of 1.225 ± 0.036 was obtained as a result of 25 runs and 5000 true coincidences per angle. The precision measure of 0.036 is calculated from the distribution of the results of the twenty-five runs and is somewhat larger than the 0.02 precision measure obtained by calculating from the counting statistics.

Frauenfelder⁶ has done some similar work on Pb^{204} and obtained results which differ for different media. His results for the nitric acid medium appear to be larger than the result reported here.

2 Albers-Schonberg, Hanni, Heer, Novey, and Scherer, *Phys. Rev.* 90, 322 (1953); Albers-Schonberg, Novey, Ruetschi, *Phys. Rev.* 91, 199 (1953).

3 Abragam and Pound, *Phys. Rev.* 89, 1306 (1953); Abragam and Pound *Phys. Rev.* 90, 993 (1953).

4 F. Coester, preprint of article submitted to *The Phys. Rev.* for publication.

5 Alder, Albers-Schonberg, Heer, and Novey, preprint of article submitted to *Helv. Phys. Acta* for publication.

6 Frauenfelder, Jentschke, Lawson, and DePasquali, preprints of three letters submitted to *The Phys. Rev.* for publication.

Furthermore, he obtained an asymmetry of 1.46 for H_2PbCl_6 dissolved in HCl.

A magnetic field of 20,000 gauss was applied to the source, and preliminary results give a null result.

The plans for the next quarter include studying the angular correlation in nitric acid with and without 0.4 μsec delay in the coincidence circuit. This is to be done in the presence and absence of a large magnetic field. It is also planned to try other liquid media in an attempt to get the larger asymmetries and then to use the magnetic field.

Attempts to measure the magnetic moment of the excited state of Hg^{197} by the above described method were temporarily abandoned. The gamma-rays undergo tremendous internal conversion. A ratio of unity for accidentals to true coincidences was obtained, but the counting rate was of the order of one true count per minute. Future plans call for a return to this problem with a faster coincidence circuit and larger solid angle.

71-3 The Angular Correlation of β -rays and Delayed Neutrons
from Br^{87} (5211-01)

L. Goodman

Experiments were conducted to determine the sensitivity of a trimethyl borate-loaded liquid scintillation spectrometer for gamma-rays. This particular counter is the one used for neutron detector of the

fast chopper time-of-flight spectrometer.

High energy gamma-rays are discriminated against in this detector by not accepting pulses larger than those produced by the $B^{10}(\eta, \alpha) Li^7$ reaction. The low energy end of the Compton electron distribution will produce pulses which are indistinguishable from the $B^{10}(\eta, \alpha) Li^7$ pulses.

With the pulse-height analyzer adjusted for optimum neutron detection, Co^{60} (1.17, 1.33 Mev) or Na^{24} (1.38, 2.76 Mev) gamma-ray sources were brought near the detector. The electronic circuitry discriminated against 85% of the Co^{60} gamma-rays and against 90% of the Na^{24} gamma-rays. Since it is only the low energy Compton electrons which are detected, and their production from zero up to some finite low energy goes roughly as $1/(h\nu)^2$, the discrimination against the 5.4-Mev gamma-rays from Br^{87} should be still better.

In the actual experiment, of course, a delayed gate will be used to discriminate against prompt β - γ coincidences, and the above scheme will reduce the accidental β - γ coincidence rate.

80-3 Molecular Beam Studies (5211-01)

R. Dalman, L. Goodman, S. Wexler
Reported by L. Goodman

The following sub-projects have been completed on the atomic beam apparatus:

The magnets and associated electronic circuits have been

installed and are operable.

The radio frequency loop has been installed.

The electron bombardment scheme for oven heating has been installed, and a beam of normal potassium atoms from a heated iron oven has been detected and deflected.

A modified oven mount consists of a tripod of two tungsten rods and one tantalum rod, making a Ta-W thermocouple junction at the oven and enabling one to monitor the oven temperature. This device has been designed, fabricated, and installed.

The optical alignment of magnets, slits, and oven has been completed.

An operable vacuum (3×10^{-7} mm Hg) has been achieved.

The hydraulic lift system for introducing ovens and detectors into the high vacuum system has been completed and is operating.

It is hoped that during the next quarter measurements on normal potassium will be carried out to check the machine and that measurements on a radioactive sample can be started.

90-3 Cross Sections for 14-Mev Neutrons (5211-01)

H. Casson and L. Goodman
Reported by H. Casson

The 90° deflection magnet for bending the deuterons of the D-T neutron source into a horizontal plane has been constructed and is being installed.

An electrostatic deflection system for adjustment of the position of the deuteron beam before it enters the field of the magnet has been built and installed. The system, consisting of two perpendicular pairs of parallel plates, has been tested and found to work satisfactorily. It should prove useful for positioning the beam on the target and for removing the beam quickly. It is expected that neutron scattering experiments will get under way during the next quarter.

91-3 Neutron Transport Cross Sections (5261-02)

A. Langsdorf

The drawings of the shielding and collimating system have been completed, and this apparatus is being constructed in the shop.

92-3 (Neutron Scattering Cross Sections by Use of the Scattering Chamber) (5261-02)

C. Hibdon

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

The measurement of ν using this equipment in cooperation with A. Jaffey of the Chemistry Division is contemplated for the next quarter.

96-3 (Pile Absorption Cross Sections) (5261-01)

D. Rose

No work has been done with the pile oscillator during the past quarter.

98-2 Total Neutron Cross Sections in the kev Region (5211-01,
5261-02)

C. Hibdon and A. Langsdorf
Reported by C. Hibdon

Preliminary measurements of total cross section as a function of energy have been made but are unsatisfactory because of the instability of the beam of the Van de Graaff machine. Further measurements will be made as soon as this instability can be eliminated or reduced to a tolerable amount.

The target assembly which holds the tantalum foils in place has been modified. As originally constructed, a stainless steel ring was in the path of the neutrons which entered the counter. As a result of this, there was a variation of the counting rate with neutron energy due to resonances in the materials of the ring. In order to reduce this variation as much as possible, a large part of the ring has been machined away. As a permanent improvement, a tantalum cup has been designed and is on order. This cup is sufficiently long so that neutrons leaving the target at back angles will emerge through the thin wall of the cup.

In order to improve the counting rate by making the scattering detector more efficient in capturing neutrons, 36 enriched BF_3 proportional counters of 16-inch length have been ordered. They will be installed in the important part of the detector near the axis. An extra amplifier to be used as a spare is being made ready for use.

99-1 Standards for Measurement of Thermal Neutron Absorption
Cross Sections (5261-01)

R. Ringo and S. Wexler
 Reported by R. Ringo

Most determinations of neutron absorption cross section require a standard absorber for comparison; such standard absorbers are also important for measurements of neutron flux and determination of eta for fissionable materials. The general opinion is that boron is the most suitable standard, though its use has raised several difficulties. Boron varies in isotopic content. Also the values reported for its absorption cross section have differed by much more than their nominal errors. Some time ago, a batch of boron was set aside as a standard, and extensive measurements of its absorption cross section were made.¹ We are now comparing samples used by other laboratories with this standard, using the danger coefficient method in CP-2. The results are shown in the table:

Table IV

<u>Original laboratory</u>	<u>σ_a as measured at</u>	
	<u>Argonne</u>	<u>Original laboratory</u>
ANL (standard)	755 $\pm$ 5	749 $\pm$ 4*
AERE, Harwell	762 $\pm$ 7	780
A/B Atomenergie, Stockholm	748 $\pm$ 7	705

* Value obtained at Brookhaven

The values obtained by Argonne and Brookhaven are in good

1. Kimball, Ringo, Robillard, and Wexler, ANL-4680.

agreement (and would be even closer to one another if a disagreement over the scattering of B_2O_3 could be settled). The disagreement with other laboratories remains and can no longer be attributed to variations in isotopic content.

Harwell and Stockholm are now checking their measurements. If they should not give reasonable agreement with the U.S. values, a new absolute measurement might be desirable.

109-2 Neutron Diffraction Apparatus (5211-01)

R. Holmes (Central Shops), R. Ringo, S. Sidhu (Met. Division)
Reported by R. Ringo

The design work is complete, and the construction roughly half done. The installation of the apparatus at CP-5 should be started in the next quarter.

110-3 Crystal Spectrometer for 0.1 to 100 ev Neutrons (5211-01)

S. Raboy and R. Ringo
Reported by S. Raboy

The search for a satisfactory metallic crystal has continued. A properly oriented copper crystal was obtained from Virginia Research Institute for trial. It turned out to be a poor crystal, giving a beam width of about 20° , the diffuse scattering being quite large.

Three Be crystals were obtained from the Metallurgical Project at M. I. T. These were tested with a monochromatic beam of 1.17 Å neutrons, together with one of the Argonne-made copper crystals.

The results are tabulated in the following table.

Table V

Results of Studies of Selected Bragg Reflections
from Test Crystals.

<u>Crystal</u>	<u>Peak Value Neutrons Diffracted in 30 sec (Scale of 512)</u>	<u>Full Width at Half Maximum of Bragg Peak</u>	<u>Lattice Plane Spacing ($\text{\AA}$)</u>
Copper Crystal	48	2°	$1.1 \text{ \AA}$
Be I	141	$1^\circ 5'$	~ 1
	56	$1^\circ 15'$	$.7$
Be II	102	$1^\circ 10'$	~ 1
	43	$1^\circ 3'$	$\sim .85$
	25	$1^\circ 5'$	$.7$
Be III	28	$1^\circ 17'$	$.7 \text{ \AA}$

It can be concluded that these crystals are not so imperfect as to broaden the beam excessively. They may, however, be so perfect as to sacrifice intensity without gain in resolution. In order to clear up this point, the neutron beam collimation has to be studied. The plan is to obtain a good powder on a good crystal (known from X-ray studies) and to use such a sample to study the width of the neutron beam. This study will be completed next quarter.

112-3 (The Neutron Spectrum of a Standard Ra-Be Photosource)

C. Egger

Work on the self-triggering cloud chamber has been delayed because of concentration on work with the hydrogen-filled cloud chamber.

114-1 Development of a Recoil Type Neutron Spectrometer (5211-01)

G. Perlow

Work has begun on a coincidence neutron spectrometer similar in principle to the one reported by Beghian et al.¹ The latter employed a stilbene scintillator in which proton recoils were measured. The scattered neutrons were detected in coincidence, at 90° to the incident beam, by means of absorption in Ag, the gamma-rays following the absorption being detected in a suitable second scintillator. The neutron spectrum was then identified with the spectrum of coincident light pulses in the stilbene, and the detection at 90° guaranteed that the proton recoils had the full neutron energy. (Timing circuits insured delays corresponding to forward scattering of the protons.)

In the instrument being developed here, the stilbene scintillator system is to be replaced by a proportional counter filled with a gas containing hydrogen or deuterium. With this the energy region of 0.5 to 0.05 Mev should be measurable. There appear to be some geometrical advan-

¹ Beghian, Allen, Calvert, and Halban, Phys. Rev. 86, 1044 (1952).

tages to the use of a deuterium or a deuterated hydrocarbon fill. The type of detector for the scattered neutrons is as yet undetermined. A variant of the liquid scintillator of Bollinger and Thomas (ANL-5031) is a promising possible choice.

A thin-walled aluminum proportional counter has been constructed, using the field-tube system of Cockroft and Curran.² A filling line with facilities for handling and purifying a variety of gases has been constructed and the sample counter filled and tested with methane and with 2,2 dimethyl propane (C_5H_{12}). The latter is a gas under standard conditions and was chosen for its large hydrogen content. The counter operates well with both gases.

115-1 Neutron Counters Containing Boron Trimethyl (5211-01)

A. Langsdorf and W. Reardon
Reported by A. Langsdorf

Hauser¹ has shown that the properties of counter tubes filled with boron trimethyl are in some respects superior to those of similar counters filled with BF_3 . In particular, the pulse-height distribution shows peaks that are sufficiently narrow to suggest that such counters might be useful in the study of the distribution of energy of neutrons. A supply of boron trimethyl has been ordered, and storage cylinders for holding it and counter tubes in which to use it are being made ready.

² Cockroft and Curran, Rev. Sci. Instr. 22, 37 (1951).

¹ V. Hauser, Z. Naturforschung (December, 1952).

120-3 Calibration of a Ra-Be Neutron Source (5211-01)

S. Harris

A spherical aluminum tank 32" in diameter has been completed and filled with a 30% (by weight) solution of $\text{NaC}_2\text{H}_3\text{O}_2$. Source No. 312 (500.06 mg of Ra + 3.000 gm of Be in a brass container + an aluminum container) has been measured by immersion in the solution. The method is described in ANL-5031 and ANL-5080. Preliminary results for Q (the number of neutrons per second emitted by the source) and also for the β counter efficiency and the standard counting rate are given for three independent runs in the following table:

Table VI

<u>Run No.</u>	<u>Q for Source No. 312</u>	<u>β Efficiency</u>	<u>K^{40} Standard (avg)</u>
1	5.57×10^6 neut/sec	4.67%	100.4 counts/min
2	5.68	4.37%	95.5
3 *	6.30	4.45	105.4

* See paragraph 2 of text.

Results have been corrected for Na^{24} decay, dead time of the Geiger counter, chance coincidences, γ -ray sensitivity of the Geiger counter, γ - γ coincidences, and neutron loss from the sphere. No correction was made for neutron loss by absorption in the source because this was calculated and found to be only about 0.3%.

The efficiency of the Geiger counter (β efficiency) was measured separately for each run. In run No. 3 a high value for Q was found, while at the same time the β efficiency was much lower than is indicated by the standard's counting rate. It is possible that the β efficiency changed somewhat in this instance between the time when the sample extracted from solution was counted and the time when the efficiency was actually measured (about 12 hr later). If Q is recalculated taking the counting rate of the standard as the true indication of the β efficiency, a value of 5.76×10^6 is obtained for run No. 3. An average value of Q from the three runs is then

$$Q = 5.67 \times 10^6 \text{ neutrons/sec} \pm 3\%.$$

This is to be compared with a value of 5.4×10^6 obtained by Egger (1952) for source No. 312 by comparison with source No. 38. The small discrepancy may be an indication that the value of 5.5×10^6 reported in 1947 for source No. 38 is slightly low.

The important absorption cross sections used in the calculation of Q are those of Na and H. The thermal cross section of H is taken as 0.329b and that of Na as 0.503b (see ANL-5031). These together contribute less than 1% of the 3% error quoted for Q , and the remainder arises from error in counting of the sample and measuring the β efficiency.

In order to obtain an accurate result for Q , at least ten runs

should be made with the same source. Replacement of the Geiger counter by a gas flow counter is desirable. Such a counter would probably eliminate much of the fluctuation in β efficiency and also allow the use of a sample with larger area.

Average Charge of Daughter Atoms After Nuclear Transitions

A paper based on work described in earlier quarterly reports has been written and submitted to the Physical Review.

132-3 Chemical Service Work S. Wexler (5211-03)

Several samples of boric acid and sodium borate, obtained from laboratories in this country and abroad, were converted into forms suitable for intercomparison by the pile danger coefficient method (see I-99-1).

133-3 Design Study of a Multi-Bev Proton Synchrotron (5211-01)

J. Livingood and M. Hamermesh
Reported by J. Livingood

Effort has been limited to study of reports originating from Brookhaven, Cambridge, and the Mid-West Summer Study group. In an endeavor to discover how many potentially interested persons now exist at ANL, preparations are being made to give an introductory course in particle accelerator theory, starting with conventional machines and

was approximately 43 cm. The seal chamber was placed in front of an F-5 Roman spectrograph. Exposures were usually for three or four days, the spectra being taken on 103 a-J emulsions. Reference spectra of H_2 and He arc lines were formed on the plates before development.

The spectral lines listed in Table VII were obtained after one 3-day exposure with the slit of the spectrograph very wide (~ 1.6 mm). None of them have been identified positively. The density of the $4277 \text{ \AA}$ line appeared to be at least an order of magnitude greater than any of the others. In addition to the line spectrum, a continuum extending up to about $4000 \text{ \AA}$ was observed. In a second exposure with slit width 75μ , only the line at $4277 \text{ \AA}$ was found on the developed plate. In neither of the experiments was any indication of the $4686 \text{ \AA}$ transition in ionized He^3 observed. The results thus far are, however, only preliminary. Further experiments are planned to define the spectra more precisely and to assign the individual lines to definite atomic and molecular transitions. It is hoped that the spectra obtained will indicate the atomic and molecular species in which the He^3 daughter is found after beta decay of molecular tritium. A subordinate but nevertheless interesting aspect of this study is the transitions which result from excitation of T_2 molecules by the beta particles emitted into the gas volume.

Table VII

Spectral Lines Observed in Tritium
Gas (Ultra-violet and Visible Regions)

3914 Å	
4087	(H _δ , ?)
4165	
4277	
4305	
4339	(H _γ , ?)
4433	
4500	
4643	
4707	
4853	(H _β , ?)
5009	
5300	
5610	

135-2 (Electron-Neutron Interaction) (5211-01)

R. Ringo

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

II. MASS SPECTROSCOPY

1-3 Mass Spectrometric Techniques (5211-08)

W. Chupka, R. Hayden, D. Hess, M. Inghram, H. Stanton,
C. Stevens (Special Materials)
Reported by M. Inghram

The hydrocarbon problem associated with the multiple filament surface ionization source (RSI 24, 518, 1953) has been materially reduced by improving the defocussing from the evaporation filaments. This was done by isolating these filaments from the ionization filament and placing them at a potential of about -10 volts with respect to the ionization filament. This decreases the efficiency of the source by as much as a factor of two, but the ratio of sample to hydrocarbon background is improved by two orders of magnitude. It is clear that the hydrocarbon problem is a "low" temperature phenomenon.

2-3 Construction of MA-17 (5211-08)

H. Stanton

Since the last report an ion beam was obtained through the complete machine. The multiplier was installed in it and found to give a gain of about 200,000 over the unassisted electrometer previously used for ion detection. Since adjustment has been barely started, the resolution of the machine is quite low (~ 1 part in 300). Most of the effort has been spent in operating it as an energy selecting machine. A gas system has also been installed.

As an energy selecting machine, ions have been obtained with only 100 volts or less between the ion box and the electrostatic deflecting plates. With the slit sizes used, this gave an energy resolution of about 0.1 ev. This value can be further improved by using narrower slits (0.005" and 0.006" slits were used) and an improved thermionic source for electrons.

An electron source comprising an indirectly heated cathode with two grids (one as a drawing-out grid and the other as an electron energy selecting grid) was built and installed in place of the tungsten filament formerly used. The new electron source should provide a ripple-free source of electrons whose minimum energy is known and controllable. The machine should then be usable for measuring appearance potentials for polyatomic gas fragments, and when coupled with the energy selection of the electrostatic deflecting system should enable a study of bond energies to be initiated.

9-1 Normal Isotopic Constitution of Hafnium (5211-03)

R. Hayden

In connection with a service analysis of neutron-irradiated hafnium, measurements of the normal isotopic composition of hafnium were made. The 174 abundance observed differs widely from previously reported values. Below are tabulated the abundances as reported by

Hibbs,¹ Reynolds,² and as observed in the present work:

Table VIII

<u>Observer</u>	<u>174/180</u>	<u>176/180</u>	<u>177/180</u>	<u>178/180</u>	<u>179/180</u>
Hibbs	.00508	.1453	.5189	.7641	.3888
Reynolds	.00567	.1491	.5289	.7763	.3914
Author	.00462	.1455	.528	.780	.389

Absolute errors in the present work are estimated as less than 1% in the case of the high ratios and as less than 3% in the case of 174/180. The 174/180 result is widely variant from both Hibbs and Reynolds, who in turn fail to check each other at this position. Both Hibbs and Reynolds ionized hafnium by electron impact on volatile vapors. In the present work ionization was by surface ionization, a method which might be expected to give a lower background peak at 174. It seems probable that the high 174/180 values, particularly those of Reynolds, are due to a mass 174 impurity introduced with the sample.

The following percentage limits for possible other hafnium isotopes were set: $170 \leq .00015\%$; $171 \leq .00015\%$; $172 \leq .00015\%$; $173 \leq .00025\%$; $175 \leq .03\%$; $181 \leq .03\%$ and $182 \leq .1\%$.

10-3 Search for Rare Naturally-Occurring Isotopes (5211-08)

D. Hess

Some time was spent assembling a gas sample system, but

1 R. F. Hibbs, AECU-556 (August, 1949).

2 J. H. Reynolds, Phys. Rev. 90, 1047 (1953).

lack of electronic apparatus precluded actual investigations.

About the end of July a break appeared in the source end.

This will probably necessitate fabrication of a new set of seals.

11-3 Technetium in Nature (5211-08)

R. Hayden, M. Inghram, J. Miller (Columbia University)
Reported by M. Inghram

The results reported in the last quarterly report on three rhenium rich molybdenum minerals complete this study for the time being. Further studies will be undertaken only if better minerals can be found.

12-3 Double Beta Disintegration of Te^{130} (5211-08)

R. Hayden and M. Inghram
Reported by R. Hayden

Vacuum difficulties have again arisen to plague the operation of MA-18, the high sensitivity gas machine which is to be used for xenon analysis. After baking at 350° C, a leak was discovered in a seven-wire kovar lead-through for electron multiplier voltages. This lead-through was replaced, and an even bigger leak was present in the new one. This leak will be tackled again as soon as commercial seals of the correct type are received. Meanwhile W. Chupka is using the instrument for CO appearance potential work, which does not require as clean a background.

The gas extraction line for purification of the extracted xenon has been completed; twenty isotopic Xe^{128} tracers have been made. The relative amounts of tracer gas in these samples is known, but the absolute amounts must still be calibrated.

31-3 Studies of Electron Impact (5211-08)

W. Chupka, R. Hayden, H. Stanton
Reported by W. Chupka

An indirectly heated L-type cathode has been incorporated into the ion source of Ma-17 and used in preliminary electron impact studies of A, Ne, and CO gas. This cathode provides an electron beam more uniform in energy than those used by previous investigators. Ionization efficiency curves comparable to those of the best previous work have been obtained. It is expected that the final adjustments and improvements of Ma-17 will lead to greatly improved data.

Ma-18 has been adapted to the study of negative ions, and a search has been made for the negative ions resulting from electron impact on CO. In addition to the O^- ions reported by previous workers, C^- ions were also found in low but usable intensity. An accurate study of the appearance potentials of the C^- ions is being made and may help resolve the question of the electron affinity of C and the dissociation energy of CO.

32-3 Complex Ion Studies (5211-08)

W. Chupka and M. Inghram
Reported by M. Inghram

The equipment being constructed for the Heat of Vaporization of Carbon, C-II-30-3, will also be used to continue this study. No results will be forthcoming before 1954. Reports on this program

will be discontinued until the work is begun again.

33-3 (Molecular States in Rare Gases) (5211-08)

D. Hess and M. Inghram
Reported by D. Hess

Nothing has been done on this program during the past quarter.

34-3 Argon Age Determinations (5211-08)

G. Wasserberg and R. Hayden
Reported by R. Hayden

Again progress has been hampered by faulty glassware.

Four kovar glass seals on the mass spectrometer have given out, each causing a loss of several weeks' work. Several calibration runs were made and one rock was dated in between accidents. An induction furnace was installed to heat the calcium in the gas purifier. This was found necessary for meteoritic samples since external heating through a quartz jacket allowed excessive atmospheric argon to diffuse into the sample through the hot quartz.

Rock samples have been obtained from the University of Toronto to check their geologically determined decay constant of K^{40} . The uncertainty in the branching ratio of K^{40} has led to considerable confusion in trying to interpret data.

III. CRYSTALLOGRAPHY

1-3 Crystal Structure of Technetium Compounds (5211-11)

W. Zachariasen

Owing to the preoccupation of the interested chemists with other projects, no further preparations of technetium compounds have been investigated.

It is planned to prepare for publication a survey of the results so far obtained.

2-3 Structural Studies of Boric Acids (5211-11)

W. Zachariasen

Monoclinic HBO_2

A preliminary account of this investigation was reported in ANL-4659, p. 65. Since then two further approximations in the refinement of the 27 parameters for boron and oxygen atoms have been carried out. It has been felt advisable to go to a fourth approximation, in view of the interesting features of the structure. This computation will be completed in the course of the autumn. Further information on atomic positions and interatomic distances will be delayed until the work has been brought to completion.

B(OH)_3

An approximate structure of this triclinic compound was described twenty years ago.¹ A precision determination of the structure

¹ W. H. Zachariasen, Report CK-2737, p. 12 (March, 1945).

based upon accurate intensity measurements with the Geiger counter spectrometer has been completed. As compared with the original structure proposal, there are small shifts in the positions of boron and oxygen atoms. However, the new investigation has led to a direct determination of the hydrogen positions.

The results for the unit cell dimensions and for the 42 parameters are:

$$\begin{array}{ll}
 a_1 = 7.039 \pm 0.001 \text{ \AA} & \alpha_1 = 92^\circ 35' \pm 1' \\
 a_2 = 7.053 \pm 0.001 & \alpha_2 = 101^\circ 10' \pm 1' \\
 a_3 = 6.578 \pm 0.001 & \alpha_3 = 119^\circ 50' \pm 1'
 \end{array}$$

	x	y	z
B _I	0.646 ± 0.001	0.427 ± 0.001	0.261 ± 0.003
B _{II}	0.308	0.758	0.239
O _I	0.424	0.302	0.261
O _{II}	0.768	0.328	0.261
O _{III}	0.744	0.650	0.261
O _{IV}	0.532	0.885	0.239
O _V	0.214	0.540	0.239
O _{VI}	0.180	0.856	0.239
H _I	0.35 ± 0.01	0.39 ± 0.01	0.25 ± 0.01
H _{II}	0.68	0.17	0.25
H _{III}	0.89	0.71	0.25
H _{IV}	0.60	0.81	0.25
H _V	0.06	0.47	0.25
H _{VI}	0.29	0.01	0.25

The structure is built up of triangular B(OH)₃ groups which are arranged in "puckered" layers 3.18 Å apart. The B-O distance is 1.360 Å while the O-H distance in the hydroxyl group is found to be 0.95 Å. The B(OH)₃ groups are linked together within a layer by means of hydroxyl bonds O-H ··· O, the oxygen separation being 2.71 Å.

20-1 Table of Squared Sines (5211-11)

A. Plettinger

In x-ray diffraction studies there is extensive use for tables of $\sin^2\theta$, as a function of θ for values of θ expressed in degree and decimal fractions thereof. No such table is available in the literature, so one has been prepared. The table gives $\sin \theta$ and $\sin^2 \theta$ to five decimal places for every interval of 0.01° in the range $0-90^\circ$.

It is proposed to issue this table so that it will be available to other workers in the field.

V. THEORETICAL PHYSICS, GENERAL

1-3 The Interpretation of the Energy States of Light Nuclei

(5211-07)

D. Inglis

✓

Investigation of the possible interpretations of the J and parity of the first excited state of O^{16} has been continued. Calculations carried out in collaboration with D. Kurath show that two-nucleon excitation to the configuration $d_{5/2}^2 p_{1/2}^{-2}$ does not account for the observed sequence of states and does not come even close enough that reasonable modifications of the interactions assumed could give a satisfactory result. Both the d-d interactions and the p-p interactions tend to make $J = 6$ (as well as 5 and 4) lie below $J = 0$. The d-p interactions have the opposite tendency, but with the exchange interactions assumed, they are only about strong enough to cancel the effect of the p-p interactions, leaving $J = 6$ about 1/2 Mev below the lowest $J = 0$ state of this configuration. It is not plausible that refinements in the interaction assumptions could reverse this order and put the $J = 0$ state more than 2 Mev below the states of high J, as required by the present experimental data. This result suggests that the alpha model is preferable to the central model as a basis for discussing these states of O^{16} and that experimental search should be made both for the missing 2^- state of the alpha model and for other states that might have been missed because of their high J.

2-3 Excited States of Light Nuclei (5211-07)

D. Kurath

The effect of interaction between states of the same (I, T) in the configurations $(1 p_{3/2})^m (1 p_{1/2})^n$ and $(1 p_{3/2})^{m-1} (1 p_{1/2})^{n+1}$ has been calculated with Majorana exchange for the nuclei A = 10, 11, 13, and 14. The effect is found to be large in some cases, indicating that the configuration $(1 p_{3/2})^{m-2} (1 p_{1/2})^{n+2}$ will also contribute noticeably. The simple cases A = 13 and A = 14 confirm that this is so. The effect of such configuration mixing on the magnetic moments of the ground states is also considerable. It is planned to complete the calculation of the $(1 p_{3/2})^{m-2} (1 p_{1/2})^{n+2}$ configuration interactions with the ground configurations, which will then account for all first order 1 p-shell interactions with the ground states. If the resulting magnetic moments are not reasonable, it would suggest that higher configurations should be mixed in (the calculation would become too cumbersome) and indicate that the jj-approximation to the ground state wave function is not very good for the 1 p-shell nuclei.

3-3 The Sequence of γ Emission in Triple Correlations
(5211-07)

E. Hellund and J. Jauch*

Reported by J. Jauch

(This report is the text of a Letter to the Editor of The Physical Review, scheduled to appear in the issue of October 15, 1953).

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Biedenhern, Arfken, and Rose¹ have noted that angular correlation data in certain cases can fix the nuclear decay scheme uniquely. However, they also discuss an example of a triple correlation where the sequence of the last two γ 's is not determined by the correlation function. This is the reaction $B^{11} (p \gamma_1 \gamma_2) C^{12}$ in which the last two γ 's are emitted according to the scheme (2 D 1 D o).

We shall prove the theorem that the same ambiguity is present in the more general γ - cascade $\{j_o (2^{L_o} \text{ pole}) j_a (2^L \text{ pole}) L (2^L \text{ pole}) o\}$. The spins of the levels are (j_o, j_a, L, o) , and the symbol 2^L denotes the multipole order of the emitted radiation.

The same conclusion holds if, in the place of the 2^{L_o} pole emission, one has to do with a particle capture followed by the emission of two gammas as in the triple gamma cascade.

There is some practical interest in the cascade of three gammas for the spins 6, 4, 2, 0. Kurath² has described a discrepancy in the decay scheme of Sc^{48} that is resolved only by the assumption that the product Ti^{48} decays by a triple gamma cascade. Experimental verification of the existence of the three gammas has been reported.³ Unfortunately, the remaining uncertainty in the decay concerning the

1 L. C. Biedenhern, G. B. Arfken, and M. E. Rose, Phys. Rev. 83, 586 (1951).

2 D. Kurath, Phys. Rev. 87, 528 (1952).

3 B. Hamermesh, V. Hummel, L. Goodman, and D. Engelkemeir, Phys. Rev. 87, 528 (1952); M. J. Sterk, A. H. Wapstra, and R. E. Kropveld, Physica 19, 135 (1953).

order of the last two gammas, according to the theorem to be proved, cannot be determined by angular correlation. An example wherein the ambiguity concerns the order of the first two gammas in a triple cascade is furnished by Cr⁵². Here, angular correlation, in principle, can establish the correct order of the transitions.

For the proof of the theorem we start with the general expression for the triple cascade as given by F. Coester and J. M. Jauch.⁴ The formula given there is valid for particle or photon emission and also includes general mixtures of multipoles. If we specialize to the case of pure multipole emission, we obtain the triple angular correlation function in the form:

$$W(\Omega_0 \Omega_1 \Omega_2) = \text{const.} \sum_{\xi_1 \xi_2 \xi_3} \sum_{j_a j_b} \sum_{k_0 k_1 k_2} C_{k_0}(\xi_0) C_{k_1}(\xi_1) C_{k_2}(\xi_2) n_1 n_2 D_{n_0}^{k_0*}(\phi_0 \theta_0) D_{n_1}^{k_1}(\phi_1 \theta_1) D_{n_2}^{k_2}(\phi_2 \theta_2) \quad (1)$$

$$(j_a j_a \parallel \Gamma(j_0 j_0 L_0 L_0) \parallel k_0) (j_a j_a \parallel \Gamma(j_b j_b L_1 L_1 k_0) \parallel k_2 k_1) (k_2 k_1 n_2 n_1 \parallel k_0 n_0) (j_b j_b \parallel \Gamma(j_c j_c L_2 L_2 k_2) \parallel k_2) \parallel R_{j_a}(\xi_0 \xi_1 \xi_2 j_b)^2$$

The spins of the four nuclear levels involved are denoted by j_0, j_a, j_b, j_c . The multiple order of the three transitions is L_0, L_1, L_2 . The Γ - coefficients are certain sums over Racah coefficients and are defined in equations (B5, B6) of Ref. 4. The variable ξ denotes the

⁴ F. Coester and J. M. Jauch, *Helv. Phys. Acta* 26, 3 (1953), esp Eq. 38, p. 11.

set of quantum numbers needed to specify the emitted radiation. Thus for photons ξ is the multipole order L and the parity.

Equation (1) may be written in the form

$$W(\Omega_0 \Omega_1 \Omega_2) = \sum_{k_1 k_2} x_{n_1 n_2}^{k_1 k_2} (\vartheta_0 \vartheta_0)^{k_1}_{n_1 0} (\vartheta_1 \vartheta_{10})^{k_2}_{n_2 0} (\vartheta_2 \vartheta_{20})_{n_1 n_2} \quad (2)$$

from which it follows that the necessary and sufficient condition that

$$W(\Omega_0 \Omega_1 \Omega_2) = W(\Omega_0 \Omega_2 \Omega_1) \quad (3)$$

is that the coefficients $x_{n_1 n_2}^{k_1 k_2}$ satisfy the symmetry relation

$$x_{n_1 n_2}^{k_1 k_2} = x_{n_2 n_1}^{k_2 k_1} \quad (4)$$

This relation implies, first of all, on account of the coefficients

$C_k(\xi)$ in (1) that

$$L_1 = L_2 \quad (5)$$

Next we see that the last of the Γ -coefficients in (1) must be independent of k_2 . This coefficient is given by

$$(j_b j_b / \Gamma(j_c j_c L_2 L_2 k_2) / 0 k_2) = (-1)^{L_2 + j_b - j_c - k_2} \frac{2j_b + 1}{\sqrt{2j_c + 1}} W(j_b L_2 j_b L_2; j_c k_2) \quad (6)$$

and the condition that it be independent of k_2 implies $j_c = 0$ and consequently $j_b = L_2 = L_1$. The rest of the coefficients are then symmetrical, and the theorem stated at the beginning is proven.

4-3 Investigation of Nuclear Shell Structure (5211-07)

5-3 Book on Nuclear Shell Structure 5211-07)

M. Mayer

There will be no report on the progress of this book during the absence of Dr. Mayer.

7-3 Collective Description of Nucleon Interactions (5211-07)

M. Ferentz

In this quarter, in collaboration with M. Gell-Mann (University of Chicago) and D. Pines (University of Illinois), the collective description has been recast into a completely quantum mechanical form. Instead of working with the equations of motion of the collective coordinates, as we did previously, we deal directly with the hamiltonian of the nucleon-nucleon interaction. Using a canonical transformation and a supplementary condition, we transform the hamiltonian into a form where the oscillatory nature of certain generalized coordinates is made manifest. The supplementary condition defines these generalized coordinates and shows that acting upon a state vector with them is identical with acting on a state vector with the isotopic-spin density fluctuation of the older formalism.

In a Letter to the Editor of The Physical Review¹ we have applied the new formalism to a number of problems connected with the giant dipole resonance in the photonuclear cross sections of heavy nuclei.

¹ Ferentz, Gell-Mann, and Pines, Phys. Rev. October 15, 1953.

8-3 (Monoenergetic Neutrons from Charged Particle Reactions)

(5211-07)

W. Reardon

No work has been done on this program during the past quarter, but calculations are to be begun in the near future.

28-2 (Angular Distribution of Elastically Scattered Neutrons)

(5211-07)

M. Hamermesh

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

29-2 Internal Conversion in Subshells (5211-07)

E. Church, M. Hamermesh, J. Monahan

Reported by M. Hamermesh

The qualitative study of internal conversion begun earlier has been continued with a study of magnetic dipole conversion. In the Pauli approximation we obtain formulas very similar to those of hyperfine structure. The transition matrix elements for M-1 conversion are those for E-2 plus a term proportional to the product of initial and final wave functions at $r = 0$. Thus an additional large term for S-S transitions is found which is allowed for M-1 and forbidden for E-2. This extra term makes M-1 convert preferentially on S electrons. For the M shell one finds the ratio $M_I/M_{II+III} = 10$ near the threshold.

For the completely relativistic formulas no simplifications seem possible.

No further work on this problem or publication is contemplated.

(Consultation on Miscellaneous Theoretical Problems)

M. Hamermesh

No work has been done during the past quarter.

31-3 Configuration Interaction in Iron Group Elements (5211-14)

J. Hall and N. Rosenzweig
Reported by N. Rosenzweig

Least squares calculations appropriate for investigating the configuration interaction in the even configurations of Fe II had previously been programmed for the AVIDAC. During this quarter, test runs were made which indicate that the detailed coding is correct.

32-3 Plural Scattering of Electrons at Oblique Incidence (5211-14)

M. Hamermesh and J. Monahan
Reported by J. Monahan

The results of this calculation were described in an earlier report. A paper on this project will be submitted to The Physical Review.

33-3 Geometry for Maximum Scattering and Minimum Dispersion
(5211-07)

J. Monahan

Completion of this problem would require a long numerical computation. Since the same information can be obtained experimentally such a calculation does not seem justifiable. The problem has, therefore, been discontinued.

34-3

Quantized Space Time (5211-14)

E. Hellund and K. Tanaka

Reported by K. Tanaka

Non-plane wave solutions of the Dirac equation which may be used in self energy calculations have been constructed. In one dimension they are as follows:

$$\begin{aligned} \phi_1 &= \begin{pmatrix} -i m t \frac{I_1}{s} + m I_0 \\ 0 \\ 0 \\ -i m x \frac{I_1}{s} \end{pmatrix} & \phi_3 &= \begin{pmatrix} 0 \\ i m x \frac{I_1}{s} \\ -i m t \frac{I_1}{s} + m I_0 \\ 0 \end{pmatrix} \\ \phi_2 &= \begin{pmatrix} 0 \\ -i m t \frac{I_1}{s} + m I_0 \\ -i m x \frac{I_1}{s} \\ 0 \end{pmatrix} & \phi_4 &= \begin{pmatrix} i m x \frac{I_1}{s} \\ 0 \\ 0 \\ -i m t \frac{I_1}{s} + m I_0 \end{pmatrix} \end{aligned}$$

where $\sqrt{x^2 - t^2} = s$ and $\hbar = c = 1$ and I_v is the Bessel function of the first kind whose argument is $[m \sqrt{x^2 - t^2}]$, and I_v is a regular solution on the light cone $x^2 - t^2 = 0$. The irregular solution is obtained by replacing

bution of this radiation produced by charged particles moving in anisotropic media has been developed for arbitrary direction of motion of the particle relative to the crystal axes. Earlier results of Ginsburg¹ for special cases are confirmed. A paper has been submitted for publication in The Physical Review.

39-1 Applications of the Theory of Angular Correlation (5211-07)

M. Ferentz and N. Rosenzweig
Reported by N. Rosenzweig

The measurement of the angular correlation (a. c.) of successive nuclear radiations has become an important tool for obtaining information about nuclear states (e. g., level spins, magnetic moment of intermediate state, etc.). The possibility of obtaining such information arises from the fact that theory usually predicts a definite a. c. for a particular set of nuclear parameters. For example, in a γ - γ cascade, the specification of initial, intermediate, and final spin and the multipole orders of the two γ -rays result in a definite a. c. function. Thus, the interpretation of a particular experiment consists in selecting that theoretical formula which is in closest agreement with the observed a. c. In practice, one needs the whole set of a. c. functions which are not ruled out by already existing knowledge of the decay scheme.

In order to be able to meet the present and future demand for explicit a. c. functions, the theoretical literature has been surveyed.

¹ V. L. Ginsburg, J. Phys. (U.S.S.R.) 3, 95 (1940) and 3, 101 (1940).

The formulas for mixed transitions in a γ - γ cascade which are given by Biedenharn and Rose¹ have been checked by reducing a general expression given by Coester and Jauch.² Explicit formulas for the mixed γ - γ cascade of Pb^{204} (studied experimentally by S. Raboy) are being calculated.

The general two-radiation angular correlation theory is being cast into a form suitable for high-speed computing machines so that a set of routines may be placed in the AVIDAC library which will allow one to calculate an angular correlation merely by specifying the kinds of radiation and the j -values of the levels. Subroutines for computing Wigner and Racah coefficients have been prepared for this purpose.

40-1 Compton Scattering (5211-14)

K. Tanaka

In the course of an investigation of gauge invariance of the S-matrix we have calculated the matrix element for the Compton effect, using the Feynman-Dyson technique, without specifying the representation of the γ matrices and without taking the initial electron at rest with respect to the gamma-ray as is usually done. The Feynman diagrams and their matrix elements are as follows:

1 L. C. Biedenharn and M. E. Rose, Rev. Mod. Phys. 25, 729 (1953).

2 F. Coester and J. M. Jauch, Helv. Phys. Acta 26, 3 (1953).

$$M \approx \left\{ \bar{U}(p') \frac{1}{\sqrt{2w'}} \not{\epsilon}' \frac{i(\not{p} + \not{k}) - m}{(p+k)^2 + m^2} \not{\epsilon} \frac{1}{\sqrt{2w}} U(p) \right. \\ \left. + \bar{U}(p') \frac{1}{\sqrt{2w}} \not{\epsilon} \frac{i(\not{p}' - \not{k}) - m}{(p-k)^2 + m^2} \not{\epsilon}' \frac{1}{\sqrt{2w'}} U(p) \right\} \quad (1)$$

where the initial state is specified by p, k, e and final state p', k', e' , and $\not{p} = p_\mu \gamma^\mu$. The conservation law is $p + k = p' + k'$. The transition probability is proportional to

$$\sum |M|^2 = \frac{1}{\mathcal{K}^2} A + \frac{1}{\mathcal{K}'^2} B + \frac{1}{\mathcal{K}\mathcal{K}'} (C + D) \quad (2)$$

where $\mathcal{K} = (kp) = (k' p')$

$$\mathcal{K}' = (k' p) = (k p')$$

and

$$\begin{aligned} A &= \not{\epsilon}' (i \not{p} - m + i \not{k}) \not{\epsilon} (-i \not{p} + m) \not{\epsilon} (i \not{p} - m + i \not{k}) \not{\epsilon}' (-i \not{p}' + m) \\ B &= \not{\epsilon} (-i \not{p} + m + i \not{k}') \not{\epsilon}' (-i \not{p} + m) \not{\epsilon}' (-i \not{p} + m + i \not{k}') \not{\epsilon} (-i \not{p}' + m) \\ C &= \not{\epsilon}' (i \not{p} - m + i \not{k}) \not{\epsilon} (-i \not{p} + m) \not{\epsilon}' (-i \not{p} + m + i \not{k}') \not{\epsilon} (-i \not{p}' + m) \\ D &= \not{\epsilon} (-i \not{p} + m + i \not{k}') \not{\epsilon}' (-i \not{p} + m) \not{\epsilon} (i \not{p} - m + i \not{k}) \not{\epsilon}' (-i \not{p}' + m) \end{aligned} \quad (3)$$

The terms C and D are the exchange terms, and the fourth and eighth factors come from the projection operators. Calculating A, B, C, D and substituting the results into (2), one finds

$$\begin{aligned} \sum |M|^2 &= 2 \left\{ \frac{\mathcal{K}}{\mathcal{K}} + \frac{\mathcal{K}'}{\mathcal{K}} - 2 + 4 (ee')^2 \right\} + 8 \left\{ \frac{(ep)^2 (e'p')^2}{\mathcal{K}^2} + \frac{(e'p)^2 (ep')^2}{\mathcal{K}'^2} \right\} \\ &+ 16 \left\{ - \frac{(ep) (e'p') (ee')}{\mathcal{K}} + \frac{(ep') (e'p) (ee')}{\mathcal{K}'} - \frac{(e'p) (e'p') (ep) (ep')}{\mathcal{K}\mathcal{K}'} \right\} \end{aligned} \quad (4)$$

Now let us take the initial electron at rest, e. g. , $\vec{p} = 0$ or $(ep) = (e'p) = 0$. Then one finds

$$\sum_p |M|^2 = 2 \left\{ \frac{k}{k} + \frac{k'}{k} - 2 + 4 (ee')^2 \right\}$$

$$p = 0$$

which is proportional to the well known Klein-Nishina formula.

A check of equation (4) is obtained from the gauge invariance of the S-matrix. The S-matrix elements must remain unchanged when the radiation field operators are subjected to a gauge transformation

$$a_\mu(x) \rightarrow a_\mu(x) + \partial_\mu \gamma(x) \quad (5)$$

where $\gamma(x)$ is an arbitrary function of x . The corresponding transformation of the Fourier components of a_μ is expressed in the substitution

$$e_\mu(k) \rightarrow e_\mu(k) + k_\mu \gamma(k) \quad (6)$$

with $\gamma(k)$ an arbitrary function of k . If we express (4) in the form

$$\sum |M|^2 = F^{\mu\nu\rho\sigma} e_\mu e_\nu e_\rho' e_\sigma' \quad (7)$$

the invariance of this expression under the substitution (6) supplies

$$F^{\mu\nu\rho\sigma} k_\mu k_\nu e_\rho' e_\sigma' = 0$$

and

$$F^{\mu\nu\rho\sigma} e_\mu e_\nu k_\rho k_\sigma = 0.$$

These relations have been verified.

The author is indebted to Professor J. M. Jauch for suggesting this problem.

VII. ELECTRONIC DIGITAL COMPUTERS

0-1 Report on the Digital Computer Symposium (4520-02)

R. Kramer, Staff Members of the Computer Group
Reported by R. Kramer

A symposium on advanced engineering techniques for digital computers sponsored by the Argonne National Laboratory with the co-operation of the Oak Ridge National Laboratory was held on August 3, 4, and 5, 1953.

The decision to hold the conference and at the same time disclose the completion of the ORACLE was made in April, 1953. A program committee composed of engineers and mathematicians well known in the computer field was assembled by Mr. J. C. Chu, who was the manager of the conference. Plans were completed in June, and notices were first sent out on June 10.

A total of 204 persons requested invitations to attend. These people represented 18 universities and associated institutions, 29 industries and industrial laboratories, and 11 governmental agencies and laboratories. Actually 164 people attended, coming from all parts of the United States, from Massachusetts to California and from Minnesota to Florida.

The meetings on August 3 and 5 were held in the Little Theatre at the Museum of Science and Industry in Chicago. The meeting in the morning of August 4 was held in the Auditorium of the Chemistry Building at the Laboratory, with the afternoon session being

devoted to an inspection tour of some laboratory facilities. The ORACLE, AVIDAC, nuclear reactors at Palos Park, cyclotron, Van de Graaff generator, and magnetic tape equipment were displayed.

A total of 22 papers were presented at five sessions. The subjects covered were as follows:

Transistors and their application to computers	3 papers
Williams tube memory: 5 on systems and circuitry; 1 on cathode-ray tube design	6 papers
Diode-capacitor memory system	1 paper
Memories using magnetic cores	3 papers
Component and materials research including research on Ferro-electrics, Ferro-magnetics, and other physical phenomena which might find application in computing machines	3 papers
Magnetic tape recording and tape memory systems	3 papers
Mathematical experience with computers	2 papers
Characteristics of the ORACLE	1 paper
	<hr/>
	22 papers total

A banquet was held at the Hotel Windermere on August 4 which was attended by 83 persons. The speaker of the evening was John W. Mauchly, who gave an interesting talk on "Computing the Weather."

All the papers which were presented are being assembled and will be included in a complete report on the conference.

Much credit is due many people at Argonne whose help made the meeting a success, but special mention should be made of the help given by Dr. J. C. Boyce and Miss Helen Shannon. Also Mr. L. C. Furney's help in planning the inspection tour contributed greatly to having this phase of the program take place with a minimum of confusion.

1-3 (Report on the Design of the AVIDAC) (1520-02)

R. Kramer

Work on this project is still being held in abeyance until work on the improvement of the AVIDAC is completed.

2-3 Improvement of the AVIDAC (1520-02)

C. Bergstrom, J. Chu, R. Kramer, D. Jacobsohn
Reported by C. Bergstrom

A. Control Console

The control console is installed with the computer, has been in successful operation, and has met the requirements of the operators very well.

B. Williams Tube Selection

Of the 100 DuMont tubes that were tested, 62 were initially rejected and returned. Of the 38 remaining, 20 are being used successfully in the AVIDAC. Of the other 17, some were kept for further experimentation; some were not successful in the machine although

the tests had indicated that they were good. The 20% yield of excellent tubes is encouraging.

C. Completion of Order List

All of the projected order list of the AVIDAC has been installed and is in successful operation.

D. Electronic Commutator for Teletype

The electronic commutator for the teletype has been designed and constructed. It will be installed during the ensuing quarter.

3-3 Operational Maintenance of the AVIDAC (4520-02)

J. Chu, R. Kramer, D. Jacobsohn, C. Bergstrom
Reported by C. Bergstrom

Since the last report further work on the AVIDAC memory has shown that the interpretation of earlier apparently successful results using 512 memory positions was overly optimistic. A closer investigation showed that a usable 512 was possible but not with the high consultation rate originally given.

It has been necessary to substitute 21 new DuMont tubes from the batch tested by David Jacobsohn for tubes in the machine which failed to operate properly. A new method of checking read-around and write-in was devised, and this new method was then used to adjust the new tubes more adequately than had been possible in the past.

The top usable read-around figure now proves to be about 40. Further investigation should allow some higher figure to be used,

but probably not in excess of 100.

By the installation of a delay device which will, when desired, limit the number of consultations at a certain spot to a safe limit but otherwise allow full speed operation of the machine, it will be possible to utilize fully the 512 location memory. This device has been designed and will be installed as soon as possible.

As in the last report, the arithmetic unit has had only a small amount of trouble again due to tube failure. New tubes have been installed in several chassis. Such tube changing will be carried forward as fast as new, properly aged and tested tubes are ready.

The tube replacement program is now in operation, and it is expected that by October 31st all tubes in the arithmetic unit will have been checked and rotated. As soon as the arithmetic unit is completed, the same program will be applied to the memory.

The equalizing setup is now complete, installed and adjusted. Some voltage lines are, however, still not correct, indicating that further adjustments must be made here.

4-3 Test Routines for the AVIDAC (4520-02)

J. Alexander, J. Hall, R. McDowell
Reported by J. Alexander

The following additional tests for the AVIDAC were coded.

1. Kitchen Sink Memory Test (Tape T-11.7). This test consolidates the previous Read-Write test and the Spill test. It has the additional feature that the contents of unused memory locations are checked so that an indication of error occurs if any memory location fails.

2. Revised Register Test (Tape T-13.1). This test is a revision of T-13 for use with the revised Ax-Of circuits.

3. Leap Frog Test (T-14.1). This is a memory sum test which has a code-moving feature. In the course of the test, the coding moves itself so that eventually each word of the test is executed from every memory location.

New tests are still being developed.

5-3 Subroutine Library for the AVIDAC (4520-02)

M. Butler (Reactor Engineering Division), J. Hall,
R. McDowell, W. Miller
Reported by J. Hall

Five routines are now in use following their machine tests.

They are:

- S-10.1 Sum and Punch Routine
- S-10.2 Variable Address Load Routine
- S-3.3 Three-Address Control for 30-10 Arithmetic (a
 floating-point routine.)
- S-5.1 Fixed-Point Square Root

S-4.3.1 Floating-Point Square Root

The floating-point routine was in use during the demonstration of the AVIDAC at the Argonne Computer Symposium.

6-3 Coding Manual for the AVIDAC (4520-02)

J. Alexander, D. Flanders, J. Hall
Reported by D. Flanders

Chapter 3 of the manual, a descriptive list of the AVIDAC's orders, has been completed and issued in Dittoed form.

7-3 The Auxiliary Memory for the AVIDAC and ORACLE
(4520-02)

R. Kramer and L. Merrill
Reported by L. Merrill

Modifications of the test rig have been completed. There remains a small amount of debugging and the writing of a brief manual for maintenance and operation. The test rig operated well during the demonstrations given for the computer symposium.

Engineering drawings for the auxiliary memory system are complete. A pilot model of the tape drive was completed, and minor changes in the design are currently being processed. Tests to determine the best materials for use in recording heads were run and the design of the heads modified accordingly. A sample of the production recording heads will be carried through the shop in the coming quarter. Considerable preliminary work aimed at the production of recording heads has already started.

8-3 (A Problem in Partitions) (5211-14)

D. Flanders

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

10-2 Report on the Control of the AVIDAC (4520-02)

J. Alexander

This report should be completed by September 15, 1953.

11-1 Automatic Stabilization of the Beam Currents in Williams Tube Memories (4520-02)

R. Klein

A circuit has been developed for increasing the reliability of Williams tube memory devices by producing automatic stabilization of the beam currents in the cathode ray tubes, thus eliminating one cause of variation of the amplitude of output pulses. One storage location in each tube is used as a test point. The circuit is designed to sample the output of this location periodically and adjust the beam current to keep this output at a constant amplitude. Since all the other storage locations of the tube use the same beam, their outputs are correspondingly stabilized. This system has been in use in the ORACLE memory for two months and has functioned satisfactorily. Almost no warm-up period and only very infrequent adjustments of intensity are required.

A paper describing this circuit has been submitted for publication to the Proceedings of the Computer Section of the Institute of Radio Engineers.

12-1 Comparison of Inspection Systems for Williams Memory
Tubes (4520-02)

D. Jacobsohn

Four Williams tube memory inspection systems were tested comparatively in order to evaluate possible improvements for the AVIDAC. These systems included the currently used Williams inspection system, the Refill inspection system of NBS, the Dot-Slide inspection system of ILLIAC, and the double inspection system that was developed at Argonne. All tests were of relative read-around ratios. The results are listed in the following table. A complete description is being published in the proceedings of the Argonne Computer Symposium.

Table IX

Relative Read-Around Ratios of
 Five 5CP1A Cathode Ray Tubes
 with Various Inspection Systems

<u>Inspection System</u>	<u>Tube No.</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>Average</u>
Williams		1	1	1	1	1	1
Refill		2	2.3	4	2	2.7	2.7
Dot-Slide		2.5	1.7	4	4	3.0	3.0
Double		3	3.4	5.3	4	5.3	4.2

Data normalized with Williams Inspection System equal to 1.

August, 1952	Computer cleaned after radium spill
September, 1952	Computer named ORACLE
November, 1952	Testing of the memory basin plug-in unit begun. Dispatch counter and MOSC completed
December, 1952	2-inch magnetic recording head completed

March, 1953	Test of the memory unit begun
May, 1953	Input and output equipment installed
June, 1953	First testing run. Final engineering test begun
July, 1953	Four major problems solved by the ORACLE.

The ORACLE is now operating on a 7-day week schedule.

During the months of July and August, the machine's operating time was about 180 hours. The efficiency of the computer was about 95%. The remaining time was spent on running test problems and making minor improvements.

Many of the test problems were run with the purpose of improvement of the memory system. The testing procedure used now will provide an abundance of useful information in concise form about the status of the memory. Tests T-10 and T-14 are coded to give the following information with regard to the read-around capabilities of the memory:

1. The stage producing errors
2. Location of the position written on when the error occurred

3. Location of the neighbor where the error occurred

4. Number of read-arounds

In addition, a quick survey of the memory can be made in which only the stage and number of mistakes on that stage are recorded. After the above information is received, the other three tests are used for adjusting the memory. These include a test having orders in the right side of the memory only while the other side is being adjusted and another test having orders in the left side for adjusting the right side of the memory. The "Roman Candle" test then allows the entire memory to be adjusted while receiving an average effect of read-around.

The allowable number for repetitive consultation of the memory is about 150.

Further minor improvements of the ORACLE are still being made; however, the computer is considered completed and has passed all acceptance tests.

Shipment of the computer to Oak Ridge is dependent upon the preliminary installation of the computer at Oak Ridge National Laboratory, and it is estimated that this will be around the early part of October, 1953.

the scalar product $a_i^T a_j = a_j^T a_i$ be given for each (i, j) such that $1 \leq i < j \leq 2n$. For $1 \leq P \leq N$ and for any sub-set $(b_1, \dots, b_{2p})$ of $(a_1, \dots, a_{2n})$ consisting of distinct vectors we define the function $\langle b_1, \dots, b_{2p} \rangle$ inductively on P as follows:

$$(1.1) \quad \langle b_1, \dots, b_{2p} \rangle \equiv \langle b_1, b_2 \rangle = b_1^T b_2, \text{ for } P = 1,$$

$$(1.2) \quad \langle b_1, \dots, b_{2p} \rangle = \sum_{h=2}^{2p} (-1)^h \langle b_1, b_h \rangle \langle b_2, \dots, b_{h-1}, b_{h+1}, \dots, b_{2p} \rangle,$$

$$b_{h+1}, \dots, b_{2p} \rangle, \text{ for } 1 < P \leq N.$$

It is desired to compute $\langle a_1, \dots, a_{2n} \rangle$ for $N = 6$ and $N = 8$ and for various sets of values of the scalar products.

It can be shown

$$(2) \quad \langle a_1, \dots, a_{2n} \rangle = \sum_{i_1, j_1, \dots, i_n, j_n} S_{i_1, j_1, \dots, i_n, j_n}^{1, 2, \dots, 2n-1, 2n} \langle a_{i_1}, a_{j_1} \rangle \dots \langle a_{i_n}, a_{j_n} \rangle,$$

where the summation is extended over all admissible arrangements $(a_{i_1}, a_{j_1}, \dots, a_{i_n}, a_{j_n})$ of the given set of vectors, an admissible arrangement being defined as one for which

$$(2.1) \quad i_h < j_h \text{ for } 1 \leq h \leq N,$$

and

$$(2.2) \quad i_h < i_k \text{ for } 1 \leq h < k \leq N.$$

Thus the number of terms on the right side of (2) is the number of distinct ways of expressing the set $(a_1, \dots, a_{2n})$ as a set of N pairs. This number

is $(2n)! / 2^n n! , = 1 \cdot 3 \cdots (2n-1)$, which is 10,395 for $N = 6$ and 2,027,025 for $N = 8$. In cases of interest, however, the number of distinct values assumed by the scalar products is relatively small, some scalar products are zero, and there is considerable cancellation among like non-vanishing terms, so that if only non-vanishing terms are collected and only non-vanishing sums of like terms are kept, the number of expressions to be evaluated is small. (In one case done by hand, with $N = 6$, the final expression involved only about 30 non-vanishing terms.) The most difficult part of the problem is the determination and collection of the non-vanishing terms, and it is this part of the problem that is to be solved by the AVIDAC.

Progress: The problem has been broken into two parts. In the first part the AVIDAC will produce a punched tape containing a list of all non-vanishing terms in (2) each term being represented by its algebraic sign and a set of symbolic values of the factors $\langle a_{i_n}, a_{j_n} \rangle$. In the second part the terms will be sorted and collected, and the result will be a similar list of terms. In this latter list, however, each type of term will appear just once and with its proper coefficient. All terms with coefficient zero will be eliminated.

A detailed formulation of the first part suitable for machine operations has been constructed. No work has been done on the second part.