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ARGONNE NATIONAL LABORATORY
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Lemont, Illinois

PHYSICS DIVISION
QUARTERLY REPORT

MAY, JUNE, AND JULY, 1954

Louis A. Turner, Division Director

September, 1955

Preceding Quarterly Reports:

ANL-5140 June, July, and August, 1953
ANL-5174 September, October, and November, 1953
ANL-5175 September, October, and November, 1953 (Secret)
ANL-5273 December, 1953, January and February, 1954
ANL-5274 December, 1953, January and February, 1954 (Secret)
ANL-5317 March and April, 1954

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

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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.

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I. EXPERIMENTAL NUCLEAR PHYSICS1-7 The Argonne Fast Neutron Velocity Selector (5211-01,
5261-01)

Lowell M. Bollinger, Duane A. Dahlberg,
George E. Thomas
Reported by Lowell M. Bollinger

Installation of Velocity Selector at CP-5

The installation of the neutron velocity selector at CP-5 has been completed. The modifications of the system (discussed in ANL-5317) are expected to result in the following improvements in neutron transmission data:

Resolution - improved by the factor $3/2$ to give a resolution of $0.08 \mu\text{sec}/\text{meter}$.

Counting rate - increased by a factor of 3.

Relative background - decreased by a factor of 4.

Preliminary tests of the system are about to begin and routine measurements will be started in about two weeks.

2-7 Liquid Scintillation Neutron Detector (5211-01, 5261-01)

Lowell M. Bollinger, Harold E. Jackson, George E. Thomas

a) Small Detectors - Reported by George E. Thomas

Two liquid scintillation units of the type described in ANL-5273, I 2-5, have been constructed and used with the Argonne fast chopper at the sixty meter detection station. These detectors have characteristics similar to the ones previously described.

Considerable difficulty has been experienced in sealing the photomultipliers to the cell for a liquid cell. Several new types of cements for this use are being tested. After a rather short term test some of the cements seem quite satisfactory for this use.

A new scintillator* is now being used in our detectors. We get the best results with the following formula:

4 g/l phenyl biphenylzl oxadiazole

20 mg/l POPOP

in equal volumes of pure toluene and enriched methylborate. The scintillator has a precipitation point of about -20° C.

Tests were made to determine the relative sensitivity of different sections of the cathode surface of several Dumont 6292 photomultiplier tubes. If any one section of the cathode surface had a marked increase in sensitivity, an improvement in resolution of the liquid scintillator could be achieved by using only this section. The photocathode surfaces were found, however, to be quite uniform except near the extreme edge where the sensitivity decreased by about 50%.

b) Scattering Detector - Reported by Lowell M. Bollinger

1) General Characteristics

A large liquid scintillation detector is being constructed for the efficient detection of neutron capture, fission and scattering events. This system is to be used with the fast chopper for the direct measurement of the cross sections for these various events.

* Phenyl biphenylzl oxadiazole and POPOP, discovered by L. N. Hayes of Los Alamos Scientific Laboratory.

The new detection system, which is called a "scattering" detector for convenience, is shown in Figure 1. It consists of an inner counter having a rectangular orifice thru it, which is surrounded by a large outer counter. The inner counter is an assembly of two mechanically independent sections and the outer counter has four sections. All these sections are filled with a boron-loaded scintillating liquid. The liquid of each of the inner counters is viewed by six photomultipliers, whereas each of the outer counters has 8 photomultipliers.

It is believed that the above counting system will be of very general usefulness in the detection of neutron reactions. As a typical example, consider one of its many intended uses, the detection of a slow neutron scattered from a sample within the inner counter. For the detection of such an event we may make use of the fact that a neutron, when absorbed in the boron of the inner counter, usually produces both an α -particle and a γ -ray by the reaction

For the detection of a slow neutron, therefore, it is intended to require that the α -particle produce a pulse in one and only one section of the inner counter and that coincidentally the γ -ray produce a pulse in one and only one section of the outer counter; moreover, both pulses must be within the correct pulse height range.

The great size and complexity of the scattering detector is made necessary by the requirements that it be both fast and efficient and that it discriminate effectively against background counts.

DETECTOR OF NUCLEAR INTERACTIONS BY SLOW NEUTRONS

FIGURE 1.

2) Construction

The mechanical work on the one section of the outer counter has been completed and another section is well under way. One section of the inner counter has been started.

All of the counters are constructed of Armco iron, with the inner surfaces porcelainized to give a highly reflective surface. All the walls of the inner counters are of 1/32" iron. The walls of the outer counters are of 1/8" stainless steel except for those that face the inner counter, which are also of 1/32" material. The photomultiplier cathode surfaces are in direct contact with the scintillating liquid.

One of the outer sections will be completed and tested within the next month.

3-7 (Transmission Measurements with the Fast Neutron Velocity Selector) (5211-01, 5261-01)

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

No new results have been obtained during the present quarter.

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

G. R. Ringo

No progress has been made during the present quarter.

11-7

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

1. New Belt Generating Voltmeter - Reported by F. Paul Mooring

The new belt generating voltmeter has been installed and is operating satisfactorily. The Van de Graaff operator can now monitor the belt charge continuously and correct for any undesirable belt charging conditions. No further report on this phase of the operation is contemplated.

2. New Focus Electrode - Reported by F. Paul Mooring

The new focus electrode, which uses electron absorbers of beryllium and x-ray shields of uranium, has been installed in the ion source. New glass insulators were also installed in the focus assembly, replacing those that had been damaged by x-rays.

The beam position is now sensitive to focus voltage. This is attributed to a slight misalignment of the focus geometry which can be corrected. It is too early to judge the real value of the new electrode.

3. Textolite Damage - Reported by F. Paul Mooring

Early in June the Van de Graaff generator suddenly refused to hold voltage. It would start sparking as soon as charge was sprayed on to the belt. The sparks seemed to be localized in the middle section. When the machine was opened, no visible source of sparking could be found. Shorting out the middle section allowed voltages of the order of two Mev to be reached. The symptoms seemed to indicate that some of the textolites might be damaged.

The main structural members of the Van de Graaff are made of textolite tubes. Figure 2 shows a section of one such tube. They are cylinders 4-1/2 inches in diameter formed from paper bonded with shellac. Aluminum shield rings (A), about 1-1/4 inches apart, are held in place by micarda pins (B) which are bonded into the textolite members with glyptal. When the shield rings were removed in the middle section, it was found that several of the pins on two of the textolite tubes had been shattered (C) and there was evidence of sparking to those particular shield rings.

Upon the advice of Professor R. G. Herb of the University of Wisconsin, one-half-inch holes (E) were drilled through the textolite tubes at the suspected points, in order that the interior surfaces might be inspected. At these places the inside surface had been blasted away as if miniature explosions had taken place (D). There were no signs of carbonization of the interior surface; the tubes, however, contained many chips from the blasted areas.

All such damaged areas were scraped smooth and shellacked (F). One-half-inch aluminum pins (G) were inserted in the drilled holes and used to align the shield rings. Fifteen such holes were repaired. Since the repair work was completed little or no sparking that could be attributed to the damaged textolites has occurred.

4. Targets - Reported by R. R. Weeks

The electrostatic beam shutter at the output of the 90 analyzer has been used for a few weeks. Its operation has been quite satisfactory.

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FIGURE 2
SECTION OF TEXTOLITE TUBE

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B 6

The targetry on the near 25° west target post has been disassembled and the components used for the new target assembly farther out the 25° west beam line. A new rotary target assembly has been constructed and installed, vacuum and electrically tested on the near 25° west target post. Final mechanical alignment is necessary before this target may be used.

5. 90° Analyzer - Reported by R. R. Weeks

Attempts to pass currents in excess of one microampere through the analyzer were continued, consuming some five weeks of machine time, protons being available for about two weeks of this time.

The analyzer was set up and several times rechecked following the procedure given in ANL-5273. Currents up to 10 μ a were obtained but with complete unreliability. Slit widths corresponding to resolving power $\sim 1:3000$ were used. Beams of $\sim 5 \mu$ a were obtained for 30-minute periods but not of sufficient reliability to be of any use. A description of some of the difficulties follows.

Even a small fraction of the entering beam must be prevented from hitting the analyzer plates because the secondary currents caused by it disturbs the accuracy to which the potential between the plates can be held. In many cases this effect drives the Van de Graaff out of control. Some of the conditions that may cause the beam to strike the plates are:

- 1) improper alignment of the entering beam,
- 2) too great an angular divergence of the beam,

3) insufficient collimation of the beam or fluctuations of the beam energy,

4) changes in the potential between the analyzer plates.

Even after following the alignment procedure mentioned earlier, perturbations of the entrance angle of rather wide latitude ($\pm .060''$ at the object slit) were found and investigated with erratic results. A single quadrupole focussing magnet permitted increased beam intensity through the object slit but gave more erratic results because of beam current hitting the analyzer plates more often.

Rapid beam energy excursions are always present in the Van de Graaff machine due to a variety of causes and are not completely controllable. During the period of the above tests we were plagued with fluctuations of the beam current that produced corresponding fluctuations of its energy. This erratic behavior was subsequently traced to flickering of the R F ion source and has been somewhat subdued. Energy jitter of this kind may be minimized with the aid of the momentum selector magnet and sufficient collimation. Although not thoroughly investigated this collimation gives good results where beams of $1 \mu\text{a}$ or less are used. Another source of energy fluctuations finally prevented further work on this project, namely, the breakdown of the main support textolites.

A fourth cause of erratic behavior was investigated by checking the stability of the analyzer's power supply and equality of the positive and negative potentials. Balance of positive and negative potentials appeared to be non-reproducible. All components in the analyzer power supply were cleaned and thoroughly tested for leakage and coated with

silicone surface-insulating grease where required to further minimize corona. The unbalance amounted to as much as .75 KV in 10 KV. The power supply utilizes two half-wave rectifiers in opposite directions supplied by a single HV AC winding. Saturable reactor control is used on the primary of the HV transformer. Normal operating adjustments in the saturable reactor produce changes in the positive and negative peaks sufficiently different to give the observed imbalance of the two outputs. These two outputs have been placed in series without connection to the junction. The midpoint is now determined by the meter-multiplier bleeder resistor stack which is stable with time.

Considerable work has been done inside the Van de Graaff machine including repairs on the textolites, adjustments on the ion source and replacement of the focus assembly. It is hoped that better results may be obtained with increased beam energy stability. Work has been resumed at 2.5 to 4 μ a of protons on the lithium target. Li^7 (p,n) thresholds have been measured and a narrow bismuth total neutron cross section resonance is to be traversed in order to obtain an experimental check on the energy resolution of the protons which have passed through the analyzer.

6. Operational Experience - Reported by Jack Wallace

During this period (May 7 to July 30 inclusive) the Van de Graaff generator has been operating at various energies up to 3.0 Mev and with proton beam currents up to 12 microamperes.

The time distribution for various experiments was as follows:

1. Proportional counter testing	Perlow	15.3 hours
2. 90° analyzer	Weeks, Hibdon, Wallace	61.7
3. Magnetic spectrometer	Holland, Mooring	45.7
4. Li-plate irradiations	J. Roberts	<u>12.6</u>
Total		135.3 hours

Time available 59 days x 8 hours	472.0 hours
Start up time and daily maintenance	29.5
Set up time and experimental equipment breakdown	55.2
Machine out of operation	252.0

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

1. Analyzer trouble - Reported by R. R. Weeks	24.0 hours
2. Textolite damage - Reported by F. P. Mooring	196.0
3. Needle valve trouble	16.0
4. New ion source	16.0

The failure of the brass needle valve to give the proper flow of H_2 gas to the ion source caused a loss of time. A possible solution to the problem was to construct a needle valve using different materials. A stainless steel valve body with an aluminum needle seat is now being constructed.

A new ion source was installed to replace the one which had been in use for ~ 500 hours. The old one gave insufficient beam currents.

cell, its gas supply system and its pumping system. Also, special entrance and exit slit arrangements for the 25° analyzer have been designed and drafted. These are to be adjustable as to slit width with an accuracy of $\pm 2 \times 10^{-4}$ inches and permit measurement of beam current incident on each slit jaw. A special mounting of the jaws has been designed to minimize the effect of heating on the slit width.

The shop has completed work on the cold traps and analyzer support framework. The gas cell support framework and special slit arrangements are under construction.

In the original planning for the experiment, a McLeod gauge was to be used to measure the pressure of the stopping gas. Now it is planned to use an alphasatron gauge instead and thus to realize a considerable saving of time in the taking of data. A McLeod gauge will be used to calibrate and check the alphasatron.

In the next quarter, shop work and other preparations for the experiment are likely to be completed and some stopping cross section measurements taken.

20-7

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

Robert E. Holland, David R. Inglis, F. P. Mooring
Reported by David R. Inglis

The proton beam became available again only a couple of days before the end of the quarter. The results on the reaction $\text{Be}^{11}(p, \alpha) \text{Be}^8$ will be included in a later report.

30-7

Scintillation Coincidence Spectrometer

(5211-01)

S. Bradley Burson

The new crystals have been packaged as described in the previous report and are ready for use. The method of combining the outputs from the two probes into a single signal has not as yet been tried since the necessary electronic circuits are not yet available.

To facilitate work in Building 330, a new table has been constructed which is provided with wheels for mounting the probe assemblies with their associated shielding.

Shortly before the shutdown at the Palos Park site, crude temperature tests showed that while some improvement had been made by enclosing the voltage reference tubes in a constant temperature oven, there is still drift in the energy calibration with changes in room temperature.

31-7

The 1.42-Minute Isomeric State in $^{192}_{77}\text{Ir}$

(5211-01)

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

At the April, 1954 Physical Society meeting at Washington, investigators from the Los Alamos Laboratory reported the results of their work on this radioactivity. They attribute the low-energy radiations associated with this isomer to Bremstrahlung caused by the intense emission of internal conversion electrons. If this result can be confirmed by the preparation of thinner sources of iridium, further investigation at this laboratory will be abandoned. These tests cannot be made until the "fast" irradiation facilities at the new reactor are made available.

45-4 The Short-Lived Activities of Zn (5211-01)

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

A report on this study is being written and will be submitted to the Physical Review.

46-4 The Decay of $_{32}\text{Ge}^{77}$ (12 hour) and $_{32}\text{Ge}^{77\text{m}}$ (52 sec) (5211-01)

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

No further experimental work has been carried out. The results have been written up and will be presented for publication in the Physical Review.

47-3 The Decay Scheme of 30-min Pt^{199} (5211-01)

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

A report on this study is being prepared and will be submitted to the Physical Review.

48-2 The Decay of $_{22}\text{Ti}^{51}$ (5.8 min) (5211-01)

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

Further examination of the normal gamma-ray spectrum disclosed the presence of an additional weak transition of 0.61 Mev. Gamma-gamma coincidence measurements showed this radiation to be in

cascade with the 0.32-Mev radiation. The search for coincidence between the 0.32 and the 0.92-Mev gamma-rays yielded no counts above the random rate. These results alone suggest the presence of two excited states in V^{51} , one at 0.320 and another at 0.92 Mev. From the corrected scintillation spectrum, the intensities of the 0.32, 0.61, and 0.92-Mev gamma-rays are estimated to be 100:1:5, respectively.

Beta-gamma coincidences were observed between the 0.92-Mev gamma-ray and beta rays. An aluminum absorption experiment on the latter resulted in a half-value thickness of 95 mg/cm^2 corresponding to an end-point energy of about 1.8 Mev. This result is compatible with the energy levels suggested in the previous paragraph as well as the beta-gamma measurements reported earlier in which the beta rays feeding the 0.32-Mev gamma-ray were shown to have an energy of about 2.3 Mev. The 0.61-Mev gamma-ray is too weak to permit reliable beta-gamma coincidence measurements.

The total decay energy is thus estimated to be about 2.7 ± 0.2 Mev. The proposed decay scheme is indicated in Figure 3.

The results of this study have been written and presented to the Physical Review for publication.

51-7 Characteristics of a Scintillation Spectrometer (5211-01)

Bernard Hamermesh and Arthur Recksiedler
Reported by Arthur Recksiedler

The crystal spectrometer has been placed in position at the reactor CP-5. A beam strength of 2.0×10^7 neutrons per sq. cm.

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B.G.

per sec is being used.

A new amplifier circuit has been built which includes a mercury switch pulse generator to eliminate difficulties in determining the zero point in energy calibration.

Variations in shielding arrangements are now being made to minimize the overall background counts being recorded by the crystals. The 3-1/2-inch crystal is placed upright in the shield approximately 10 inches directly below the beam. There are also positions in the shield where two two-inch NaI(Tl) cubes may be placed in a horizontal plane with the neutron beam.

52-7 (Capture Gamma-Ray Spectra Using a Scintillation Spectrometer) (5261-02)

Bernard Hamermesh and Arthur Recksiedler
Reported by Arthur Recksiedler

No further measurements have been made during this period.

60-6 7.7-Meter Bent Crystal Spectrometer (5261-02)

Bernard Hamermesh and David Rose
Reported by David Rose

During this quarter, the crystal table drive and the interferometer were completed. The interferometer has been adjusted and a preliminary check shows its operation to be satisfactory. The crystal table drive still requires some final adjustment to be made for

smoother operation, but otherwise gives the required performance.

The lead collimator has been virtually completed and the track sections should be finished in several weeks. The latter have provided some preliminary experience with the radius generating fixture originally designed for use on the crystal clamp blocks. The crystal clamp blocks should be completed in the next quarter and the quartz crystal which is presently expected in October should be bent. Also, all shop work is expected to be completed and the instrument fairly well assembled during the coming quarter.

70-7

Measurements of Nuclear Moments by Angular Correlation

(5211-01)

Victor E. Krohn and Sol Raboy
Reported by Sol Raboy

During the series of measurements to determine the gyromagnetic ratio of the 3×10^{-7} -sec isomeric state of Pb^{204} a third gamma-ray was found in coincidence with the two well-established gamma-rays. The separate measurement which confirms the existence of this third gamma-ray of about 900 kev was described in a letter submitted for publication in the Physical Review.

An article on the determination of the gyromagnetic ratio of the 3×10^{-7} metastable state in Pb^{204} is being prepared for publication and will be submitted soon to the editor of the Physical Review.

In the past quarter, a study of Ta^{181} was undertaken. Hf^{181} β -decays to an excited state of Ta^{181} which decays by successive γ emission to the ground state of Ta^{181} . The cascade studied was a 132-kev

gamma-ray followed by a 480-kev gamma-ray. The 480-kev excited state is an isomeric state with a half-life of 10^{-8} sec. The gyromagnetic ratio of this state was determined to be $+1.20 \pm 0.12$ nuclear units. The details of the experiments are described in a letter submitted to the Physical Review for publication.

The W^{187} to Re^{187} decay¹ is the next scheme to be studied. W^{187} decays to Re^{187} by several β -decays. In one particular branch the excited state of Re^{187} decays by the emission of a 480-kev gamma-ray followed by a 70-kev and 132-kev gamma-ray. The 480-kev transition terminates in a metastable state which has a half-life of 5×10^{-7} sec. The angular correlation of the 480-kev and 132-kev in delayed coincidence is the goal for the next quarter. Results up to now indicate either a very small anisotropy or none at all. More work on this scheme will be done next quarter.

The counter apparatus used for these experiments is being made automatic. This will be completed in the next quarter.

It is also planned to study some alpha-gamma coincidence. Novey² has studied the α - γ correlation in Am^{241} . The gamma-ray is 60 kev and is the result of a transition from an excited state with a half life of 6×10^{-8} sec to the ground state of Np^{237} .

1. F. K. McGowan, Phys. Rev. 93, 471 (1954).

2. Preprint of article submitted to Physical Review.

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

It was previously reported¹ that the atomic beam magnetic resonance method has been used to measure the nuclear spin of the 3.1 hr $\text{Cs}^{134\text{m}}$ isomer. A spin of 8 (in units of $\hbar$) was unambiguously established. Further measurements were made on resonances of the $[F = I + 1/2, m_F = -F \longleftrightarrow F = I + 1/2, m_F = -(F - 1)]$ type at progressively higher fields in order to determine the hyperfine structure separation and the nuclear moment of $\text{Cs}^{134\text{m}}$. These transitions are listed in Table I along with the corresponding ones in stable Cs^{133} , the latter being used to measure the magnetic field. In general, each frequency value is an average of the results of two experiments. The widths of the resonance curves at half-maximum were of the order of 100 Kc/sec.

The hyperfine structure separation ($\Delta \nu$ in Mc/sec) can be shown to be related to the low field transition (ν in Mc/sec) of $\text{Cs}^{134\text{m}}$ by:²

$$\Delta \nu = \frac{(\nu - g_I K)(g_J K - \nu)}{\left[\nu - g_I K - \frac{(g_J - g_I) K}{2I + 1} \right]}$$

where $K = \frac{\mu_0 H}{h}$ (μ_0 is the Bohr magneton, H the field in gauss as measured by observing the corresponding transition in Cs^{133} , and h is the Planck's constant). g_I and g_J are the nuclear and electronic g-factors,

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1. Dalman, Goodman, and Wexler, ANL-5317.
 2. Luther Davis, Jr., Thesis, MIT (1948).

respectively, and I the nuclear spin (in $\hbar$). The nuclear g -factor was calculated from an approximate estimate of the hyperfine structure separation as 7.5×10^{-5} ; g_J was taken to be 2.00238. Inspection of the above relation shows that the value obtained for $\Delta \nu$ depends on the sign of g_I and thus on the sign of the nuclear moment. Values of $\Delta \nu$, however, would be expected to be independent of ν only for the correct sign of g_I . Consequently, the consistency of the $\Delta \nu$ values is an indication of the sign of the nuclear magnetic moment. In columns 3 and 4 of Table I are collected the calculated $\Delta \nu$'s for g_I taken as negative and positive, respectively. Since the hyperfine structure separations calculated on the assumption of g_I being negative are more consistent than those for g_I of opposite sign, the magnetic moment of $\text{Cs}^{134\text{m}}$ appears to be positive. The result is in agreement with the shell model calculations of Dieter Kurath of the Physics Division. Our best value for $\Delta \nu$ is seen from the table to be 3684.3 ± 0.5 Mc/sec. The magnetic moment of $\text{Cs}^{134\text{m}}$ as calculated from the Fermi-Segre relation is then $+1.10$ nuclear magnetons.

A letter entitled "Nuclear Spin and Magnetic Moment of 3.1 hr $\text{Cs}^{134\text{m}}$ " appeared in *Physical Review* 95, 570 (1954).

The radiofrequency apparatus necessary for determining the hyperfine structure separation of $\text{Cs}^{134\text{m}}$ directly has been assembled and is undergoing tests.

Preliminary work required for the measurement of the spin and magnetic moment of 50-day $\text{In}^{114\text{m}}$ is under way. A new oven capable of operating properly at the high temperatures necessary has been constructed. The deflection pattern of an inactive In beam is under study.

Table I
Observed Resonances and Calculated $\Delta\nu$
of $\text{Cs}^{134\text{m}}$

(all values in Mc/sec)

$\nu_{\text{Cs}^{133}}$	$\nu_{\text{Cs}^{134\text{m}}}$	$\Delta\nu_{\text{Cs}^{134\text{m}}}$ for g_I negative	$\Delta\nu_{\text{Cs}^{134\text{m}}}$ for g_I positive
9.365 $\pm$.010	4.480 $\pm$.015		
17.218 $\pm$.010	8.293 $\pm$.020		
43.940 $\pm$.010	21.934 $\pm$.020		
90.937 $\pm$.010	48.403 $\pm$.010	3681 $\pm$ 5	3698 $\pm$ 5
164.105 $\pm$.030	97.140 $\pm$.025	3682 $\pm$ 1	3689 $\pm$ 1
282.845 $\pm$.020	201.666 $\pm$.020	3684.3 $\pm$ 0.5	3695 $\pm$ 0.5

90-7

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

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

Construction and trouble-shooting have continued from the past quarter. The modification of the pressure tank has been completed and it is now considerably easier to gain access to the ion source.

The new R F ion source has been installed and is now in satisfactory operation. Focussed deuteron beams of about 200 microamperes are easily obtained.

The pumping of the vacuum system has been improved by the installation of a new high-speed oil diffusion pump with more adequate water-cooled baffling.

91-7

Neutron Transport Cross Sections; Angular
Distribution of Scattered Neutrons (5261-02)

Raymond O. Lane and Alexander Langsdorf, Jr.
Reported by Raymond O. Lane

The apparatus for the experimental study of the angular distribution of scattered neutrons has been completed and is ready for preliminary tests. The arrangement consists of five neutron detectors spaced at approximately 30-degree intervals around a semicircle. The apparatus was described in some detail in the previous quarterly report, ANL-5317.

The efficiency of each of the five detectors was measured with a calibrated Ra-Be source (mean energy approximately 5 Mev) placed at the position occupied by the center of the scattering sample. The resulting efficiency was 15% for the arrangement of counters used inside the detector. Since extended scattering samples and extended detectors are employed here to obtain reasonable statistics in counting, the counting rates observed must be interpreted in terms of the mean angle of scattering as "seen" by each detector rather than the nominal value of the angle of the center line of the detector. The detectors have been set in place with center lines at the following angles to the forward direction of the beam; $22^{\circ} 18'$, $54^{\circ} 4'$, $91^{\circ} 40'$, $112^{\circ} 25'$, and $143^{\circ} 54'$, with the first three observing in transmission and the last two observing in reflection. For these nominal angles J. Monahan of this division has calculated mean scattering angles which represent the largest possible deviations from the above nominal angles together with the maximum rms deviation from the

mean. They are; $26.54^\circ \pm 5.39^\circ$, $55.43^\circ \pm 4.98^\circ$, $91.23^\circ \pm 5.61^\circ$, $112.83^\circ \pm 2.43^\circ$, and $143.70^\circ \pm 2.39^\circ$, respectively.

Currently the rotating lithium target serving as the neutron source is being assembled after being modified to fit the new space and performance requirements. Upon satisfactory testing of the rotating target, preliminary measurements of angular distributions will be made.

98-6 Total Neutron Cross Sections in the kev Region (5211-01,
5261-02)
Alexander Langsdorf, Jr.

This program has been so successful that we plan to improve the technique for greater precision. Several sources of error are now well understood and can be better controlled by building new equipment.

A crucial part of the improvement is to stabilize the proton beam energy more closely. Among the items needed in this part of the improvements are: an improved resistor-divider for the electrostatic analyzer voltage, accurate to 0.002% if possible, and with several voltage taps instead of but one as on the present divider. Also needed is a better potentiometer; one is on order that is rated as five times as precise as our present one. Finally, we intend to add a shunt type vacuum tube voltage regulator system designed to control only through a narrow range ($\sim 1\%$) within which the beam passes through the analyzer without hitting either deflecting plate. (We now know that if beam hits either plate, the voltage on the plate must be allowed to drop until steps are taken to shut off the beam (as by a shutter), because the large secondary ion emission from the plates on bombardment by the beam prohibits maintaining voltage when this happens.)

Another part of the improvement will be by building identical dual collimator-detector systems receiving neutrons at equal angles to the proton beam direction. The transmission samples will be placed alternately in front of one, then the other, detector. This system will minimize many sources of systematic error and decrease statistical errors by better use of the time available for taking data.

102-4

Neutron Cross Section Measurements by the Self-Indication Technique (5211-01)

Alexander Langsdorf, Jr., J. M. Monahan, L. A. Turner
Reported by Alexander Langsdorf, Jr.

1. Poor Resolution

One of the purposes of the self-detection technique is the exploration of a wide energy region rapidly with poor resolution in order to determine whether there is interesting structure within this region. Since the method cannot concern itself with fine details of the scattering resonances within this resolution interval, it is unnecessary to introduce such details in a theoretical treatment of the method. Thus we assume that the scattering cross section as a function of energy is given by a series of equally spaced resonances, each of the same height, i. e. ,

$$\sigma(E) = \frac{\sigma(r)}{4} \sum_{j=-\infty}^{\infty} \left[(E - jD)^2 + \Gamma^2/4 \right]^{-1} + \sigma_p .$$

For all but S-resonances, or for very broad resonances, $\sigma(r)$ is approximately the "peak" cross section at resonance; D is the separation between resonances, and σ_p is the potential scattering cross section. Carrying out the formalism described in a previous report of this title,

we obtain

$$\begin{aligned}\sigma_a &= \frac{\pi}{2} \frac{\Gamma}{D} \sigma^{(r)} + \sigma_p \\ \overline{\Delta \sigma^2} &= (\sigma_a - \sigma_p)^2 \left[\left(\tanh \frac{\pi \Gamma}{D} \right)^{-1} - 1 \right] \\ \overline{\Delta \sigma^3} &= (\sigma_a - \sigma_p)^2 \left[\left(\tanh \frac{\pi \Gamma}{D} \right)^{-2} + 1/2 \left(\sinh \frac{\pi \Gamma}{D} \right)^{-2} - 3 \right. \\ &\quad \left. \left(\tanh \frac{\pi \Gamma}{D} \right) + 2 \right]\end{aligned}$$

Thus a measurement of these quantities would result in obtaining the parameters $\sigma^{(r)}$, σ_p , and Γ/D .

2. Good Resolution

The nature of the self-indication technique suggests the possibility of obtaining more exact measurements of the resonance parameters for levels which are otherwise unresolvable. In order to investigate this possibility, let

$$\delta = |E_2 - E_1| > \Gamma$$

where δ is the energy resolution of the incident neutron beam. The shape of the single resonance is given by

$$\sigma(E) = \frac{\sigma^{(r)}}{k^2 + 1} + \sigma_p$$

where

$$k = \frac{E - E^{(r)}}{1/2 \Gamma}.$$

$E^{(r)}$ denotes the neutron energy at resonance. In this case

$$\begin{aligned}\sigma_a &= 1/2 \frac{\Gamma}{\delta} \sigma^{(r)} T + \sigma_p, \\ \overline{\Delta \sigma^2} &= 1/2 \frac{\Gamma}{\delta} \sigma^{(r)^2} \left\{ \frac{\Gamma/\delta}{1 + \Gamma^2/\delta^2} + 1/2 T - 1/2 T^2 \frac{\Gamma}{\delta} \right\}\end{aligned}$$

where

$$T = \tan^{-1} \frac{2\Gamma\delta}{\frac{\Gamma^2}{\delta^2} - 1}.$$

If, now, it is possible to carry out the measurement of σ_a and $\overline{\Delta\sigma^2}$ for two different known values of δ , say δ_a and δ_b , without including a new level within the resolution energy, then the ratio of the two measured values of $\overline{\Delta\sigma^2}$ depends only on the level width Γ and the known values of δ_a and δ_b . With Γ known, the "peak" cross section, $\sigma^{(r)}$ and σ_p can then be obtained from the measured values of σ_a .

Another possible use of this technique is the determination whether a broad resonance is actually a single resonance or a combination of two or more unresolved resonances. This aspect of the method is now being investigated.

108-1

An He^3 Neutron Spectrometer

Frank Lynch

It is proposed to build a small proportional counter containing He^3 at high pressure, about 20 atmospheres, for neutron energy measurement using the He^3 (n,p) T reaction. Preliminary tests on the performance of He at this pressure will be made using a large proportional counter, now available, filled with He^4 .

110-7

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

Sol Raboy and G. R. Ringo
Reported by G. R. Ringo

The spectrometer has been moved from CP-3 to CP-5 but not set up. It needs fairly elaborate new shielding because of the high fluxes of CP-5. This has been designed and is now being made in the shops.

114-7

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

Gilbert J. Perlow

The double-proportional counter method discussed in the two preceding reports has been tried with fair success. Using monochromatic neutrons from $\text{Li}^7(p,n)\text{Be}^7$ at the Van de Graaff generator, pulse height distributions were obtained at neutron energies of 100, 200, 350, 400, and 500 kev.

The distribution at 100 kev showed a considerable admixture of accidentals, a result anticipated considering the circumstances of the test. At 200 kev, a good peak of width 14% at half maximum was obtained with but slight accidental contamination. The width was 24% at 350 kev for reasons probably associated with electronic drift. Accidentals were negligible at this and higher energies.

At the counter pressure used (3.7 cm Hg of CH_4), the diameter of each of the counters is equal to the range of a proton of ~ 370 kev. For neutron energies above this, but less than that corresponding to two counter diameters (550 kev), one may expect an asymmetric

broadening of the lower energy portion of a line. This was observed at 400 and at 500 kev. At 400 kev the right hand (i. e., higher energy) half width at half maximum was 8% and the left hand 12%, while at 500 kev the corresponding numbers were 6% and 25%. At higher energies (not tried) the pulse height spectrum should bear little resemblance to the neutron spectrum.

There have been three ideas for getting rid of the effects of the above phenomenon ("fold-over"), which date back to the inception of the idea for the spectrometer. The first idea is to use a third counter after the second, so that a recoil, which would otherwise expend energy in the wall, may enter the third counter and the entire event be discarded by anti-coincidence. This scheme is difficult to put into practice, since any construction which distorts the electric field in the second counter will spoil the additive properties of the pulses from the first and second counters. It may yet be tried, however. The second idea involves only the original two counters but with an electronic selection of the ratio of the individual pulse height for an acceptable event. Thus, for example, if the pulse from the first counter (i. e., the one closest to the neutron source) is required to be equal to or greater than that from the second, the fold-over should be removed (and the efficiency roughly halved). This has been tried, but due to a circuit defect was not successful. Improved circuits are being developed. The third method consists in varying the counter pressure or in having a multiplicity of units at different pressures. This latter is being attempted. Although the efficiency for a desired group is independent of the pressure to first order, the multiplication at a given voltage and hence the

energy scale is not, and considerable cross calibration is necessary.

When the device is used for reactor spectrum measurements, an absolute energy scale is required. Because of the low pressures used, such devices as internal α sources, x-rays, etc., are not expected to be successful. The idea at present is to calibrate by means of scattering resonances, doing a transmission measurement on certain chosen scatterers with the reactor beam as source.

115-3 Boron Trimethyl (5211-01)

Louis Basile

Approximately 20 liters of boron trimethyl, enriched with isotope B¹⁰, were obtained from Alexander Langsdorf for purification of the gas. After several attempts to purify the gas by fractional condensation it became evident that the impurity forms a stable complex with boron trimethyl and could not be removed by this technique. It is suspected that one of the impurities is diethyl ether. The method decided upon for purification, therefore, was to form an amine complex with boron trimethyl, remove all of the impurities, and finally recover the purified gas by dissociating the amine complex.

Preliminary work seems to indicate that pyridine may be the amine to use for formation of the amine complex. Separation of the pyridine from boron trimethyl seems to be more easily accomplished than it is with triethyl amine. Work along these lines appears very promising. When a method of purification is fully developed we may have to build a large capacity system to handle the large volumes of gas that are involved.

120-7 (Calculation of a Ra-Be Neutron Source)

This program has been discontinued.

133-6 Accelerator Project (5211-14)

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

Members of the Midwest Accelerator Conference met in Madison for two months, June 21 - August 14, for concentrated study of accelerator problems. E. A. Crosbie worked with the group throughout the summer, while M. Hamermesh spent 3 weeks with the group. A paper entitled "Coupling of Betatron and Phase Oscillations in a Synchrotron", by E. A. Crosbie and M. Hamermesh is being issued as a MAC report. This paper treats the coupled oscillations by use of difference equations. It also gives a simple treatment of the adiabatic variation of parameters for systems of linear differential or difference equations.

135-6 Electron-Neutron Interaction (5211-01)

G. R. Ringo

A measurement of the coherent scattering amplitudes for neutrons of krypton and xenon is to be made by reflection of neutrons from the surface of liquified krypton and xenon. The apparatus for this measurement was built in February (1954). In the past quarter some improvements have been made in the vacuum plumbing and other mechanical features of this apparatus.

140-3

A Gaseous Scintillation Counter (5211-01)

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

The gas cell with two photomultiplier tubes whose pulses are added has been operated successfully. For still greater efficiency in light collection, a cell using six DuMont multiplier phototubes has been built. The associated electronic circuitry is now being tested.

It has been found that the poisoning effect of the plastic color shifter is reduced if the window is machined out of solid polystyrene containing tetraphenylbutadiene.

A paper on this subject, Phys. Rev, 95, 600 (1954), was presented at the April meeting of the American Physical Society.

We applied for a patent on the gas scintillation counter.

141-1

Uranium Fluorescence Photometer (5211-13)

Frank Lynch

An instrument is described for microanalytical analysis by a fluorescence method. It is sensitive, linear, and stable. Both an unknown and a reference sample of the same constitution are excited to fluorescence by ultraviolet light emitted in pulses by an ac-powered mercury arc lamp. The resulting pulsed fluorescent light from each sample is incident on a separate vacuum phototube. The ratio of the fundamental ac components of the photoelectric currents flowing in the two phototubes is measured automatically by a servo-mechanism. In such a system, the measurement is independent of the intensity of the exciting

ultraviolet light, the thermionic currents of the two phototubes, and the temperature of the fluorescent samples. A simplified optical system provides good efficiency. Either solid or liquid samples may be rapidly measured. For uranium analysis the instrument may be calibrated to read full scale for $5 \cdot 10^{-1}$, $5 \cdot 10^{-9}$, $5 \cdot 10^{-8}$, and $5 \cdot 10^{-7}$ gram of uranium. Although it is designed primarily for uranium analysis, the filters may be changed to permit measurement of other materials which can be analyzed by fluorescence methods.

A large amount of time has been spent on amplifier instability in the third instrument which manifests itself as a long term drift of about 2%. This has not been encountered previously and it has been difficult to ascertain the cause.

A report has been completed and is undergoing unclassification. It will be submitted to the Rev. Sci. Instr. for publication.

142-1 Electron Accelerator (5211-13)

H. Bruce Phillips, Robert K. Swank, Warren L. Buck
Reported by Robert K. Swank

Although this program did not originate this quarter, it has not been previously described in any publication. It may therefore be appropriate to summarize briefly its objectives.

The electron accelerator is designed to be used for excitation of scintillators in place of nuclear particles (beta or gamma), for making measurements of the properties of the scintillators. For this purpose the accelerator has two distinct advantages over nuclear particles:

(1) The time of occurrence of the pulse can be exactly synchronized with the recording apparatus.

(2) The magnitude of the pulse (which contains many particles) can be made manyfold larger than the magnitude of the pulse from an individual nuclear particle.

Although the accelerator will be used for the measurement of various properties of scintillator, e. g., efficiency, spectra, and decay times, the measurement of decay times of fast scintillators places the most stringent requirements on the apparatus. The following is a summary of the requirements which should be fulfilled by the machine now under construction:

1. Minimum pulse width:	10^{-10} second
2. Peak current:	10^{-5} ampere
3. Maximum electron energy:	125,000 ev
4. Total energy in minimum width pulse:	750 Mev
5. Maximum repetition rate:	1000/sec
6. Exit window thickness:	5×10^{-5} inch
7. Approximate energy loss in window (at full energy)	4000 ev

The pulse is generated by sweeping the cathode ray beam across a narrow slit. This is done at low electron energy. Once through the slit, the electrons are accelerated by a series of electrodes to the full potential and are subsequently brought to a sharp focus on the exit window. The electron gun and sweep generator are isolated at negative high potential and the exit window is at laboratory ground potential.

As of the end of this quarter, the mechanical parts of the accelerator tube are completed, together with the voltage divider for supplying the accelerating electrode potentials. The vacuum system has been completed and tested. The high voltage power supply, parts for which were obtained from L. Goodman of this division, has been assembled. The overall housing and framework is complete except for one panel through which the operator will be able to view the high voltage assembly. The isolated "hot" circuitry cage is made, with appropriate corona rings. A new sweep circuit has been built for use with a type "5 x P" cathode ray oscilloscope which was previously built. The sweep and oscilloscope will be used for displaying the scintillation pulses on a linear time base. The four fastest sweeps (10, 20, 50, and 100 m μ sec/cm) have been calibrated and the linearity is satisfactory. A new camera mount has been designed and is now in the shop. This will be used in the photographing of oscilloscope traces in the collecting of decay time data. The main pieces of apparatus yet to be designed and built are:

1. A master pulsing circuit for synchronizing various parts of the apparatus.
2. A sweep and grid gate generator for the electron gun, to be operated in the "hot" cage.
3. A 215-kev coupling condenser for sending the synchronizing pulse into the "hot" cage.
4. D. C. supplies for the electron gun.
5. A current supply for the focussing magnet.
6. A photomultiplier housing.

7. A pulsed photomultiplier supply.

8. A pulsed oscillator for calibrating the oscillograph sweep.

The last three items are not essential to the testing of the machine, since substitute equipment already exists. They will be essential, however, for obtaining the best performance of the apparatus.

143-1 Plastic Scintillators (5211-13)

Louis J. Basile and Warren L. Buck
Reported by Louis J. Basile

Our present work in the development of plastic scintillators falls into three main categories: (1) the investigation of new plastics other than the conventional vinyl toluene or styrene, in the hopes of obtaining increased light output and improved efficiency as other desirable quantities; (2) the preparation of plastics loaded with heavy elements for increased counting efficiency for gamma-rays, and (3) the preparation of boron-loaded plastics for the detection of thermal or epi-thermal neutrons.

During the past quarter no work has been done in the first category.

For preparing plastics loaded with a heavy element, vinyl iodide, CH_2CHI , appears to be a desirable compound to use since it contains a double bond and a heavy element. A small amount of vinyl iodide was obtained and samples were prepared in an attempt to co-polymerize this substance with styrene or vinyl toluene. The samples are still in the constant temperature bath undergoing polymerization and

as a result have not as yet been tested. During the first two weeks of polymerization it was observed that the samples that contained 1% vinyl iodide polymerized much more readily than samples which contained 10%. This may be due to the decomposition of vinyl iodide, forming iodine or hydrogen iodide which would inhibit polymerization. When the samples become completely polymerized, they will be tested. More vinyl iodide has been ordered to continue this phase of the work.

In attempting to prepare boron-loaded plastic oscillators, decaborane, $B_{10}H_{14}$, appears to give the most promising results. Unfortunately our supply of decaborane has been exhausted. We received a crude product containing about 5% decaborane from the Callery Chemical Company and are in the process of recovering the substance. When an ample supply of decaborane is obtained this work will be continued.

Attempts were made to copolymerize diborane, B_2H_6 , with both vinyl toluene and styrene. Polymerization was very slow at low temperatures. At higher temperatures a reaction took place resulting in a dark brown solution. We have not been able to polymerize successfully vinyl toluene or styrene in the presence of diborane.

B-trichloroborazole, $B_3N_3H_3Cl_3$, was prepared by the reaction of ammonium chloride with boron trichloride. Samples were prepared containing various concentrations of B-trichloroborazole in vinyl toluene and styrene. After several weeks at polymerization temperature the solutions turned a milk-white color, indicating that this substance could not be used for our purpose. We do intend to try other substituted borazoles in future work.

Several samples of polystyrene containing approximately

2% by weight of tetraphenylbutadiene, and a single sample of polymethylmethacrylate containing 1% tetraphenylbutadiene, were prepared for possible use as "spectrum shifters" in connection with a gaseous scintillation counter under development by C. Egger and C. Huddleston.

144-1

Scintillation Counter Techniques (5211-13)

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

A light-tight assembly was designed for the new DuMont type 6363 (3-inch diameter) photomultiplier. This assembly is similar to those previously designed for the type 5819, 6292, and 6364 photomultipliers.

It provides for:

- (1) Excluding external light from the photomultiplier.
- (2) Ready attachment or removal of scintillators.
- (3) Electrical shielding of the photomultiplier.
- (4) Magnetic shielding of the photomultiplier.
- (5) Insulation of the envelope to prevent electrical

leakage through the glass when negative power supplies are used.

Fourteen photomultipliers were potted in light-tight assemblies and two cesium iodide crystals were canned during the quarter, aside from routine measurements of pulse height resolution and signal-to-noise ratio.

146-1

A Rotating Condenser Electrometer (5211-13)

Frank Lynch

The purpose of this development, as set forth in an earlier I. R. D. progress report, is to construct a dynamic condenser for converting an electric charge into an ac signal which will be superior to those in use and will be suitable for manufacture. A rotating condenser in vacuo is expected to be superior to a gas-damped vibrating reed in the following respects:

1. There is no ionization inside the envelope of the rotating condenser.
2. It is possible to evaporate coatings onto the condenser plates after the assembly is sealed and evacuated.
3. The conversion efficiency is largely independent of driving power.
4. By a suitable choice of number of poles of the driving motor and plates of the condenser plates the condenser can be driven with 60 cps power without generating a signal which is an harmonic of 60 cps.
5. The detector can be improved and simplified by the use of a commutator.

A model of the rotating condenser electrometer is nearly complete. It employs a stainless steel shaft with synthetic sapphire ring bearings and a tungsten carbide thrust plate. Mounted at the top of the shaft is a ten-plate rotor, and near the bottom of the shaft is a small permanent magnet. Driving torque is provided by a rotating magnetic field external to the evacuated envelope. All insulators are constructed of synthetic sapphire.

148-1

Electrical Conduction in Dielectrics (5211-13)

Raymond J. Munick

This is a continuation of a study of good electrical insulators, which was begun in the Instrument Research and Development Division and reported in ANL-5177 and ANL-5118 under the title of Insulators. The immediate objective is to obtain the characteristics of the currents observed in circuits containing specimens of Lucite, Fluorothene, polyethylene, polystyrene, and Teflon, to compare these characteristics with each other and with those that have been observed for other dielectrics.

The specimens are circular disks, 1/8 inch thick, 3 inches in diameter. In the current-measuring circuit a specimen appears as the dielectric of a parallel-plane capacitor with guard ring, having electrodes of evaporated aluminum. The primary purpose of the guard ring is to intercept flow of charge around the edges of the disks. Current from the guarded electrode (10^{-10} to 10^{-16} amp) flows through a multimegohm resistor connected across the input of a vibrating reed electrometer, the output of which is recorded on an Esterline-Angus milliammeter. The remaining electrode is either grounded or connected to batteries (300 to 2400 volts).

Preliminary measurements on Lucite have indicated a behavior similar to that of other dielectrics.¹ When a voltage is first applied, the

1. M. F. Manning and M. E. Bell "Electrical Conduction and Related Phenomena in Solid Dielectrics", Revs. Mod. Phys. 12, 215 (1940); A. F. Joffe', The Physics of Crystals, (McGraw-Hill Book Company, Inc. New York 1928); L. Hartshorn, "A Critical Resume' of Recent Work on Dielectrics", J. Inst. Elec. Engrs. (London) 64, 1152 (1926).

current at first decreases with time as t^{-n} , where n is about 1.1 for Lucite, but it eventually decreases more slowly to an almost steady value. If after sufficient time the voltage is removed and the third electrode grounded, the current at a given time after removal is equal in magnitude but opposite in direction to that at the same interval after application less the steady current. This reverse current decreases toward zero as t^{-n} . Successive voltage changes contribute additively to the current, in accordance with the so-called Hopkinson superposition principle. From 25 to 49° C there was no appreciable change in the time-dependent current for Lucite, but the steady current increased sixteen-fold.

The principal achievements of this quarter were to measure the time-dependent currents from liquid nitrogen to room temperature and the steady currents from 25 to 49° C for two specimens each of Lucite, Fluorothene, polyethylene, polystyrene, and Teflon.

With decrease of temperature below that of the room, there is no significant change in the exponent n for the time-dependent currents, but there is a noticeable change in the magnitudes. For polyethylene, polystyrene, and Teflon the time-dependent currents showed a general decrease with decrease of temperature. However, the time-dependent currents for Lucite and Fluorothene, which, respectively, are about one hundred and ten times greater than the others at room temperature, showed a four-fold increase to maxima in the neighborhood of -30 and -55° C, respectively. This unprecedented behavior is explicable in terms of the permanent electric dipoles indicated by molecular structure and by the frequency dependence of the permittivity and the magnitude

of the dielectric loss factor under alternating voltage. The ordering of the dipoles in the applied field induces the time-dependent current in the circuit. Increase of thermal agitation with temperature decreases the rate of ordering. Decrease of temperature increases the rate of ordering until such a low temperature is reached that the dipoles are "frozen in position" and ordering is hindered. Hence, the time-dependent current passes through a maximum as the temperature is lowered. Polyethylene, polystyrene, and Teflon, which show no signs of such a maximum, have a non-polar structure and are noted for their small dielectric loss factor and almost constant permittivity over an extremely wide range of frequencies.

The steady currents showed an exponential increase with temperature from 25 to 49° C, that is, the steady current is given by a relation of the form

$$I = I_{\infty} \exp (-W/kT),$$

where

W = activation energy,

k = Boltzmann's constant,

T = absolute temperature,

I_{∞} = steady current at infinite temperature,

I = steady current at temperature T .

If the currents are expressed as conductivities for the purpose of comparison, the values at room temperature are grouped in the neighborhood of 10^{-20} mho per cm, with Lucite nearer 10^{-19} .

The activation energies are summarized in Table II.

Table II

Activation Energies in Electron Volts	
Material	W
Lucite	1.157 ± 0.010
Fluorothene	0.694 ± 0.018
Polyethylene	1.121 ± 0.086
Polystyrene	0.718 ± 0.035
Teflon	0.810 ± 0.021
Values and standard errors were obtained by least squares adjustment of two sets of three points.	

Recently the same temperature dependence has been reported^{2,3} for Perspex, Polythene, and polytetrafluoroethylene, which are equivalent to Lucite, polyethylene, and Teflon, respectively. The respective activation energies reported by Fowler and Farmer² were 0.5, 1.5, and 1.1 electron volts, whereas Ramsey³ reported 0.5 for polythene.

Since this exponential dependence of current upon temperature is consistent with several mechanisms that have been found or suggested for conduction in dielectrics, further experiments are needed to tell whether the current is carried by electrons, holes, or ions.

2. J. F. Fowler and F. T. Farmer, *Nature* 173, 317 (1954); 171, 1020 (1953); 174, 136 (1954).

3. N. W. Ramsey, *Nature* 172, 214 (1953).

II. MASS SPECTROSCOPY

1-7 (Mass Spectrometric Techniques) (5211-08)

Mark G. Inghram

There are no results to report at this time.

2-7 Construction and Operation of MA-17 (5211-08)

Henry E. Stanton

During the last quarter further refinements in the mass spectrometer were introduced as follows:

A new pumping lead and pump were installed for the gas sample system so that the roughing pump was placed below the laboratory floor.

A new diffusion pump power panel with safety circuits and warm-up relays was constructed and installed. The diffusion pumps are now protected against power failure and subsequent restoration of service as well as two types of water failure, while pumping as continuously as possible.

A new control panel for the source was obtained from Electronics and installed. New cables from it to the source were installed providing shielding for several of the pick-up sensitive leads.

It is proposed during the next quarter to try baking our portions of the machine to reduce the background which is still high.

10-7 (A Search for Rare Naturally Occurring Isotopes) (5211-08)

David C. Hess

No elements have been "searched" this quarter. Time has been spent adjusting MA-16.

12-7 (Double Beta Disintegration of Te^{130}) (5211-08)

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

No progress has been made on this problem this quarter.

14-7 Fission Yield Determinations (5211-08)

Ellis P. Steinberg and Lawrence E. Glendenin (Chemistry Division), Richard J. Hayden, Mark G. Inghram
Reported by Mark G. Inghram

(Reports on this program have previously been classified and have appeared in the classified supplements to the quarterly reports. Of these the two latest are ANL-5274 and ANL-5175.)

The fission yields of the light group of fission products produced by slow neutrons in U^{233} have been studied. Fine structure is observed similar to that previously found in U^{235} . A similar peak is found on the high mass side at a mass value complementary to that of the heavy nucleus containing 82 neutrons (closed shell) as was found for U^{235} . A paper has been submitted to the Physical Review.

17-2 (Long-Lived Activities) (5211-08)

David C. Hess

Samples are being bombarded for this program.

29-1

Gaseous Species in Equilibrium with Metal-Metal
Oxide Systems (5211-09)

R. F. Porter and P. Schissel (University of Chicago),
Mark G. Inghram
Reported by Mark G. Inghram

The evaporating species in equilibrium with Al-Al₂O₃ in a Knudsen cell were identified and studied by the mass spectrometer. Intense ion current of Al₂O⁺ formed from gaseous Al₂O were observed. At T = 1750° K these ions were at least 1000 times as intense as all other ions attributable to other gaseous oxides. The results yield a value for ΔH_{298} of 259 ± 7 k cal/mole for the reaction $\text{Al}_2\text{O} (\text{g}) = 2\text{Al} (\text{g}) + \text{O} (\text{g})$.

A paper on this work has been submitted to the Journal of Chemical Physics.

30-7

The Heat of Vaporization of Carbon (5211-09)

William A. Chupka and Mark G. Inghram
Reported by Mark G. Inghram

The experimental work on the study of C, C₂, and C₃ effusing from a Knudsen cell has continued. The temperature variation of the vapor pressures of these species is being investigated as well as the vapor pressures themselves. From these data two independent values of the heat of vaporization of each of these species can be obtained.

The results reported in the previous quarterly report, ANL-5317, have been presented in a letter submitted to the Journal of Chemical Physics and scheduled for early publication.

31-7

Studies of Electron Impact

(5211-08)

William A. Chupka and Henry E. Stanton
Reported by Henry E. Stanton

During this period a number of runs were made on CO^+ , O^+ , C^+ , N_2^+ and Ne^+ to determine appearance potentials. The latter gas was used as a calibrating agent.

Generally, values obtained in the literature were found, although the measured value for CO^+ in these runs was about 3/4 volt below that found by Hagstrum (Rev. Mod. Phys. 23, 185 (1951)). Errors in the determinations for CO^+ were about 1/2 volt so the discrepancy appears to have no significance. The values obtained for C^+ and O^+ ions scattered somewhat more than for CO^+ and Ne^+ .

Appearance potential measurements were also made for C^+ and O^+ ions of varying initial kinetic energies by changing the ratio of the ion accelerating voltage to the electrostatic deflection voltage. If one plots the appearance potential vs the ion kinetic energy, the resulting straight line, when extrapolated to zero kinetic energy, gives the appearance potential for that ion at zero energy. This procedure substantially eliminates the effects of background ions, since they are generally formed at zero kinetic energy, i. e., thermal energies. This procedure was particularly helpful for O^+ where CH_4^+ , suspected as a contaminant, appeared to be present.

33-4 (Molecular States in Rare Gases) (5211-08)

David C. Hess

This program has been discontinued for an indefinite period and will not be reported on further until such time as it again becomes active.

34-7 Argon Age Determinations (5211-08)

Richard J. Hayden and G. J. Wasserburg (University of Chicago)

Reported by Richard J. Hayden

The work completed to date has been summarized in a letter to the editor of the Physical Review and in a paper to Geochemical et Cosmochemica Acta. The abstracts of these papers are the following:

A Lower Limit to the Age of the Universe

G. J. Wasserburg and R. J. Hayden

(Submitted to the Physical Review)

The ages of two stoney meteorites were determined by measuring the A^{40}/K^{40} ratio using an isotopic dilution technique. Using the branching ratio determined by the authors, the ages obtained were $4.82 \pm .20 \times 10^9$ and $4.57 \pm .20 \times 10^9$.

$A^{40} - K^{40}$ Dating

G. J. Wasserburg and R. J. Hayden

(Submitted to the Geochemical et Cosmochemica Acta)

The A^{40}/K^{40} ratios and the Pb-U ages of various coexisting potassium feldspars and uraninites were determined. It was found that

with a branching ratio $\lambda_e / \lambda_\beta = 0.085 \pm 0.005$ and a decay constant $\lambda = 0.55 \times 10^{-9}/\text{yr}$, the A^{40}/K^{40} ages could be brought into agreement with the Pb-U ages for samples ranging from 260 to 1860 m. y. No evidence was found for the loss of argon by diffusion from potassium feldspars.

35-3

(Studies of Negative Ion Emission)

(5211-08)

William A. Chupka and Henry E. Stanton
Reported by Henry E. Stanton

Nothing has been done on this subject pending improvements in the performance of the machine.

III. CRYSTALLOGRAPHY

1-7 (Crystal Studies of Technetium Compounds) (5211-11)

2-7 (Structural Studies of Boric Acids) (5211-11)

6-3 (Studies of Curium Compounds) (5211-11)

These programs will be reported on in the next quarterly
report.

V. THEORETICAL PHYSICS, GENERAL

1-7 Interpretation of the Energy States of Light Nuclei (5211-07)

David R. Inglis

Nuclear collective rotation properties which are sometimes associated with surface waves on a droplet of classical irrotational fluid have been derived from particle wave functions in a rotating non-spherical oscillator potential. Although this problem was first carried out as an extension of the nuclear collective vibration problem, by use of the adiabatic approximation in time-dependent perturbation theory in the laboratory system, it has been found neater to present it in an article to appear in the Physical Review as an equivalent stationary perturbation calculation in the rotating system as is customary in molecular theory. The rotational energy obtained with first-order nucleon wave functions is shown to be proportional to $J(J + 1)$, as observed, with the proportionality constant the same as obtained by the irrotational assumption in the droplet model. The observed proportionality constant is about one fourth as large, suggesting that a higher-order calculation would introduce a closer approximation to rigidity of the nucleus.

2-7 Excited States of Light Nuclei (5211-07)

Joseph M. Cook and Dieter Kurath
Reported by Dieter Kurath

From the point of view of time consumption there are evidently three major sections to the problem of doing the intermediate coupling calculation on the AVIDAC. These are:

1. Extraction of all possible energy matrix elements for a configuration of N nucleons in the $1p$ shell, where $N = 3, 4, 5, 6$.
2. Matrix multiplication with the wave functions of given (J, T) to obtain energy matrix elements classified according to these angular momentum and isotopic spin quantum numbers.
3. Solution of the secular determinants for every (J, T) for each N -nucleon configuration.

In this quarter the first step has been carried out for all N . The operations of the second step have been coded for the AVIDAC, tested, and the step was carried out for $N = 3$ and 4 . The operations involved in the third step have been done on the Oak Ridge Computer (ORACLE) and the code is being translated for the AVIDAC. This operation, which is diagonalization of a matrix and determination of eigenvalues and eigenfunctions, will be useful for other problems as well as the present one. The code has been translated by Ruth Freshour of the computer section, and is ready for testing on the AVIDAC.

4-7 Investigation of Nuclear Shell Structure (5211-07)

Maria Goeppert Mayer

Work on the "Unified Nuclear Model" has continued with no very significant results.

Some calculations concerning the β decay of K^{40} were undertaken. Since geologists are interested in the heating produced by this

decay, the ratio of neutrinos to electrons was determined.

5-7 Book on Nuclear Shell Structure (5211-07)

Maria Goeppert Mayer

The manuscript was checked by the staff editor of Wiley for corrections of the English. It was read again and checked. Some revisions were made and recent data inserted. Proof is expected soon.

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

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

A paper entitled "Collective Model of Giant Resonances" was presented at the Photonuclear Conference at the University of Pennsylvania on May 4, 1954. Other than this, the program has been inactive this quarter.

10-3 The Effect of Inelastic Scattering in the Analysis of Scattering Resonances (5211-07)

Morton Hamermesh and James E. Monahan
Reported by James E. Monahan

The calculation of the effect of inelastic scattering on the angular distribution of neutrons scattered from Na^{23} has not yet been completed.

11-2 (On the Magnetic Moment of RaE) (5211-07)

Dieter Kurath

This work is not to be submitted for publication and no further reports will be made since progress made elsewhere on experimental determination of the spin of the RaE nucleus make it superfluous.

29-6 (Internal Conversion in the L and M Subshells) (5211-07)

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

There is no report to be made at this time, but one will be included in the next quarterly report.

31-7 (Configuration Interaction in Iron Group Elements) (5211-14)

Norbert Rosenzweig

Reporting will be discontinued until this program again becomes active.

34-7 Quantized Space Time (5211-14)

Katsumi Tanaka

In a previous paper, we have established a criterion for selection of states on the basis that the states permit space and time localizable properties through the device of introducing noncommutative geometry.

A unitary transformation matrix U , which gives the plane wave solution in the zeroth order and a time localized solution of the Dirac equation is the first order when it operates on a plane wave solution, is determined. The time spectrum has been found at the origin.

37-6 (On the Relation of the Schrodinger and Boltzmann Equations)
(5211-14)

Katsumi Tanaka

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

39-5 (Applications of the Theory of Angular Correlation)(5211-07)

Melvin Ferentz and Norbert Rosenzweig
Reported by Norbert Rosenzweig

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

41-4 Solutions of the Dirac Equation for a Free Particle (5211-14)

Katsumi Tanaka

There was not enough new material to warrant publication.

The report will be terminated.

42-3 (Second Order Focussing for the Magnetic Spectrometer)(5211-14)

Roland F. Herbst

The calculations previously reported (ANL-5317, V 42-2) have been used in the design of the new mass spectrometer. This work will not be published separately nor will further reports be made.

43-3

The S-Matrix

(5211-14)

Fritz Coester, Morton Hamermesh, Katsumi Tanaka
Reported by Katsumi Tanaka

The equivalence of different formal limiting processes employed in the theory of scattering is discussed by comparing the integral equations which hold for finite values of the parameter.

A paper entitled "Limiting Processes in the Formal Theory of Scattering" has been submitted for publication in the Physical Review.

46-1

Nuclear Forces and β -Decay Matrix Elements (5211-07)

Roland F. Herbst

The following is the abstract of an article published in the Physical Review for October 15, 1954. There will be no further reports.

Abstract

The matrix elements of β decay are reduced to nonrelativistic form under the assumption that the nuclear Hamiltonian contains interactions involving odd operators. Particular attention is given to an interaction which gives rise to a spin orbit effect.

VI. REACTOR THEORY

7-2 Lectures on Neutron Transport Theory (5211-07)

Bernard I. Spinrad

(The first and only report so far on this subject was in ANL-5174, Physics Quarterly Report for September, October, and November 1953.)

The lectures previously reported under this section number have been discontinued. The notes to present have been submitted to publishers for comment. If, as expected, publication is arranged, work on the preparation of a book will be continued. The tentative title is "Transport Theory of Neutrons", and the subject matter to be covered is identical with that in the original prospectus for the lecture series.

Chapters completed in rough draft are:

- I. Introduction
- II. The Diffusion Approximation
- IV. Harmonic Methods
- V. The Method of Integral Equations

Chapters IV and V are in very rough draft, and contain material which will be transferred to Chapter III (Numerical Methods) and Chapter VI (Monte-Carlo Methods).

VII. ELECTRONIC DIGITAL COMPUTERS

1-7 (Report on Design of the AVIDAC) (4520-02)

Raymond F. Kramer

No progress has been made because of the pressure of other work.

2-7 Improvements of the AVIDAC (4520-02)

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

1. A new and complete set of cathode ray tube controls were installed on the end bay of the AVIDAC memory. These controls eliminated the previous type of controls that caused trouble, resulting in greatly improved memory reliability.

2. Air conditioning was installed and is operating on the arithmetic unit.

3. A new punch order is added to the order list. The order supplies a carriage return, facilitating greater flexibility in the teletype output format.

3-7 Operational Maintenance of the AVIDAC (4520-02)

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

Preventative Maintenance of the AVIDAC

1. The plug-board which was made up to replace focus and

intensity potentiometers in the memory was installed and is now working.

2. The tube rotation program is up-to-date and is quite effective in reducing trouble.

3. The following is a time tabulation for the AVIDAC from May 1 to July 31. This shows that the machine was available for 231-1/2 hours out of a possible 311 hours.

Total time available	311 hours
Time lost due to trouble	79-1/2 hours
Net time available	231-1/2 hours
Total trouble time	81 hours

4-7	<u>(Test Routines for the AVIDAC)</u>
5-7	<u>(Sub-Routine Library for the AVIDAC)</u>
6-7	<u>(Coding Manual for the AVIDAC)</u>

These programs are herewith discontinued under separate titles. In the future progress will be reported under program VII-2 to be re-titled "The AVIDAC".

7-7	<u>The Auxiliary Memories for the AVIDAC and ORACLE (4520-02)</u>
	Raymond F. Kramer and Leslie Merrill
	Reported by Leslie Merrill

The magnetic tape memory for the ORACLE was completed and shipped to Oak Ridge at the end of June. About one week of time was spent testing the finished unit. Because of the limited time, tests restricted

to demonstrate the interchangeability of the recording heads were run. Results indicate that the heads are interchangeable.

Shop work on the AVIDAC unit has been finished. Wiring and testing remain to be done.

10-7 (Report on the Control of the AVIDAC) (4520-02)

Donald A. Flanders

Little progress has been made during the current quarter.

13-4 Computer GEORGE (4520-02)

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

During the last quarter, a decision was reached that rather than revise the AVIDAC to fit the core memory, a new computer is to be built. It was named "GEORGE". The logical feature of GEORGE is essentially as reported in the last quarterly report.

The preliminary logical design is completed. Two working models of the arithmetic units were tested with satisfactory results. The adding carry time is about four microseconds which is two times faster than the ORACLE and four times faster than the AVIDAC.

Greater operational reliability is emphasized throughout the engineering design. Vacuum tubes and crystal diodes are derated according to their operational conditions rather than by a fixed factor. Precision components are to be used throughout the computer whenever possible.

The completion date of GEORGE is tentatively set at the summer of 1955.

VIII. APPLIED MATHEMATICS AND COMPUTATION, GENERAL

2-7 IBM Methods and Procedures (4520-02)

Nye F. Morehouse, Jr.

- (a) The tables of $\Delta S/D$ for R. Meyerott and G. Keller have been completed.
- (b) The flux distributions formerly run on IBM are now being run on the AVIDAC.
- (c) H. Hummel's Serber-Wilson flux problem is being run on the AVIDAC.
- (d) The zone melting problem has been completed and the results are being published by the Chemical Engineering Division.
- (e) Computations are being run for the fast exponential experiment.

12-5 (Computations of Traces of Gamma Matrices) (4520-02)

Donald A. Flanders

No further work has been done on this problem.

13-2 REAC Methods and Procedures (4520-02)

Nye F. Morehouse, Jr.

- (a) The fuel mixture studies have been completed and the results are being published.
- (b) The equation

$$\frac{d^2 y}{dt^2} = \left(\frac{\pi b}{10} \right)^2 \left(\sqrt{\frac{10}{t}} e^{-\frac{10}{t}} - y \right)$$

was solved for W. McGonnagle of the Remote Control Division.