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1-10

The Argonne Fast Neutron Velocity Selector (5200-01)

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

The new fast neutron chopper has been installed at CP-5 and is now in use. Design specifications have, in general, been satisfied. The fast neutron opacity of the rotor and the counting rates obtained are both somewhat higher than expected. The system has been used routinely at a speed of 10,000 rpm, but continuous operation at full speed (15,000 rpm) is being hampered by mechanical vibrations apparently caused by deficiencies in the damping mechanism at the bottom of the rotor.

The 1024 channel time analyzer which uses magnetic core storage has been completed and tested by the Electronics Division. It is to be installed within the next week. Its operating characteristics are as follows:

- (a) channel widths range from $1/2$ to 12μ -sec.
- (b) the storage capacity is 65,000 counts per channel.
- (c) a dead time of 16μ -sec follows each stored count.
- (d) the 1024 channels are divided into 4 groups of 256 channels, each of which may be delayed independently relative to an arbitrary zero time.
- (e) two detector inputs may be used simultaneously. Half of the 1024 channels are used to store information from

one detector and the other half from the second detector.

2-10

Neutron Detectors (Formerly - Liquid Scintillation
Neutron Detectors) (5200-01, 5220)

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

A boron-loaded liquid-scintillation neutron detector of the same general design as that described in the last quarterly report is under construction. The detector proper is 2-1/4" x 16" x 1"; it has four photomultipliers equally spaced along the length of the detector.

A liquid scintillation detector made of a quartz tube 2" in diameter and 24" long, with a photomultiplier at each end, has been constructed and its properties investigated. It was hoped that internal reflection would give a more uniform light collection. However, the total light collection proved too small for a time-of-flight detector.

Noble gas scintillation detectors of the type invented by Eggler and Huddleston are being investigated for use as fission detectors with the time-of-flight spectrometer. The extreme ease of construction and operation should be emphasized. Using an R. C. A. 6342 photomultiplier with a flow system of argon-10% nitrogen a pulse of five volts from the fission fragments can be realized. Due to the short response time we expect to use a reasonably large amount of fissionable material without alpha pile-up problems.

A multiple-plate fission detector has been constructed for

use with the time-of-flight spectrometer. The outside dimensions are 2" x 6" x 5". There are eighteen foils, each 1-1/2" x 5-1/2" x .001" with a foil spacing of 7/32". The foils are attached at each corner to teflon-insulated steel rods. Any combination of foils may be connected electrically to any one or more of the steel rods. The foils will be painted with a zapon 235-enriched uranium oxide mixture. The amount of uranium coating will be 1 mg/cm², giving a total of 1753 mgs. The detector will be filled with an argon, carbon dioxide mixture to atmospheric pressure.

Boric oxide, zinc sulfide, silver activated wafers for neutron detection are being investigated. A technique previously described in the literature is being used for fabrication. Wafers 0.040" thick have been fabricated and found to be satisfactory as neutron detectors. An effort is now being made to optimize wafer thickness, zinc oxide concentration, and detector geometry for use in time-of-flight measurements.

3-10

Transmission Measurements with the Fast Neutron
Velocity Selector

Lowell M. Bollinger, Robert E. Cote' and James
M. LeBlanc
Reported by James LeBlanc

The transmission measurements on Selenium and Bromine have been continued. Several resonances in the energy region above 1000 ev have been assigned to Se⁸⁰.

Resonance parameters have been determined for several of the lower energy resonances in Br. These parameters are listed in Table I.

TABLE I

<u>Resonance Energy</u> (ev.)	<u>Isotope</u>	<u>σ_o</u>	<u>$\sqrt{\Gamma}$</u>	<u>$\sigma_o \sqrt{\Gamma}$</u>	<u>$\sigma_o \Gamma^2$</u>
35.6	79	3700	0.44	1630	716
54.3	79	1210	0.45	545	245
101	81	-	-	-	1400
134	81	-	-	-	3300
188	79	1200	0.47	560	270
204	79	-	-	59	-
238	79	-	-	-	5700
293	79	-	-	180	-
318	79	-	-	-	3100

Two additional Br resonances at 392 and 467 ev have been assigned to Br 79, but it has not been possible to obtain parameters for these resonances.

6-9 (Spiral Velocity Selector for Slow Neutrons) (5220-01, 5220)

G. R. Ringo

No work has been done on this apparatus in the present period.

11-10

Installation and Operation of the Van de Graaff Generator
(5200-01, 5220)

Jack Wallace

1. New Structural Textolites for the Van de Graaff Generator

The new structural textolites have been in operation since their installation in March, 1955. The generator has been operated 870.0 hours and there has been no evidence of trouble of the nature we were having before the rebuilding.

The machine was successfully operated to 3.4 Mev with no indications of trouble.

This is the final report on this sub-topic.

2. Targets

No further work has been done on installation of a new 25° beam target on the east side of machine. It has been delayed pending installation of a beam bending magnet and moving of the 180° magnetic spectrometer.

A rotating target assembly has been completely reworked at the end of the 90° analyzer. A new shutter design, pump-out block valve and cold trap has been installed. Design work was done by Paul Mooring.

3. Operational Experience

During this period (May 1, 1955 to October 31, 1955) the Van de Graaff generator has been operating at various energies as called for by the different experimenters. Proton beams were used most of the

time but some work was done with a deuteron beam.

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

1. Lithium Layer - Mooring	19.5 hours
2. Inelastic Scattering of Neutrons on Na-Mooring, Monahan and Raboy	117.5
3. Beam Oscillator - Holland	64.1
4. Sodium Resonance Scattering - Lane	40.7
5. $S^{32} (da) P^{30}$ - Lee, Mooring	48.0
6. $B^{11} (da) Be^9$ - Inglis, Lee	15.8
7. Energy Losses in Various Gases	38.0
8. $C^{12} (dd) C^{12}$ - Lee, Hausman	55.8
9. Total Cross Sections - Hibdon	125.0
10. Irradiation of Plates - Ringo	5.0
11. Self Detection - Mooring et. al.	16.3
12. Proportional Counter - Perlow	62.2
13. Angular Distribution	83.8
<hr/>	
Total	691.7 hours
Time available (128 x 15 hours)	1920.0 hours
Start up and daily maintenance (128 x 1.0 hours)	128.0
Experimental setup which ties up generator and machine time available but not used.	431.0

Generator out of action.

(1) 90° analyzer pad and plate alignment, cooling water pump replacement	157.5 hours
(2) Rotating target trouble	25.5
(3) R. F. oscillator trouble	37.5
(4) Humidity too high to open machine to make repairs	113.0
(5) Installation of air conditioning	60.0
(6) Current leakage from 25° Analyzer plates	60.0
(7) Miscellaneous repairs	216.8
Total	670.3

For the results of above-mentioned experiments see the respective authors individual reports. It is believed that much more time than mentioned above was lost because of high humidity affecting the electronic equipment used by the various experimenters.

14-9

Pulsed Neutron Beams for the Van de Graaff Generator
(5200-01, 5220)

Robert E. Holland

A preliminary run on the Van de Graaff generator has been completed using an externally pulsed proton beam on a lithium target to produce neutrons. After a flight path of 50 cm., the neutrons were detected with one of three counters described below. The time-of-flight was measured by using pulses from the neutron detector to start charging a condenser in a circuit for converting time delay to pulse height, similar to that described by Lewis and Wells ("Milli-Micro-Second Pulse Techniques"). The

condenser stopped charging upon the arrival of the next timing pulse from the beam deflection oscillator, and the voltage on the condenser, which is proportional to the elapsed time, was measured on a ten channel pulse height analyzer. In a parallel circuit, a slow single channel pulse height analyzer was placed in coincidence with the ten channel analyzer, and permitted time intervals to be measured only if they originated from neutron detector pulses of the proper height.

In an effort to find a fast detector suitable for low energy neutrons, three arrangements were tried, all of which involved a sodium iodide scintillator. In the first method, the sodium iodide crystal was shielded from the direct neutron beam and a can filled with amorphous boron was set in the neutron flux so that the sodium iodide could detect the 480 kev gamma ray from the reaction $B^{10}(n,\alpha)Li^{7*}$. This arrangement gave large backgrounds with low counting rates and was abandoned. Next a silver disk was used in place of the boron and the sodium iodide used to detect the gamma rays resulting from capture of neutrons. This method gave a much larger counting rate and lower background than the first scheme. Third, the sodium iodide crystal was exposed to the direct neutron beam, with no shielding or other material nearby. Capture gamma rays from the iodine were used and the pulse height selector was set so as not to accept pulses from the activation of the iodine. In this way, much better results were obtained than with the silver detector, probably due to the higher efficiency for detecting gamma rays. The efficiency was about one per cent for neutrons of a few hundred kev energy and can undoubtedly be improved

considerably.

Using the last detector arrangement described, with a flight path of 50 cm, the time width of the peak due to 223 kev neutrons was 9.1 milli-micro-seconds. Of this, between 5 and 7 milli-micro-seconds could not be accounted for by target thickness, detector thickness and beam pulse width, and is presumably due to jitter in the trigger circuit and in the scintillator - phototube setup. This time jitter can undoubtedly be reduced.

15-6

Stopping Cross Sections of Gases for Heavy Ions
(5200-02, 5230)

Merle T. Burgy

During the past six months, preparation for this experiment was substantially completed and some preliminary work was done with the apparatus at the Van de Graaff accelerator.

The preparations involved, chiefly, the completion of the supply system for the stopping gases, the completion of apparatus involving a four way gas valve for supplying any of four gases to the accelerator ion source without opening the tank, and construction of a control system for the high voltage supplied to the 25° electrostatic analyzer. This control system is similar to that in use with the electrostatic analyzers of the Van de Graaff.

Some preliminary work was done toward constructing a radio frequency high-voltage supply for the 25° analyzer, but this work indicated that commercial r.f. transformers could not provide the power output that was desired, so a commercial low frequency high voltage supply

was ordered.

In the work done with the accelerator, it was found that the arrangement for aligning the differentially pumped cell for the stopping gases worked very well. The four way gas valve also worked well, but leaks developed in the lines from two of the gas tanks to this valve, so only two gases were used with the ion source-hydrogen and nitrogen. The alignment of the 25° analyzer with the ion beam proved to be difficult and time ran out before the exit slit could be got into position. Thus no attempts at measurement of stopping cross section could be made.

It is believed that most of the trouble with the alignment of the analyzer arose from lack of experience and that much less difficulty will be met at the next attempt. Several small improvements in the apparatus were suggested as a result of this first tryout and are being made.

16-3

A New Neutron Counting System

(5200-01)

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

Experiments are being conducted to discover the optimum design of the proposed neutron counters. Four different geometries are being studied. The final design will be based on the results of the current experiments.

17-3

The Energy Spread of Neutrons from Lithium Targets
(5200-01, 5220)

Alexander S. Langsdorf, Jr., James E. Monahan
F. Paul Mooring
Reported by F. Paul Mooring

To date all experimental data indicate that the thin metallic lithium layers prepared by the methods we use are non-uniform. We plan now to study the properties of thin films of various lithium compounds in the search for a good neutron source. A new target assembly has been designed and built for this study.

A paper on this problem was given at the Neutron Energy Conference held at Argonne National Laboratory on June 3 and 4, 1955.

18-1

Differential Cross Sections for Neutron Resonance Scattering
(5200-01, 5220)

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

Because of the theoretical interest in Na^{23} and its availability as a single isotope, differential scattering cross sections were measured for neutrons of 220-850 kev using the Van de Graaff accelerator and apparatus previously described (ANL-5317, P. 37). The energy spread of the neutrons was 30 kev. Total scattering cross sections obtained by integration of these data are in reasonable agreement with those of Stelson and Preston, Phys. Rev. 88, 1354, 1952. A phase-shift analysis of these data is now being carried out. A neutron beam having a width of 15 kev was used to measure the scattering by Be^9

near the 620 and 810 kev resonances. These data have not yet been reduced but will be put on the AVIDAC shortly.

When suitable samples are available, N^{14} and O^{16} will be studied in a similar manner.

20-10

Energy States of Light Nuclei from Charged Particle
Reactions (5200-01, 5220)

Linwood L. Lee, Jr., F. P. Mooring and
David R. Inglis
Reported by Linwood L. Lee, Jr.

The magnetic proton spectrometer has been used to investigate states in P^{30} by means of the $S^{32} (d, \alpha) P^{30}$ reaction. If isotopic spin T is assumed to be a good quantum number, then only states of $T = 0$ should be observed in this reaction. Preliminary measurements indicate a ground state Q of 4.831 ± 0.020 Mev in agreement with other measurements. Excited states at 0.655 and 0.975 Mev have also been observed. The former is in good agreement with the result reported by Endt, Kluyver, and Van der Leun (Phys. Rev. 95, 580, (1954)) from the $Si^{29} (p, \gamma) P^{30}$ reaction, but indicates that the level is $T = 0$ rather than $T = 1$ as previously reported. The calculated Coulomb energy difference from the $T = 1$ ground state of Si^{30} predicts a $T = 1$ state at about 0.220 Mev excitation in P^{30} . No such state has been observed in the present investigation, in agreement with isotopic spin selection rules.

22-1 Scattering of Charged Particles (5200-01, 5220)

Jan Yntema

60 inch Scattering Chamber

Work has been started on the design of a 60 inch scattering chamber and associated equipment for use with the external beam of the cyclotron.

24-1 The Decay of Sn^{123} (125 day) (5200-01, 5220)

Robert C. Doerner

The gamma-ray spectrum of 125 day Sn^{123} has been investigated with the Argonne 256 channel scintillation spectrometer. Sources were prepared by neutron irradiation of SnO_3 enriched in Sn^{122} . Sixty days after irradiation, peaks have been observed at about 0.16, 0.27, 0.4, 0.9, 1.1, 1.4, 1.7, 1.8, 2.0, 2.3 and 2.6 Mev. Because of the low intensity of the source, coincidence measurements did not prove fruitful and no decay scheme has as yet been proposed. A new sample is presently undergoing a three month irradiation (terminating January 15, 1956) in order to obtain a sufficiently active source to continue these measurements.

25-1 Decay of Ba^{139} (85 min.) (5200-01, 5220)

Robert C. Doerner

In 1935 Amaldi, et. al.¹ reported a neutron-induced activity of about 80 minutes which they assigned to an isotope of Ba.

Pool and Cork² in 1937, produced an 85.6 minute activity by deuteron bombardment of Barium, showed it to be a beta-emitter and suggested that it was the Ba¹³⁹ isotope. This isotopic assignment was later verified by Pool and Quill³ in experiments producing the species by the (n,p) reaction on La¹³⁹. Hahn and Strassmann⁴ reported the 85 minute Ba¹³⁹ activity as the grand-daughter of a fission product, Xe¹³⁹. A gamma-ray of about 600 Kev was first reported by Kalbfell and Cooley⁵ who also set an upper limit of 1 Mev to the beta-transition energy. Subsequent investigations^{6,11} lead to the scheme of Mitchell and Hebb¹², shown in Figure 1. The 163 Kev level in La¹³⁹ has been confirmed by the K-capture measurements in Ce¹³⁹ of Pruett and Wilkinson¹³.

-
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 2. M. L. Pool and J. M. Cork, Phys. Rev., 51, 1010, (1937).
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 11. N. P. Heydenbury and G. M. Temmer, Phys. Rev., 93, 906 (1954).
 12. A. C. G. Mitchell and E. Hebb, Phys. Rev. 95, 727 (1954).
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Fig. 1

We have undertaken an investigation of the decay of Ba^{139} using the Argonne 256 channel scintillation spectrometer. Sources were prepared by irradiation of BaCO_3 enriched in Ba^{138} in CP-5.

The pulse-height distribution associated with 85 minute Ba^{139} is displayed in Figure 2. The data for this curve were obtained in well-collimated geometry using a 2 inch cubic NaI (Tl) crystal. Analysis of the distribution confirms the presence of the two known gamma-rays at 0.163 and 1.43 Mev and in addition shows two new weak gamma-rays at about 0.84 and 2.2 Mev.

Measurements of continuous beta-spectra and of internal conversion electrons with the variable field 180° spectrometer have been suspended temporarily pending the completion of the magnetometer.

26-1 Decay of Ca^{49} (8.9-min.) and Sc^{49} (57-min.) (5200-01, 5220)

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

Two presumably isomeric activities of 2.5 hours and 30 minutes produced by deuteron irradiation of calcium, were assigned to Ca^{49} by Walke¹. Sc^{49} was found to emit beta rays of 1.8 Mev with a half-life of 57 minutes. It appeared to be a daughter of the above Ca activities. Later experiments by der Mateosian and Goldhaber², in which enriched Ca^{48} was irradiated with thermal neutrons, did not confirm either of the above calcium activities. Instead, it was found that

1. H. Walke, Phys. Rev. 51, 439 (1937); 52, 777 (1937); H. Walke, F. C. Thompson, and J. Holt, Phys. Rev. 57, 163 (1940). 57, 171, (1940).
2. E. der Mateosian and M. Goldhaber, Phys. Rev., 79, 192 (1950).

Fig. 2

Ca^{49} decayed with a period of 8.5 minutes, emitting a beta ray of 2.7 Mev and hard gamma rays. The 1-hour Sc^{49} daughter was observed to emit beta rays measured as 2.4 Mev, and no gamma rays. Study of these activities was undertaken with the new 256-channel analyzer in order to determine the gamma-ray energies and the decay schemes.

Two gamma rays of 3.07 ± 0.05 and 4.04 ± 0.06 Mev, with relative intensities of about 8.5 : 1 were resolved in the NaI (Tl) pulse distribution, using 2-1/4 inch cubic crystals and a 4 inch Pb collimator. Except for a distribution of low-energy pulses attributable to Sc bremsstrahlung, the entire spectrum decayed with the same period, measured as 8.9 ± 0.2 minutes. No pulses not attributable to back-scattered Compton quanta, 0.51 Mev annihilation quanta, or random coincidences were observed in spectra taken in coincidence with all the various peaks associated with these two gamma rays. In particular, the intensity of a possible 0.98 Mev gamma ray in cascade with the 3.07 Mev radiation can be asserted not to exceed about 3% of the intensity of the latter.

In beta-gamma coincidence absorption experiments, the beta rays in coincidence with the 3.07 Mev gamma ray were found to have an energy of 2.12 ± 0.10 Mev. Beta rays of 0.9 ± 0.2 Mev were coincident with the 4.07 Mev gamma ray. The Sc beta rays remaining after decay of the Ca^{49} were measured in the same experimental arrangement to have an energy of 1.80 ± 0.10 Mev. Anthracene pulse distributions of the beta rays were in qualitative agreement with

these values. From these distributions, it can be asserted that the intensity of a possible 5.19 Mev ground-state beta component does not exceed one percent of the 2.12 Mev component.

Taking the branching ratio from the gamma intensity measurements, $\log (ft)$ values of 5.02, 4.31, and at least 8.3 are obtained for the 2.12, 0.9, and 5.19 Mev beta rays respectively. Thus the first two are allowed and the last is at least 2nd forbidden. The Sc beta ray has $\log (ft) = 4.95$ and is allowed.

The level scheme shown in Figure 3 is entirely consistent with these data. The level assignments are just those predicted by the single-particle model. The $\log (ft)$ values alone do not preclude an interchange of the assignments of the two excited states of Sc^{49} , but the gamma-ray branching from the 4.04 Mev level permits a decision. With the assignments as shown, both the 4.04 and the possible 0.98 Mev transitions would be M1, while with the assignments switched, the 4.04 becomes E2. Crude single-particle estimates³ of the transition probabilities indicate a 4.04-/0.98 Mev intensity ratio of 7.0 in the first case and 0.6 in the latter. Experimentally, the ratio is not less than about 3, so the given assignments are established. The single-particle estimates should be fairly reliable, especially for relative values, in the case of Sc with a single proton outside the closed shell at 20.

3. V. F. Weisskopf, Phys. Rev. 83, 1073 (1951).

DECAY SCHEME OF ^{49}Ca & ^{49}Sc

Fig. 3

PHG-017
11-17-55
B.G.

The total decay energy of 5.19 ± 0.12 Mev is consistent with published beta decay systematics⁴.

Subsequent to the completion of this research, we received a pre-publication copy of a forthcoming report on these same activities from Oak Ridge⁵. The results therein are in excellent agreement with ours except for the beta-ray energies, particularly that of the scandium daughter. The principal calcium component and the scandium beta are given as 1.95 ± 0.05 and 2.05 ± 0.05 Mev respectively, compared to our values of 2.12 ± 0.10 and 1.80 ± 0.10 Mev respectively. The discrepancy of 0.4 Mev in the relative energies of the two components is well outside of all quoted errors. We believe that our relative values should be fairly reliable since both energies were measured in the same arrangement with the same source.

The decay scheme and level assignments proposed by the Oak Ridge group are identical with those of Figure 3. They resolved one additional gamma ray, given as 4.68 Mev and intensity 0.34%. On closer examination we find our data to be consistent with the existence of a weak gamma ray of 4.7 ± 0.1 Mev and intensity 0.8%. The corresponding beta ray of 0.5 Mev (not observed) would have $\log (ft) = 3.99$. There is no obvious single-particle assignment for the corresponding level.

4. K. Way and M. Wood, Phys. Rev. 94, 119 (1954).

5. G. D. O'Kelley, N. H. Lazar, and E. Eichler, private communication (to be published in Phys. Rev.)

These results will be presented at the Chicago meeting of the American Physical Society (November 1955), and subsequently submitted for publication in the Physical Review.*

27-2 Decay of I^{128} (25-min.) (5200-01)

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

Further studies have confirmed both of the suspected new gamma rays mentioned in the previous report. No evidence was found for a gamma ray of 0.255 Mev. The energies obtained for the four gamma rays are 0.452 ± 0.003 , 0.535 ± 0.003 , 0.76 ± 0.01 , and 0.987 ± 0.006 Mev.

The 0.452- and 0.535- Mev gamma rays were found to be strongly coincident with each other, but not with either of the other gamma rays or the 0.027-Mev X-ray peak (presumably Te X-rays). The sum of the energies of these two transitions is in excellent agreement with that of the 0.987-Mev gamma ray, which must therefore be the crossover.

While the above work was in progress, a new report on this activity was published¹ which was in very good agreement with all the above findings. There was sufficient additional data given on beta-ray energies, branching ratios, etc., to establish the decay scheme of I^{128} beyond reasonable doubt. In view of this it was not deemed advisable to pursue the work further, and the program has been dropped. No publication of the results is planned.

1. N. Benczer, B. Farrelly, L. Koerts, and C. S. Wu, Bull. Am. Phys. Soc. 30, No. 5, p. 9 (June, 1955).

* Published in Physical Review 102, 457-8 (April 15, 1956).

28-3

Decay of Ce^{143} (33-hour)

(5200-01)

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

The previously reported data and conclusions have been submitted to the Physical Review, and are scheduled for publication in the issue of January 1, 1956. This project may be considered closed.

29-3

Decay of Nd^{151} (12-min.) and Pm^{151} (27-hr.) (5200-01)

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

There has been no further work done on this program in this report period. It is believed that the necessary experiments have now become much more practicable, with the advent of the new analyzer. It is expected that the study will be further pursued in the immediate future.

31-1

Decay of Yb^{177} (1.9-hour)

(5200-01)

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

The earliest observations of activities induced by neutrons in Yb reported period of about 3.5 hours ^{1,2} that was probably

1. J. K. Marsh and S. Sugden, Nature 136, 102 (1935).
2. G. Hevesy and H. Levi, Kgl. Danske Videnskab. Selskab, Mat. -fys. Medd. 14, No. 5 (1936); Nature 137, 185 (1936).

due to a Lu contaminant. Atterling, et. al.³ were perhaps the first to see the true Yb activities, reporting a 1.9-hour beta emitter and two longer lived periods. The two long activities are now definitely assigned³⁻⁶ to Yb¹⁶⁹ and Yb¹⁷⁵, indicating that the 1.9 hour period may be assigned to Yb¹⁷⁷. This assumption is supported by the activation cross section for fast neutrons. However, a genetic relationship to the 6.8-day beta activity that is now definitely assigned^{3,5,7} to Lu¹⁷⁷ has never been proved. The presence of this activity in Yb sources has been mentioned^{6,8} by several authors, but none has asserted that its intensity was fully consistent with its being a daughter product of Yb¹⁷⁷. The Lu¹⁷⁶ capture cross section is large compared to those of Yb, so the activity could always have been due to Lu impurity. In a recent study⁹ using very pure Yb samples, the conversion lines of this well known¹⁰ Lu activity could not be found, nor did there appear to be any 6.8-day components in the beta

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3. H. Atterling, E. Bohr and T. Sigurgeirsson, Arkiv. Mat., Astron., Fysik 32A, No. 2 (1945).
 4. W. Bothe, Z. Naturforsch. 1, 173 (1946).
 5. M. G. Inghram, R. J. Hayden, and D. C. Hess, Jr., Phys. Rev. 71, 270 (1947).
 6. J. M. Cork, H. B. Keller, W. C. Rutledge, and A. E. Stoddard, Phys. Rev. 78, 95 (1950).
 7. G. Wilkinson and H. G. Hicks, Phys. Rev. 74, 1733 (1948).
 8. F. K. McGowan, Phys. Rev. 76, 1730 (1949); ORNL-952 (March 1951).
 9. J. M. Cork, M. K. Brice, L. C. Schmid, and R. G. Helmer, Private communication (to be published in Phys. Rev.).
 10. J. M. Hollander, I. Perlman, and G. T. Seaborg, Revs. Mod. Phys. 25, 469 (1953).

spectrum. That the activity was altogether absent is not yet definite, but there remains some doubt about the assignment of the 1.9-hour Yb to mass 177.

1.9-hour Yb is reported¹¹ to decay to the ground state of the daughter Lu nucleus by a beta ray of 1.30 Mev in 88% of the cases, and to excited states at 0.119 and 0.146 Mev in 3% and 9% of the cases respectively. The 0.119-Mev level is interpreted as the first rotational level, which is to be expected from the systematics of nearby nuclei. The 0.146-Mev level has a measured lifetime of about 1.2×10^{-7} seconds^{8,11}, and the K-conversion coefficient of the transition to the ground state is measured¹¹ to be 0.63 ± 0.08 . The transition is interpreted as 90% E1 plus 10% M2. Spin and parity assignments have been made for the levels.

A portion of the same Yb sample used in Cork's recent study has been made available. The conversion-electron spectrum has been examined in the magnetic spectrographs, and preliminary scintillation studies of the beta and gamma spectra have been carried out. Samples have thus far been prepared only with thermal neutron irradiation, so that the 4.2-day period of Yb¹⁷⁵ is strongly activated and interferes seriously with observations of the 1.9-hour spectrum.

Both the gamma rays reported by de Waard¹¹ are observed, and it is verified that the highest-energy beta ray is not in

11. H. de Waard, Phil. Mag. 46, 445 (1955).

coincidence with the gamma rays and proceeds to the ground state. In addition, two new gamma rays of energies 1.080 ± 0.006 and 1.228 ± 0.006 Mev are found to decay with this period. They are of roughly equal intensity roughly 15% of that of the 0.150-Mev gamma ray. The 1.080-Mev transition is found to be coincident (resolving time 3×10^{-6} sec.) with the 0.150-Mev gamma ray. Undoubtedly there exists a level at 1.228 Mev from which these transitions proceed to the 0.150-Mev level and the ground state respectively. Beta rays of very low energy are observed in coincidence with these two gamma rays.

Conversion lines have been observed for the gamma ray of energy 0.150 ± 0.001 Mev, in slight disagreement with de Waard's value. The other low energy gamma ray could be seen only in scintillation spectra taken in coincidence with beta rays of energy > 0.5 Mev because of interference from the intense transition of 0.114 Mev in the 4.2-day activity. The energy determination is not very precise and is given as 0.120 ± 0.002 Mev.

Conversion lines of the 6.8-day Lu^{177} could not be seen in the presence of those from the 4.2-day activity in samples irradiated for 2 hours. In the previous study⁹ the much longer irradiation of 30 days would have favorably affected the ratio of these two activities, but would have simultaneously increased competition from the 33-day Yb^{169} . As yet it cannot be asserted that the evidence in either case definitely precludes the possibility that Lu^{177} is the daughter of 1.9-hour Yb.

neutron beam.

52-10

Capture Gamma Ray Spectra Using a Scintillation
Spectrometer (5200-01, 5220)

Bernard Hamermesh and Carroll C. Trail
Reported by Carroll C. Trail

The gamma ray spectrum from neutron capture in Hg has been studied with a large NaI crystal which is three inches in diameter and three inches tall. Gamma rays have been resolved having energies of 380, 680, 900 and 1200 kev. No gamma rays of higher energies were resolved.

Measurements with two crystals, to obtain the cascade scheme, are in progress.

55-2

Capture Gamma Ray Spectra for Neutrons with
Energies from 0.1 ev to 10 ev. (5200-01, 5220)

Bernard Hamermesh, Sol Raboy, G. R. Ringo
and Carroll C. Trail
Reported by Carroll C. Trail

A design of a shield for the scintillation counters has been completed. It has ten inches of lead shielding instead of the eight inches of lead of an earlier design. This additional shielding is provided because of the expected higher background resulting from an increase in power at CP-5.

Compton Electron Magnetic Spectrometer for Neutron
Capture Gamma Rays. (5200-01, 5220)

Richard S. Preston

Groshev, Adyasevich and Demidov¹ have described a magnetic spectrometer which measures the energies of forward Compton electrons produced in a thin extended radiator by neutron capture gamma-rays. The forward electrons are focussed on a slit by a homogeneous 90° magnetic field, and then analyzed in a 180° inhomogeneous field. The method has already proved to be particularly useful in the gamma-ray energy region from 1 Mev to 10 Mev.

A study of this method has shown that it is practical for use with the CP-5 reactor. In addition, certain modifications of the method might result in increased counting rates and improved resolution. In particular, the use of homogeneous fields throughout would simplify the magnet construction and, at the same time, would permit the concurrent measurement of intensities at a number of separate energies, or allow the use of a wider radiator. However, such improvements would be made at the expense of increased complication of other details of construction and operation. Some of these alternative possibilities are now being studied and compared in order to determine which one should be adopted for a spectrometer for use at Argonne.

1. L. V. Groshev, B. P. Adyasevich and A. M. Demidov, International Conference on the Peaceful Uses of Atomic Energy, A/Conf. 8/P/ 651 U.S.S.R. , July 5 , 1955.

60-10

7.7 Meter Bent Crystal Spectrometer (5200-01, 5220)

Bernard Hamermesh and David Rose
Reported by Bernard Hamermesh

During the last six months most of our efforts were put on the problem of getting a bent quartz crystal. At the end of June the quartz crystal plate arrived. It was 12" x 12" in area and was 6 mm thick. After a very careful examination of the plate for sub-visible cracks, it was etched in HF. The clamp block in which the quartz was to be clamped had an aperture of 8" x 8". The clamping operation was carried to the point where contact curvature over a 2" width at the center of plate was obtained, when the plate cracked.

The break in the quartz was such as to permit cutting three plates each 5-3/4" x 4". A new clamp block with an aperture of 4" x 2-3/4" was prepared. The new clamp has a focal length of 7.68 meters. One of the 5-3/4" x 4" plates was bent against the new clamp with complete contact over 90% of the aperture.

In addition to the work on the quartz plate a large amount of time was spent on the crystal table drive. A new set of pinion gears was made in Central Shops. These combined with a change to no pre-load on the central spindle bearings have improved the operation of the drive to a point where it can be used satisfactorily.

The wiring of the control console has been completed and final checking of the electronics is in progress. It is planned to install the small bent crystal in the spectrometer and to place a source

in CP-5 very soon.

70-10

Measurement of Nuclear Moments by Angular
Correlation

Victor E. Krohn and Sol Raboy
Reported by Victor E. Krohn

A. Am^{241} (Collaboration with T. B. Novey, Chemistry)

The study of the attenuation of the α - γ angular correlation in liquid media has been continued and it has become clear that part, but not all, of the observed attenuation is an exponential function of the time. The extrapolations to zero time give anisotropies which vary by a factor of at least two, depending on the kind of acid used. This result makes the interpretation of the measurements with a magnetic field rather difficult.

An attempt will be made to improve the control of the acid concentrations and to determine how well sources can be reproduced.

B. $\text{Pb}^{204\text{m}}$ (In collaboration with J. Huizenga, Chemistry)

The anisotropy of the prompt (374-899 kev) gamma rays has been measured in solid (PbO) sources, enriched in Pb^{204} , prepared by inelastic scattering of fast neutrons, and in 6 N HCl solutions prepared by milking lead from a resin column containing Bi^{204} which had been separated chemically from a lead target bombarded with 22 Mev deuterons.

The latter sources have been used for a repetition of the measurements of the anisotropies of the delayed (914-374 and 914-899 kev) gamma rays.

The results for the prompt gamma rays fall close to the value 0.167 expected from the scheme $4(E-2) 2(E-2) 0$. One then expects the two delayed pairs to have identical angular correlation functions with an anisotropy of 0.408, which is inconsistent with our previous results for the delayed pairs. It is now realized that corrections to such data are necessary.

These additional corrections to the new results for the anisotropies of the delayed pairs are incomplete, but it seems likely that the values will be consistent, or nearly consistent, with the expected 0.408.

C. W¹⁸⁷

Very little time has been spent on this program since the last report.

D. General

The Co⁶⁰ cascade is being used for a study of the effects of inter-crystal and room scattering on results obtained with windows set to accept pulses smaller than the photopeak. These studies are pertinent to the corrections of the Pb^{204m} measurements.

80-10

Molecular Beam Studies

(5200-01, 5220)

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

A. Atomic beam magnetic resonance studies of radioactive
54 m. In^{116m} have been carried out on the atomic P_{1/2}

state. Resonances have been found at 7.30 and at 27.93 Mc./sec., at magnetic fields for which the inactive In^{115} resonances were at 8.000 and 30.455 Mc./sec. respectively.

The spin is thus established as $I = 5$; the magnetic moment $\mu_n = +4.4$ n. m.; the hyperfine splitting $\Delta \nu = 9000$ Mc./sec.

B. The equipment is being prepared for study of the $P_{3/2}$ atomic state of In^{116m} . Preliminary work is being carried out on the inactive In^{115} for observation of resonances and optimizing of R. F. power and resonance widths.

The calculation of the secular determinants has been coded for the AVIDAC by Ruth Freshour. The calculations are applicable to any combination of I and J , and include magnetic dipole and electric quadrupole interactions.

C. Long-lived material contaminates the oven section of the beam apparatus during measurement so that after several runs the level of activity in the oven chamber may become hazardous. With the present arrangement it is difficult to clean up the oven system without spreading an annoying amount of activity throughout the room.

In order to correct this deficiency, stainless steel thimbles containing the oven mount have been designed to fit into the oven chamber.

When the thimble becomes contaminated, it will be removed from the apparatus and sent over to "Reclamation" for cleaning.

D. It would be advantageous to be able to monitor the inactive material in the beam at the same time that one is collecting a radioactive sample. One way to do this would be to place a surface ionization wire behind and perpendicular to the collector slit so as to intercept a small fraction of the beam. The loss in intensity would have to be compensated for by a more sensitive and selective collector.

Another method is to accelerate the ions produced at the hot wire through a small mass spectrometer to an electron multiplier. An electrostatic accelerating and focussing system has been designed and tested by observing the electrons emitted from a hot wire and focussed on a fluorescent screen.

E. A mechanical beam chopper and an A. C. amplifier have been tried with a surface ionization detector for the detection of an In beam. Although this detection scheme did not prove to be superior to the vibrating reed electrometer when using a meter to read the signal, it does allow an instantaneous observation of the signal on an oscilloscope.

Instead of using the mechanical chopper, the R. F. may be modulated with low frequency when searching for a resonance. The small ambient beam will not give rise to an A. C. signal, but that part of the beam reaching the detector because of a resonance will do so. This should make the search for the resonance much more sensitive.

Modification of existing R. F. equipment to allow this modulation has been requested.

Frank J. Lynch and Leonard S. Goodman

Reported by Frank J. Lynch

In order to discriminate against currents flowing to the collector of the hot wire detector which are not due to the molecular beam, a chopper has been installed in the beam ahead of the detector. The beam was chopped at 10 cps., and a tuned amplifier and synchronous detector were used. The chopper, which has sapphire bearings, is driven by magnetic coupling to an external synchronous motor. The external motor also drives a commutator which acts as a synchronous detector.

Although the meter goes to zero when the beam is turned off, it was found that very large bursts of charge arrive at the detector sporadically causing large meter deflections. A non-synchronous linear detector with short time constant was tried, to permit more rapid recovery from the bursts. The amplifier was changed from a band pass amplifier with Q of 10 to a low pass amplifier with 30 cps. cut off so that small changes in phase of the chopper do not affect the reading.

Due to the long time constant in its input circuit, the vibrating reed electrometer has more freedom from the bursts than the a. c. system. The mechanism of the bursts is not understood, but when the opportunity arises, an effort will be made to reduce or eliminate them.

90 -10

Cross Sections for 14-Mev Neutrons (5200-01,5220)

Harvey Casson, Leonard S. Goodman, Jack
Haugnes and Louis A. Rayburn
Sections 1, 2 and 3 reported by Louis A. Rayburn
Section 4 reported by Harvey Casson

1. General Remarks

In the course of some preliminary cross section measurements it was found that the neutron yield from a clean Zr-T target would decrease by a factor of two or more after a thirty-minute bombardment with approximately 100 microamperes of deuterons at 110 Kev. This behavior was attributed to carbon buildup on the target from pump oil that had condensed on it. This problem was solved by modifying the target chamber so that the target could be heated and by putting a copper sleeve, which could be cooled to liquid nitrogen temperature, in the target chamber. The pump oil on the target could then be driven off by heating the target and would condense and stay on the cold copper. After these modifications were made a decrease of only approximately 25 % in the neutron yield was noted after about 5000 microampere-hours of operation.

The fast coincidence circuit was found to be very unstable in day-to-day operation. Daily variations in the resolving time of a factor of two were common. These troubles were finally traced to electronic components (some carbon resistors and a germanium diode) that were very temperature sensitive. These components were replaced by ones that were much less temperature dependent and the coincidence

circuit was kept at approximately the same temperature from day to day. These changes resulted in greatly enhanced stability of the circuit.

In an effort to improve energy resolution of the alpha counter it was replaced by a counter of the same scintillating material but with one interface between dissimilar materials in the counter assembly eliminated. This resulted in improvement by an approximate factor of two in the resolution and in alpha pulse size.

2. Angular distribution of elastically scattered 14-Mev neutrons

The shield for the neutron counter has been selected, (it consists of 24 inches of lead between the neutron source and counter), and placed into position. The spectrometer table has been modified so that the angular resolution is now 3.7 degrees. Measurement of the differential elastic scattering cross section of lead is now in progress. Differential elastic scattering cross section measurements of bismuth and perhaps tantalum and tungsten are planned for the immediate future.

3. Total cross sections

Transmission measurements were made on hafnium, palladium, and tantalum but the data were not self consistent. It is believed that the causes of these inconsistencies have been removed. Samples of neodymium and samarium metal have been received (on loan) from Dr. Frank Spedding at Ames, Iowa. Data from a set of transmission measurements on neodymium, samarium, and hafnium are now being analyzed.

4. Inelastic scattering of 14-Mev neutrons

The detection of inelastically scattered neutrons by the following time-of-flight method has been attempted. The scatterer and neutron detector were mounted on a movable assembly in which the angle of scattering and the distance between the scatterer and neutron detector were kept constant. The motion of the scatterer was along the axis of the neutron cone (as defined by coincidences with the d-T alpha particles). The diameter of the scatterer was larger than that of the neutron cone in the region of operation.

Within the range of movement of the scattering assembly, the effective geometry for detection of scattered neutrons using alpha-neutron coincidences remained essentially constant. The same fast coincidence circuit as was used in the angular distribution experiment was used in the present work. The resolving time was about 2.5 millimicroseconds.

By measuring the fast coincidence rate as a function of the distance, x , from the Zr-T target to the scatterer, one might hope to observe a number of peaks: (1) elastic scattering peak, (2) peaks due to discrete energy groups of inelastically scattered neutrons, and (3) a gamma peak, if the gamma rays produced in the scatterer are energetic enough to actuate the neutron detector.

The speed, v , of a scattered particle may be expressed in terms of the location of its peak relative to the elastic peak:

$$v = \frac{v_0}{1 + \frac{x - x_0}{d}}, \text{ where } v_0 \text{ is the speed of a}$$

14-Mev neutron, x_0 is the value of x for the elastic peak, and d is the distance from the scatterer to the detector.

In preliminary measurements using a carbon scatterer, three peaks were observed: the elastic peak, gamma ray peak, and an inelastic peak corresponding to the excitation of the 4.4 Mev level of C^{12} . Several runs were made at different scattering angles. Further measurements on carbon are in progress. Work on other elements is contemplated.

91-10

Neutron Transport Cross Sections; Angular Distribution
of Scattered Neutrons (5200-01, 5220)

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

The data of October 1954, and February 1955 have been extended by a series of measurements in September 1955 so that data are at hand on 39 elements, each measured at five angles and at about twenty energies between 30 and 1700 kev with about 80 kev resolution. The elements measured include: H(as CH_2) Li, Be, B, C, F (as CF_2), Na, Mg, Si, P, S, K, Ti, V, Cr, Fe, Co, Ni, Cu, Zn, Si, Zr, Nb, Mo, Pd, Ag, Cd, In, Sn, Te, Ta, W, Pt, Au, Tl, Pb, Bi, Th, U.

Reduction of all these data to give differential cross sections at the angles measured, and coefficients of the Legendre poly-

nominal expression $\sigma(\theta) = \sum_{e=0}^4 a_e P_e(\cos \theta)$ has just recently been successfully carried through using the AVIDAC, thanks particularly to Herbert Gray, and to the other computer staff personnel in general. These computations give results not yet corrected for plural scattering.

The endeavor to make these corrections properly has become a major effort. James Monahan and one of us (A. Langsdorf) has worked out an exact formulation for the emergent flux of singly and double scattered neutrons for any given set of theoretically exact a_e 's for a beam of neutrons incident at an arbitrary angle on a flat plate infinite in two dimensions. For thin plates, the singly and doubly scattered flux account together for most of the scattering, and since the total of all neutrons singly and doubly scattered can also be calculated from our analysis, the residual error due to neglect of higher orders can be defined and partially corrected for. During the summer, manual computations from this theory have been partially carried out (with computational aid by Ralph Ehlert) and are being pursued to give numerical results this fall. The method is based on calculating emergent flux using the measured values of the a_e , then correcting the measured a_e , and repeating if necessary to converge on the corrected final a_e . The analysis neglects the energy degradation after scattering, and neglects capture. For most cases the assumptions so made cause negligible error in making the corrections, which are only expected to be about 10% in most cases; final results to 3% accuracy are all that is expected at this time.

The exact formulation of the amount of doubly scattered emergent flux was so successful that it seemed interesting to try to extend the solution to include triple scattering and possibly all orders of scattering. An exact formulation of this problem soluble for an arbitrary set of a_e seems not to have been carried out previously even for double scattering. [S. Chandrasekhar has carried out a solution exact in all orders for any values of a_0, a_1, a_2 , provided all a_e 's for $e > 2$ are zero. He believes it is possible to extend his theory to finite a_3 , but it would be excessively complex for this case and essentially impractical for non-zero values of a_e for $e > 3$. See his book, Radiative Transfer, Oxford, 1950].

We are not yet sure that it is impractical to extend our method beyond second order scattering, but the problem seems to be complicated enough so that work on it may be discontinued soon. Up to this time, a number of interesting developments have been made which suggest further ones. A full report on the analysis made so far is in preparation.

The single and double scattering corrections are themselves complex enough by our analysis that manual calculations are impractical for all 40 elements at 20 energies. The calculations of corrections are now being coded for the AVIDAC. Depending on the time involved in getting this calculation carried through, we shall either publish our results after making corrections by extrapolation from manual calculations of a few typical cases, or publish them when analytically

corrected using the results from the AVIDAC.

Graphs of the differential cross sections and the a_e 's will be prepared soon for the existing data uncorrected for plural scattering, so that they may be available to all interested persons. The AVIDAC computations are still being printed out, so the graphs could not be made in time to be included in this report.

98-9

Neutron Cross Sections in the Kev Region
(5200-01, 5220)

Carl T. Hibdon

The transmission cross sections of Na and Al in the low kev energy range were measured by flat detection with a neutron resolution width of about 500 ev, and those of Fe and Cr from 1 to 86 kev with a resolution width of about 300 ev.

a) Sodium

A number of points for sodium were measured in the energy range from 1 to 5 kev using NaF samples in order to cover the resonance near 3 kev. No well defined minimum occurred before the resonance but there was a prominent asymmetry. A maximum of 144 barns was measured near 3 kev and is above the theoretical height of 120 barns for $J = 0$ ($\ell = 1$ or 2) but well below the two possible s-wave peaks having J values of 1 and 2 ($\ell = 0, 1$ or 2) and peak height of 355 and 580 barns, respectively. The width at half the measured height is 350 ev, but the resonance is undoubtedly narrower. An analysis of the data will be made in an attempt to determine the parameters Γ and J.

b) Aluminum

The transmission cross section of Al over the energy range from 1 to 15 kev was measured using Al metal samples of 99.9% purity. The cross section gradually decreased from a value slightly below 1.5 barns to less than a barn with the exception of a maximum of 2 barns near 7 kev.

c) Chromium

The transmission cross section of chromium was measured from 1 to 86 kev using metal samples of 99.8% purity prepared by the Battelle Memorial Institute for Pratt and Whitney Aircraft Corporation who requested the measurements. A small amount of $\text{Cr}^{53}_2\text{O}_3$ (90% Cr^{53}) was also measured over the region from 3 to 10 kev.

TABLE II

Resonances of Chromium

Energy of Peak in Kev	σ_{max} in barns Flat- Detection	σ_{max} in barns Self- Detection	σ_{max} in barns from $\text{Cr}^{53}_2\text{O}_3$ Flat-Detection	σ_{max} in barns from $\text{Cr}^{53}_2\text{O}_3$ Self-Detection	Comments
4.25	27		135	220	Clearly Cr^{53}
5.4	28		108		" "
6.3	24		97		" "
7.2	20		108		" "
8.0	20		123		" "
8.8	18		210		" "
24	3.7				Small, partially resolved

TABLE II (Cont'd)

Energy of Peak in Kev	σ_{max} in barns Flat- Detection	σ_{max} in barns Self- Detection	σ_{max} in barns from $\text{Cr}^{53}_2\text{O}_3$ Flat-Detection	σ_{max} in barns from $\text{Cr}^{53}_2\text{O}_3$ Self-Detection	Comments
30	4.2				Small clearly resolved
38	3.2				Small clearly resolved
51	25 (29.8 for 100% isotope)	33.2 (39.6 for 100% isotope)			^{52}Cr Asymmetry. Deep minimum before resonance.
67	3.7		12.3		Clearly Cr^{53}
73	2.8				Small, resolved Deep minimum at 86 Kev. Resonance of Cr^{52} near 90 Kev.

The peak at 51 Kev is well resolved with a deep minimum (0.86 barns at 47 Kev) before the resonance, and has a prominent asymmetry, which assigns with certainty the value $\ell = 0$. Since the spin of Cr^{52} is 0, only one S-wave peak height of 53 barns at 51 Kev is possible. The measured peak height by self detection is 80% of this value, which is sufficient to confirm that $g = 1$ and $J = 1/2$. The deep minimum at 86 Kev (0.83 barns) is indicative of another resonance of Cr^{52} near 90 Kev, and because of the minimum the J and ℓ values are the same as for the 51 Kev resonance.

By self-detection at 4.25 Kev using $\text{Cr}^{53}_2\text{O}_3$ as the absorbing sample and a metallic scattering detector of $\text{Cr}(9.5\% \text{Cr}^{53})$, a cross section of 220 barns (for 100% isotope) was obtained. This peak value is well above the possible peak of 82 barns for $J = 0$ ($\ell = 1$ or 2)

and unambiguously rules it out. The next two possible peak heights for s-wave interaction, of 240 and 390 barns, corresponding respectively, to $J = 1$ and 2 ($\ell = 0, 1, 2$ or 3), are indistinguishable, but since the measured peak height is so near the 240 barn peak height, it is very probable that the 390 barn peak is the correct one. The width of this resonance by self-detection is no more than 200 ev. No minimum before the resonance could be resolved with such a thin sample.

Reasonable upper and lower limits for the quantity

$\Gamma_n^0 / \bar{D}$ can be determined for the six resonances of Cr^{53} in the 3 to 10 kev region assuming they all have the same J and ℓ values, since by measurements of the $\text{Cr}_2^{53}\text{O}_3$ sample they all appear to have widths of the same order of magnitude and since by self-detection the resonance at 4.25 kev has a width of 200 ev or less. Γ_n^0 is defined as $\Gamma_n^0 / \sqrt{E_0}$ (e. v.) and $\bar{D}$ is the average spacing of levels having the same J and ℓ values. According to the cloudy crystal ball model $\Gamma_n^0 / \bar{D} = \frac{(\sum \Gamma_n^0)}{\Delta E}$ where ΔE is the energy interval (10 kev).¹ Taking the average width of the resonances as 200 ev $\frac{(\sum \Gamma_n^0)}{\Delta E} = 15 \times 10^{-4} \text{ ev}^{-1/2}$. For an average width as low as 100 ev the ratio is $7.5 \times 10^{-4} \text{ ev}^{-1/2}$ as compared with the predicted value of $9 \times 10^{-4} \text{ ev}^{-1/2}$ at a peak for $A \simeq 55$.²

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1. R. S. Carter, J. A. Harvey, D. J. Hughes and V. E. Pilcher, Phys. Rev. 96, 113 (1954).
 2. H. Feshbach, G. E. Porter and V. F. Weisskopf, Phys. Rev. 96, 448 (1954).

d) Iron

Armco iron samples were used for these measurements. A small amount of $\text{Fe}_2^{54}\text{O}_3$, (93.06% Fe^{54}) and of $\text{Fe}_2^{56}\text{O}_3$ (99.9% Fe^{56}) were also used at some resonance peaks. The results are given in Table III.

TABLE III

Resonances of Iron					
Energy of Peak (Kev)	σ_{max} Flat Detection	σ_{max} Self-Detection	σ_{max} for $\text{Fe}^{54}_2\text{O}_2$ Flat-Detection	σ_{max} of $\text{Fe}^{56}_2\text{O}_3$ Self-Detection	Comments
7.2	11				Apparently Fe^{57}
8.1	17		147 (158 for 100% Isotope)		Fe^{54} . Asymmetry. Narrow width
29	52.9 (57.8 for 100% Isotope)	75.5 (82.4 for 100% Isotope)		82.6	Fe^{56} . Prominent Asymmetry. Deep minimum before resonance.
38	7.4				Small, partially resolved
43	6.8				Clearly resolved

TABLE III (Cont'd)

Resonances of Iron

Energy of Peak (Kev)	σ_{max} Flat Detection	σ_{max} Self- Detection	σ_{max} for Fe ⁵⁴ Fe ₂ O ₃ Flat- Detection	σ_{max} of Fe ⁵⁶ Fe ₂ O ₃ Self- Detection	Comments
54	7		38 (40.8 for 100% isotope)		⁵⁴ Fe Asymmetry. Narrow Width.
77	14.2 (15.5 for 100 % isotope)	22.6 (24.7 for 100% isotope)			⁵⁶ Fe minimum before resonance
89	10.4 (11.4 for 100% isotope)				⁵⁶ Fe deep minimum before resonance.

The resonance at 29 kev due to Fe⁵⁶ is well resolved, having prominent asymmetry and a deep minimum of 0.60 barns at 25.5 kev. Of this amount 0.30 barns is attributable to the potential scattering of the other isotopes of iron. This minimum together with the prominent asymmetry assign with certainty the value $\ell = 0$. Since the spin of Fe⁵⁶ is 0, there is only one possible s-wave peak height, 92.8 barns for $g = 1$ and $J = 1/2$. The measured height is 89% of this value.

There is a pronounced minimum before each of the resonances at 77 and 89 kev. Each resonance has a peak sufficiently high to assign it to Fe^{56} with $\ell = 0$, $g = 1$ and $J = 1/2$. The minimum between these resonances of 1.05 barns indicates an s-wave interaction interference between the two resonances.

There are indications of the presence of several resonances in the 10 to 20 kev region and also in the 35 to 65 kev region. They are probably attributable to the less abundant isotopes of iron.

2. Analysis of S-Wave Resonances

The product $\sigma_0 \sqrt{\Gamma}$ of S-wave resonances can be obtained by a graphical method in which only points on the high energy side of the resonance and points at energies less than the minimum before the resonance are used. Any point used must satisfy the condition $(\frac{E-E_0}{\sqrt{\Gamma/2}})^2 > 1$. The method has the advantage that points used are in regions where the value of the cross section is less sensitive to the resolution width of the neutrons than near the peak of the resonances. For this analysis the Breit-Wigner single level dispersion formula for neutron scattering can be arranged in the following form:

$$\sigma_s - \frac{\sigma_0 \sqrt{\Gamma}^2}{4 (\Delta E)^2} (1 - 2 \sin^2 \delta_0) = \sigma_p - \frac{\sigma_0 \sqrt{\Gamma} \sin \delta_0 \cos \delta_0}{\Delta E} \quad (1)$$

where $\Delta E = E - E_0$, $\sigma_0 = 4\pi A^2 g_J \ell$ and δ_0 is the phase angle.

The second term of the equation is quite small compared to the fourth term. Effectively then the equation is linear and a plot of σ_s versus $1/\Delta E$ for the points meeting the condition $(\frac{2\Delta E}{\sqrt{\sigma_0}})^2 \gg 1$ is a straight line whose slope and intercept are, respectively, $\sigma_0 \sqrt{\sin \delta_0 \cos \delta_0}$ and σ_p . Using this value of $\sigma_0 \sqrt{}$, ideally, various values of σ_0 are chosen and $\sqrt{}$ computed until values are found that will satisfy equation 1. Practically, either one or two values of σ_0 are possible for S-wave interactions. This limits the values of $\sqrt{}$ to no more than two corresponding to the J values.

For a well isolated resonance due to a material of a single isotope this method provides a quick, simple analysis to obtain the one or two possible values of $\sqrt{}$. In practice all points used must be corrected for nearby resonances and for the potential scattering of other isotopes. It is difficult to obtain a straight line plot unless the corrections are reasonably accurate.

A rough value of $\sqrt{}$ can be obtained by use of the equation involving the locations of the maximum and minimum points of a resonance.

$$E_{\max} - E_{\min} = - \frac{\sqrt{}}{2} (\tan \delta_0 + \cot \delta_0) \quad (2)$$

This equation involves inaccuracies in determining the exact maximum and minimum points and uncertainties about the value of the nuclear radius used to evaluate δ_0 .

Measurements have been obtained for several S-wave type resonances and the above analysis has been applied to those which are sufficiently far from other resonances. The results are tabulated in Table IV.

TABLE IV

Widths of S-wave Resonances

Isotope	E_0 K ev	σ_0 Γ Barns - ev	σ_0 Barns	Γ ev	$\Gamma_{(ev)}$ from Max and Min. points	σ_p from graph
Cr ⁵²	51	62,700	52.8	1190	1700	3.32
Fe ⁵⁶	29	75,260	92.9	810	1140	3.52
Ni ⁵⁸	65	67,360	42	1600	2200	3.75
Bi	12	19,940	103	195	218	8.67
			124	160		

3. Improvement of Neutron Counting Equipment

In order to obtain an increased neutron counting rate without loss of resolution the present counting equipment (elephant) is in the process of improvement. Thirty new B-10 enriched BF₃ counters 16 inches long are to be installed together with the 36 old ones. The collimator has been converted to accept inserts having a slit type opening

1-1/4 inches long. Slit widths of 3/8 and 1/4 inches are to be used.

If the counting rate is sufficient, a slit 1/8 inch wide will be used when the best obtainable resolution is needed.

In the past an insert having a circular hole of 1/2 inch diameter has been used. The shielding material of this slit has been modified so that it may still be used when large samples can not be obtained.

The paraffin drum which holds the BF_3 counters will now accommodate 86 of them. The 66 16 inch counters will be used. A few shorter used counters will also be installed in the outer holes of the drum.

4. Studies with the Annular BF_3 Scattering Counter

The results of the measurements of ν for Pu^{241} have been issued in an ANL report (ANL-5396) under the title: "Thermal Neutron ν for Pu^{241} " by A. H. Jaffey, C. T. Hibdon and Ruth Sjoblom. This concludes the project.

102-7

(Neutron Cross Section Measurements by the Self-Detection Technique)

James E. Monahan

There is nothing new to report on this subject.

108-4

He³ Neutron Spectrometer

(5200-04, 5220)

Frank Lynch

A system for filling a proportional counter at 300 psi has been assembled and tested for leaks. It has provision for continually recirculating the counter gas through a hot copper purifier and a cold trap.

One atmosphere liter of He enriched 4% in He³ has been received. Because of a large H³ contamination it will be introduced into the counter by passing through a cold trap at liquid He temperature.

A counter similar in construction to that of Bachelor and small enough for insertion in the critical assembly has been finished by the machine shop. The insulator which supports guard and field tubes is constructed of invar and vycor cemented together with a thermosetting epoxy resin.

Materials are being procured for constructing brazed insulator assemblies of alumina porcelain and kovar using the titanium hydride vacuum process. No difficulty is expected in producing these seals on the basis of experiments with these materials. These insulator assemblies will permit baking out the counter at 600° C before filling.

The development of the 60 cps regulator for the 10,000 V supply has been abandoned because of inherent slowness of response. A regulated R. F. supply has been designed and is under construction. It uses a d. c. amplifier to control the B supply of the R. F. power

Charles Egglar and Charles M. Huddleston
Reported by Charles M. Huddleston

Cloud chamber measurements were made in March of neutrons from positions No. 273 and No. 348 of the EBR. The film was read by Mr. V. Ehlers and Miss P. Legault during June and July. The normalizing of those results, together with the higher energy nuclear emulsion results of the Roberts group at Northwestern University, is now in progress. We hope to publish the results of this investigation along with the earlier work at positions No. 1 and No. 118 in the Journal of Nuclear Science and Engineering in collaboration with G. R. Ringo and V. E. Krohn.

It is not expected that there will be any further quarterly reports of this work unless other spectra are investigated by the same technique at some future time.

Gilbert J. Perlow

During the period in which the shop was fabricating the three-chamber spectrometer, some tests were made with the two-chamber model using continuous spectra at CP-5. These were generally

inconclusive for a variety of reasons. It is planned to repeat them this fall.

The three counter spectrometer is like its predecessors except that a third chamber of annular shape follows the second. The counters are electrically isolated by a grid having 98% transparency for protons. The third counter is operated in the proportional region and is in anti-coincidence with the other two. The first set of tests at the Van de Graaff generator was made in August and was considered successful. A continuation of these was made in October, after some electronic improvements. It was also successful. It was found that some of the low energy tail that had resisted interpretation in previous runs could be ascribed to defective lithium targets (evaporated on Ta). Good targets produced excellent peaks. The weak second neutron group from the target corresponding to the first excited state in Be^7 was clearly resolved. This was the case even when the energy was such that the main peak was discarded by the anti-coincidence counter. With another target of comparable thickness as judged from the position of the maximum of a yield curve, the second group was unobservable. When the two yield curves were compared, it was found that the yield at maximum was several times higher for the good target. Presumably this effect can be exploited to obtain a quick test for uniformity of deposition of lithium.

Some few problems remain in the spectrometer development program, and it is possible that more will show up when data are taken with continuous spectra. In particular, the variation of efficiency

with energy is independent of the counter pressure for beams which illuminate essentially the entire counter, but a given spectrum may have to be measured with a more constricted beam.

115-6

Boron Trimethyl

(5200-02, 5230)

Louis Basile

Reported by Louis Basile

As reported in ANL 5497, a supply of trimethylboron was ordered from a commercial source. We have been asked by the vendor to be relieved of obligations on this order due to difficulties encountered in preparation of the compound.

We also inquired of the Bureau of Aeronautics if a sample of this compound is available and could be furnished to us. We were informed that none was available and present plans did not call for preparation of any.

In regard to future work on this project there appears to be little choice. Obtaining the pure compound from a commercial source appears to be a lost cause. We can try obtaining some from Germany. We can take on the project ourselves of trying to prepare a pure compound. This can be done but additional help is needed. Another possible choice is to drop the project altogether. Our present plans do not call for continuing work on this project in the immediate future.

Reporting will be discontinued until such time as it again becomes active.

116-1

Methyl Borate

(5202-02, 5230)

Louis Basile and George Thomas
Reported by Louis Basile

In connection with the making of scintillation detectors for the neutron chopper, the problem arose of recovering enriched methyl borate from the solutions. A simple procedure was developed and is being reported

The solution consisted of a mixture of methyl borate, toluene, and various scintillation phosphors. The toluene-methyl borate mixture was first distilled leaving behind a residue consisting of the phosphors. The distillate was then held at -80°C for a period of time. At this temperature a phase separation takes place. The methyl borate separates from the toluene forming two layers. After a period of time the methyl borate freezes and the liquid toluene can be carefully pipetted away. All operations are carried out under an argon atmosphere to protect the methyl borate from decomposition.

The purified methyl borate was tested as a neutron detector. The results show that the purified product gave better results than the original commercial product.

This will be the only report on this subject. This closes the project.

Design Study for a Multi-Bev Proton Accelerator

During this period the following reports were issued:

Remarks on the Theory of FFAG Fields

Edwin A. Crosbie and Morton Hamermesh
Progress Report No. 7

Contains a derivation of the equation of motion in coordinates relative to a general equilibrium orbit, and corrects some errors which appeared in the paper of K. Symon, MURA, KRS-8.

Use of Unified Treatment of FFAG Fields

Edwin A. Crosbie
Progress Report No. 8

Derives the general expressions (up to terms in $1/N^2$, where N is the number of sectors) for the radial and vertical betatron wave-lengths, in terms of quantities measured relative to a general equilibrium orbit.

Stability Conditions and Half-Integral Defocussing Effects of a Spirally Ridged FFAG

Lee C. Teng
Progress Report No. 9

Calculates the loss of beam intensity in passing through half integral resonances.

Proposal for a High Current 25 Bev Proton Accelerator

Edwin A. Crosbie, Martyn Foss, Melvin Ferentz,
Morton Hamermesh, H. Haussman (Ohio State)
John J. Livingood, John H. Martin, Lee C. Teng
and Louis A. Turner

This contemplates the construction of a two-stage proton accelerator; the first stage to be a synchrocyclotron of 2 Bev energy employing the striped-pole version of the FFAG principle and to serve as an injector for a striped pole FFAG ring accelerator. Transfer of ions from one machine to the other to be by means of the Teng continuous injection scheme. Representative parameters and cost estimates are given.

Continuous Injection into a Circular Ion Accelerator

Lee C. Teng
Internal Report No. 4

Describes the use of regenerative deflector and regenerative inflector so as to transfer ions from a stable orbit in one magnetic particle accelerator into a stable orbit of a second similar machine, without the use of any pulsed techniques. This has appeared in The Review of Scientific Instruments, 27, 106, 1955.

Radio-Frequency Studies for the 25-Bev Accelerator

John H. Martin

Some of the problems in the design of the injector's RF system arise from the great size of the cyclotron D. A method for driving its 0.10 μ f capacity to ground has been worked out and given a

0.08 scale model test. It is driven as a portion of a $3/4$ wavelength resonant tapered line. The model shows that the tapering pushed the transverse mode on the D safely above any operating frequencies. It also shows that the required 50% tuning can be accomplished by a combination of series and shunt variable capacitance without introducing appreciable loss. 100 to 125 KW will be required to produce 25000 volts (RMS) on the D lip.

The proposed accelerating system in the ring magnet calls for an RF cavity with a high available voltage and about 4 percent frequency modulation. An approximately half scale model of a cavity, tunable 4.5 percent, has been made and tested. The rotating paddle tuner lowers the effective aperture shunt resistance about a factor of 3 down to 70,000 ohms referred to the full scale model. This will require a pulse power into the cavity of about 1.5 megawatts to produce an aperture voltage of 320,000 (RMS).

134-2

Atomic and Molecular Excitation Following β^- -decay of Tritium (5200-02, 5230)

Sol Wexler

The previous progress report contained a sketchy proposal to study the spectroscopy of the decay products from negative beta emission in atomic and molecular tritium. It is now possible to state the problem in more quantitative terms.

1. Excitation of $(\text{He}^3)^+$ from β^- decay of atomic tritium.

If in beta emission the nuclear electron leaves the atom in a time that is short compared to the period of orbital motion, the sudden change in nuclear charge "shakes" the electronic cloud. The reorientation of the electronic shells to fit the coulombic field of the $Z + 1$ nucleus (in negative beta emission) can promote one or more electrons to excited states or to the continuum. The simplest case,

has been treated theoretically in an exact manner, since the appropriate wave functions are known. Migdal¹ has shown that the probability of finding the $(\text{He}^3)^+$ in a given excited level (ns) following beta emission from H^3 in its ground state is given by the relation.

$$W(\text{ns}) = \frac{2^9 (2n-1)^{2n-4}}{(2n+1)^{2n+4}} n^5.$$

Numerical values for formation of the seven lowest states are listed in Table V.

1. A. Migdal, J. Phys. (U.S. S.R.) 4, 449 (1941).

TABLE V

Probabilities of Atomic Transitions from H^3 (1s) to the (ns) state in $(He^3)^+$

$(He^3)^+$ State	W (ns)
1	0.703
2	0.25
3	0.013
4	0.0045
5	0.0022
6	0.0013
7	0.00080

The problem then, is to devise an experiment to measure the probabilities of formation of several of the excited states of the helium - 3 ion produced in beta decay of atomic tritium, and thereby to have a test of the validity of the "sudden change in nuclear charge" theory.

The characteristic radiation from each of the excited atomic states of $(He^3)^+$ would obviously indicate its presence in the beta transition. If it were possible to measure the intensities of all the optical transitions from each excited state, a straight-forward test of the above-mentioned theory could be made. However, only a few of the transitions are observable with the spectroscopic equipment available; these lines are listed in Table VI. Thus it is necessary to be able to calculate the total intensity of radiation from a given excited state, using the intensity measured for one or two of the atomic transitions. Fortunately, the theory

of radiative transitions for the single electron case has been treated exactly by several writers. Condon and Shortley² list the probabilities of electronic transitions from each excited state (up to $n = 6$) to all states of lower energy. Maxwell³ and Slack⁴ have extended the calculations to the 7s level. The relative intensities observed experimentally for the transitions listed in Table VI can therefore lead directly to the relative rates of formation of excited $(\text{He}^3)^+$ in the 4s through 7s states when these ions are produced by negative beta emission in atomic tritium.

TABLE VI
Optical Transitions in $(\text{He}^3)^+$ Which May Be Observed

<u>Transition</u>	<u>λ (Å)</u>
4s - 3p	4687.16
5s - 3p	3204.10
6s - 3p	2734.17
6s - 4p	6561.98
7s - 3p	2512.02
7s - 4p	5413.10

Experimental Progress :-

A circulating system containing the gas exposure cell has been constructed. The gas cell has been designed to throw the

-
2. E. U. Condon and G. H. Shortley, *The Theory of Atomic Spectra* (Cambridge, 1951) p. 136.
 3. L. R. Maxwell, *Phys. Rev.* 38, 1664 (1931).
 4. F. G. Slack, *Phys. Rev.* 31, 527 (1928).

maximum amount of light possible into the 30' grating spectrograph available.

A thorough search of the literature was made to learn the most efficient method for dissociating tritium molecules; the electrical discharge method appears to be most suitable. A high frequency discharge is being tested, and a glow discharge tube is being constructed. A Wrede gauge to measure the partial pressure of atomic tritium has been built.

Installation of the vacuum frame hood has been completed, and a vacuum line for purification of the tritium is nearly finished.

It is planned to measure the spectral intensities with multiplier phototubes (RCA 1P28 and 7216). To decrease the photocathode currents to negligible levels the tubes are to be refrigerated at liquid nitrogen temperatures. A specially designed cold trap is under construction. The auxiliary electronic equipment is on order.

2. Proposed study of molecular excitation following β^- -decay of T_2 .

The previous progress report also related a proposed experiment to measure the vibrational-rotational bands of $(T:He^3)^+$ formed in the ground electronic state as the result of beta emission from molecular tritium. The probabilities of the molecular ion being produced in several vibrational states have been calculated by Cantwell⁵.

5. Murray Cantwell, Preprint (To be published).

If the spectrum is to be observed the molecular ion must live long enough for the radiative transition to occur (i.e. a few milliseconds). However, as a result of literature searches and discussions it was learned that there are two possible reactions of $(\text{T: He}^3)^+$ with molecular tritium which occur in times of the order of 10^{-9} second under the conditions of the proposed experiment. These are (a) the bimolecular reaction $(\text{T: He}^3)^+ + \text{T}_2 \longrightarrow \text{T}_3^+ + \text{He}$ and (b) degradation of vibrational energy by collision. Inasmuch as these two competing reactions are so much faster than the radiation process, the experimental study of molecular excitation following beta decay of T_2 has been abandoned. It may be mentioned that, were it not for the difficulties stated, observation of the vibrational spectra of $(\text{T: He}^3)^+$ might possibly have been accomplished with the Pb-Te photoconductive surfaces and infrared spectrometer available at Northwestern University.

135-9

Electron Neutron Interaction

(5200-04, 5220)

M. F. Crouch (Case Institute of Technology)
 Victor E. Krohn, George R. Ringo
 Reported by Victor E. Krohn

Work has continued on the apparatus for measuring the coherent scattering amplitude for neutrons on krypton. The measurements gave roughly the expected amplitude, but a reliable quantitative result was not obtained.

The main problem at the present time is avoiding boiling and turbulence in the liquid krypton mirror. At present, we are able to

obtain a placid mirror when the krypton is condensing slowly at pressures from about 40 to 90 pounds absolute. Several minor modifications of the apparatus have been planned in order to insure that a good mirror will be available for longer periods of time.

138-1 A Recording Spectroradiometer (5200-02, 5230)

H. Bruce Phillips

A new electro-mechanical design has been evolved which is much more compact than the original one. Several servo-mechanisms have been built in bread-board style and two finished assemblies have been made in the shop. The device is taking shape nicely both on paper and on bread-board. Work is not being pressed however, and we shall not report unless the research becomes active again.

139-2 Liquid Scintillators (5200-02, 5230)

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

To investigate further the possibility of incorporating elements of higher atomic number into liquid scintillators, the effect of adding small concentrations of iodobenzene, m-iodotoluene, or 1-iodonaphthalene to a toluene-diphenyloxazole liquid scintillator was determined. Measurements of light-output vs. concentration of the iodo-compound showed all three of these compounds to be very effective quenchers. For example, the light-output of the liquid scintillator is cut

in half by addition of only 0.9% (by weight) of iodobenzene, and the other two iodo-compounds produced equivalent quenching effects. However, since iodobenzene and similar compounds are known to be unstable, it is possible that the observed quenching action was due to the presence of decomposition products such as free iodine. Further investigation of this effect will be undertaken.

A considerable amount of time and effort has been devoted to the purification of various solvents and fluors for use in subsequent investigations of liquid scintillators. Attempts to eliminate the yellow color from commercially-obtained 1-methylnaphthalene and dimethylnaphthalene by distillation and by adsorption have thus far been unsuccessful, although literature references to the former compound indicate that it is a colorless liquid when pure. Approximately four pounds of reagent grade naphthalene have been additionally purified by successive recrystallizations from hot ethanol. The effectiveness of distilling this naphthalene, and of passing it in solution through an adsorption column, has proved to be difficult to establish, but further work is planned. Evidence that the original reagent-grade naphthalene was relatively impure was provided by the pronounced yellow color of a concentrated alcohol solution and by changes in the ultraviolet absorption after successive recrystallizations.

Principal effort is now being devoted to purification of a sizeable quantity of toluene, since this has proved to be one of the most useful solvents for liquid scintillators. Spectrophotometric measurements

have shown that toluene obtained from different commercial sources, or different lots from the same source, may vary widely in purity, but distillation appears to be quite effective in purifying this material. Purification of toluene by adsorption is also under investigation.

During the efforts to purify toluene it has been noted that the presence or absence of dissolved oxygen has a pronounced, reversible effect upon the ultraviolet absorption of this solvent. This may be observed by alternately bubbling oxygen and argon through a sample of toluene and noting the alternately increased and decreased ultraviolet absorption. It is felt that this phenomenon is probably related to the oxygen-quenching effect upon the scintillation light output of toluene solutions as reported previously in the literature.

Interpretation of the results of previous experiments on liquid scintillators has been hampered by the lack of knowledge of the degree of oxygen quenching taking place. Although it has now been established that dissolved oxygen does quench many of the well known liquid scintillators, little is known about the details of this quenching process. For example, it has been stated that the effects of oxygen quenching are suppressed by an increase in the activator concentration or by the addition of secondary activators, but data on these effects have not been published.

During the last two months we have designed a system for the preparation of liquid scintillators under a controlled atmosphere, which may be air, argon, nitrogen, or other gas. The construction of

this apparatus is nearly complete. With this system, the concentration of an activator, or other constituent, may be changed by a factor of 100 without exposing any of the ingredients to the outside atmosphere. It is also possible to bring a sample to equilibrium with a number of different atmospheres in succession, without removing the sample from the measuring system. The light output of the scintillator is determined by measuring the response (d. c.) of a photomultiplier upon exposure of the sample to β rays. This measurement is made without removing the sample from the controlled-atmosphere system.

With good fortune, the performance of this system should be determined during the coming month. Until these tests are completed, the reporting of the details of the apparatus will be deferred.

140-6

A Gaseous Scintillation Counter

(5200-02, 5230)

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

The detection of light of de-excitation of noble gases by a photomultiplier tube when the gas is excited by heavy charged particles has been found useful in the counting of fission fragments and is expected to function satisfactorily as a neutron detector.¹ However, our recent efforts with 4" 6364 Dumont photomultipliers whose photo-cathodes subtended a solid angle at an alpha particle source of about 50% of 4π indicate that the phototube technique is just not sensitive enough to give

1. L. Bollinger and G. Thomas, private communication.

sufficient resolution for neutron spectroscopy. It may still be that a photo-cathode of greater efficiency in the far ultraviolet would be satisfactory. That matter should be explored.

With the usual gas cell filled to a pressure of three atmospheres of argon, a lead sulphide photo-conductor², measuring 2 cm. x 2 cm., gave pulses in response to alpha-particles. A differential analysis showed a resolution of 15% for a solid angle of 5%. Negotiations are in progress for procuring a photo-conducting shell to surround the alpha-source. Noise problems can be largely obviated by requiring coincidence between two portions of the photo-conducting envelope.

The use of a photo-conductor lacks the quick response of the photo-multiplier technique but appears to have the advantage of greater sensitivity.

142-4

Electron Accelerator

(5200-02, 5230)

H. B. Phillips

During this period most of the work on the accelerator has been concerned with the beam-pulsing circuits and the associated power supplies. An electrical bread-board model of the trigger and sweep circuits was evolved which operated satisfactorily. However when the circuits were built into their chassis several difficulties arose. Although much effort had been made to keep lead inductances and stray

2. Kindly supplied by Dr. Cashman of Northwestern University

capacitances to a minimum, the chassis-built model suffered from the effects of the new wiring. A second chassis model was then built, in which critical attention was given to layout so as to obtain very short lead lengths. At this stage it was found that the remaining inductive effects resulted from the internal inductance of some of the capacitors being used. A number of experiments were made to determine the types of capacitors suitable for use; in some cases it was necessary to put five capacitors in parallel in order to reduce the inductance to a suitably low value. When it is considered that currents of several amperes are being switched in about 10 millimicroseconds, it is easy to see that inductances must be reduced to a small fraction of a microhenry if severe transients are to be avoided. The present sweep circuit is operating satisfactorily, and work is now being concentrated on the power supplies. There are no unusual difficulties involved here, the problem being to keep weight and cost low and efficiency high. The power supply design is almost finished now.

143-4

Plastic Scintillators

(5200-02, 5230)

Louis Basile and Robert K. Swank
Reported by Louis Basile

We are investigating the possibility of developing more efficient plastic scintillators by the addition of new or untried compounds to the plastic.

Samples of tetraphenylallene in both vinyl toluene and styrene were prepared. This compound reacts with the monomers to form a dark green colored solution. This discoloration, of course, eliminates use of this compound for the purpose intended.

Samples of plastics containing difluorenyl as an additive had no effect on light output whatsoever. It may be that a wave length shifter has to be added to the mixture. This was not investigated further.

Some preliminary work has begun using POPOP as a scintillation phosphor in plastics. While the results were very encouraging they are not conclusive due to breakdown of the equipment. We will continue this investigation further.

Loaded Plastic Scintillators with Heavy Elements .

We are continuing the investigation of the effects of the addition of various metallo-organic compounds on the relative light output of plastic scintillators. Preliminary studies have been made with tetraphenyltin, triphenylarsine, triphenylstibine, triphenylbismuthine and diphenylmercury.

Samples containing triphenylstibine in polyvinyl toluene discolored. We have not been successful in preparing clear plastics containing this compound. Triphenylarsine acts as a quencher. Another disadvantage of this compound is the low atomic number of arsenic. Triphenylbismuthine is a definite quencher. With the fluor additives that we tried, we were able to get a better response but not enough. Samples

containing tetraphenyltin gave the best light response of the organo-metallic compounds tried. However, this compound also has some serious disadvantages; it is difficult to obtain pure tetraphenyltin, there is a low percentage of heavy metal in the compound, and the substance has a limited solubility in vinyl toluene.

In the previous report, ANL 5497, we made note of the fact that diphenylmercury turns yellow on standing. We have investigated this phenomenon and found that diphenyl mercury is sensitive to U-V light. If a freshly sublimed sample is irradiated with U-V light, the sample will turn yellow after a short period of time. In view of this, all operations involving the use or handling of diphenylmercury are now done under dark-room conditions.

We also observed that under certain conditions for polymerization, samples of polyvinyltoluene containing diphenylmercury discolor. We are at a loss to explain this phenomenon. Conditions are now standardized whereby we can obtain clear samples of diphenylmercury in polyvinyltoluene with limitations on concentration of the additives and polymerization temperature.

We have prepared samples containing diphenylmercury and terphenyl in polyvinyltoluene in the absence of U-V light. Addition of small amounts of diphenylmercury significantly reduces the light output. Increasing the concentration of diphenylmercury correspondingly decreases

the light output further. The amount of terphenyl present appears to have little effect. Holding the amount of diphenylmercury fixed, varying the concentration of terphenyl from 3% to 5% results in little change in light output of the plastic.

We intend to continue this phase of the investigation in greater detail. In an attempt to activate the mercury loaded plastic we intend to try other scintillation phosphors and combinations of them.

One of the best heavy element-loaded plastic scintillators so far prepared, No. 227, containing diphenylmercury in polyvinyltoluene activated with terphenyl and tetraphenylbutadiene was examined with the scintillation spectrometer. This scintillator is 13/16" diameter by 1/2" thick and contains 4.18% mercury, by weight. Its response to β rays was found to be 21% of our standard anthracene crystal. An independent measurement with gamma rays was found to give 23% of the anthracene standard. These response figures are in terms of light output per unit energy absorbed, and the two values are in agreement within experimental error. This is about half the scintillation response of a good plastic scintillator containing no mercury.

The pulse amplitude spectrum of plastic scintillator No. 227 was obtained, using a Cs^{137} gamma ray source (Energy = 662 kev). No photoelectric peak was observed. For comparison, the spectrum of a plastic scintillator having the same average pulse size,

but containing no mercury, was obtained. The two spectra were distinctly different in the region where the photoelectric peak would be expected, the mercury-loaded scintillator being relatively higher than the non-loaded scintillator. Upon subtraction, the difference curve showed a peak at a pulse height 10% smaller than the calculated position of the photoelectric peak. Because of the errors inherent in subtracting the two pulse amplitude distributions, the observed position of the peak is considered to be in agreement with the calculated position. Measurement of the area under the "photoelectric" peak so obtained indicated that approximately 2% of the gamma ray counts were caused by photoelectric absorption. For a sodium iodide scintillator of the same mass, this figure would be about 12%. A much larger photoelectric effect will be observed at lower energies. Similarly, a much greater apparent photoelectric effect will be observed in larger scintillators as a result of multiple processes. The possibility of preparing giant mercury-loaded plastic scintillators may outweigh the disadvantage of smaller pulse amplitude (as compared with NaI) for application in "total absorption" spectrometers.

A remarkably clear colorless crystal of decaborane was accidentally grown during the process of purification of this compound. The crystal was observed to fluoresce under ultraviolet light so its scintillation properties were investigated. Using neutrons from Be^9

(α , n) C^{12} , pulse amplitude distributions were obtained with and without the source and with and without paraffin moderator. Thermal neutron pulses were observable, but were of the same magnitude as photomultiplier noise pulses. No indication of a peak in the distribution could be observed. It was concluded that the scintillation response of this crystal was too small to be of practical value.

Boron Loaded Plastic Scintillators

We have not prepared any boron loaded plastics during this past interval. We have prepared some triethylborazole for use in both plastics and liquid scintillators. We will continue preparing this material until we have a reasonable supply for testing.

We are also purifying decaborane for use in plastics and liquid scintillators.

144-4

Scintillation Counter Techniques

(5200-02)

John S. Moenich

In the last six months thirty-five crystals were canned for various divisions. It may be of interest to note that during these six months new techniques had to be developed to meet the requests for well-type crystals and for needle probes. Three of the former have been made during this period.

In an attempt to cut the cost of crystal cans, which at the present time are machined and to realize a more water tight package through soldering techniques, some research was done on electro-forming of thin copper cans for use in some canning applications. No difficulty was encountered in the actual forming process and good, durable coatings up to eleven mils thick could be obtained in three hours plating time. The present problem is the removal of the finished cans from the mandrels without injury to either cans or mandrels.

Potting of photomultipliers has gone through some minor developments. Thinner light guides are being utilized to minimize drop in pulse height and the bakelite ring which formerly was used to center and essentially float the tube in the potting can has been eliminated. A solid piece of lucite machined to proper dimensions does both jobs of transmitting light and centering tube and in addition provides better insulation in the vicinity of the cathode.

In the last six month period twenty-seven tubes were potted for various divisions.

145-3

Organic Crystal Scintillators

(5200-02, 5230)

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

Work was continued on this program during the first four months of this period but was discontinued on September 1, 1955.

No further work is planned at this time and reporting on this program will be discontinued. The reasons for stopping are as follows.

Since the beginning of this investigation, crystal boules containing the following substances have been prepared:

1. pure methylbiphenyl
2. methylbiphenyl plus tetraphenylbutadiene (TPB)
3. methylbiphenyl plus diphenyloxazole (PPO) (3 boules)
4. pure naphthalene
5. naphthalene plus anthracene (AC)
6. naphthalene plus diphenyloxazole

The first three items above were reported in the previous progress report. For completeness, we present here the data taken on all the above samples. These data are presented in Figure 4. The figure gives the light output for β rays, relative to the light which would be given off by an anthracene crystal for the same absorbed energy. The values of the light output are not absolute, but merely indicate the relative response of the type 5819 photomultiplier tube used in the measurements. Of the systems studied to date, none appear to have any practical value as scintillation counters.

Two major difficulties have greatly slowed the progress of this work and reduced the accuracy of the experimental results:

1. The presence of the activator strongly influences the crystal-growing habit of the host. At the concentrations

Fig. 4

needed for proper activation, the crystal boule in most cases degenerated into a milky, wax-like substance .

2. The concentration of the activator in most cases did not vary as anticipated. In one case, the concentration at each point along the axis was measured in the center of the boule as well as the average over the whole cross section. Comparison of the results showed a large erratic fluctuation of concentration radially out from the center. In only one case (diphenyloxazole in naphthalene) did the concentration of the activator vary exponentially along the axis as expected. The failure of this expected behavior is ascribed principally to heterogeneous separate crystallization of host and activator. In one case, extremely low values of the solubility constant, k , caused the concentration of the activator to remain practically constant throughout the boule.

The rather limited number of systems investigated does not preclude the possibility that other systems may lend themselves more readily to preparation of samples by this method. Furthermore, refinement of the experimental apparatus might reduce or eliminate some of the difficulties. However, it appears more fruitful at this time to devote more time to work on liquid and plastic scintillators and, in the near future, to the measurement of decay times with the new electron accelerator.

146-4

Rotating Condenser Electrometer

(5200-02, 5230)

Frank Lynch

An electrometer using the rotary converter has been constructed and tested. Some difficulty was caused by an intermittent electrical contact between the stainless steel shaft of the rotor, and the tungsten carbide thrust plate. Liquid Gallium was tried and gave good contact, but crept up over the sapphire ring bearing causing excessive friction. With a V pivot and bearing, Gallium would probably be satisfactory. At present, the converter has been operating satisfactorily in air, with graphite on the thrust plate. Work on this project has been discontinued temporarily.

147-3

Alpha Air Proportional Counter

(5200-02, 5230)

Frank Lynch

The report on this development was shortened and several figures eliminated at the request of the editor of the Review of Scientific Instruments. It is now scheduled for publication in the December issue. This publication completes work on the project.

Raymond J. Munick

A change in terminology has been made since the previous reports. The steady current from a dielectric will be referred to as the conduction current, since it must correspond to conduction of charge through the dielectric, and the transients that appear after changes in voltage will be referred to as polarization charging, or discharging currents.

A re-calibration of the thermistor bridge which was used to determine temperature in the measurements of conduction currents in Plexiglas led to changes of the values. An example of the revised data is shown in Figure 5. They indicate that the conductivity is represented sufficiently well by an equation of the form

$$\sigma = \sigma_0 \exp (-W/kT),$$

where σ is the conductivity, k is Boltzmann's constant, T is the absolute temperature, and σ_0 and W are constants. The results of a least-squares evaluation of the constants are listed in Table VII.

In view of the hypothesis that the observed electrical conduction in Plexiglas is predominantly ionic, it is worth noting that solid dielectrics in which ionic conduction is known to predominate exhibit such an exponential temperature dependence with constants of the

Fig. 5. Logarithm of conductivity vs reciprocal absolute temperature for Plexiglas M2 with constant voltage of 315. Dots taken with increasing temperature, squares with decreasing temperature.

same order of magnitude. For example, for sodium chloride σ_0 and W are reported as 1×10^6 mhos/cm and 1.90 ev respectively¹ as contrasted with 3.7×10^5 and 1.460 for Plexiglas. The value of 1.460 for W is in good agreement with a value of 1.6 ev reported for unplasticized Perspex², which like Plexiglas is a polymer of methyl methacrylate.

TABLE VII

Least-squares Estimates of the Constants in the Equation

$$\sigma = \sigma_0 \exp (-W/kT).$$

Specimen	σ_0 (mhos/cm)	W (electron volts)
M1	$(10.0 \pm 4.4) \times 10^5$	1.4709 ± 0.0123
M2	(5.4 ± 1.7) "	1.4657 ± 0.0075
M3	(3.25 ± 0.91) "	1.4524 ± 0.0077
M4	(3.9 ± 1.5) "	1.4550 ± 0.0103
Average	$(3.75 \pm 0.69) \times 10^5$	1.4600 ± 0.0044

Measurements of the conduction current in Plexiglas as a function of voltage were continued at 60° C and extended to 75.8° C and 3125 volts. At first glance, the data indicate current directly proportional to voltage, but a closer analysis, which includes corrections for the superposition of charging and discharging currents at 60° C,

1. R. M. Barrer, Diffusion in and through Solids, (University Press, Cambridge, 1951), p.264, Table 64.
2. J. F. Fowler and F. T. Farmer, Nature 175, 516 (1955).

indicates that above about one kilovolt (electric intensity of about 10 kilovolts per cm) the current increases more rapidly than linearly, as shown in Figure 6. Graphical analysis indicates that a part that increases exponentially as either V or $\sqrt{V}$ is superimposed on the linear part (V is voltage). A tentative interpretation of these results is that the linear and exponential parts correspond to ionic and electronic components of the current, respectively.

Changes have been made in the experimental setup in order to eliminate several suspected sources of error. For example, a coaxial cable in the circuit from insulator specimen to electrometer has been replaced by a rod within a rigid, brass tube. The 10^{12} ohm current-measuring resistor has been replaced by a polystyrene capacitor, and even this capacitor and the remaining current-measuring resistors (10^{11} , 10^{10} , and 10^9 ohms) can be readily disconnected from the electrometer in order to measure the rate of drift of the electrometer potential. Other changes have been made to secure better temperature control and measurement.

A Plexiglas specimen, even though grounded on one side and connected directly to the electrometer on the other side, shows oscillations in current about zero of as much as 10^{-14} amperes in amplitude with a period of approximately fifty minutes, which correspond to oscillation in room temperature of about 0.5°C in amplitude. A treatment, which consists of maintaining the Plexiglas sample at 120°C between two brass plates at the same electrical potential for about twenty hours, was

Fig. 6. Current vs voltage at constant temperature. x's represent Plexiglas M3 at 60.6°C. Circles represent Plexiglas M2 at 60.1°C. Current from Plexiglas M3 at 75.8°C is about ten times larger, but behavior with respect to voltage is about the same.

found to be sufficient to eliminate the effect. It was surmised that the oscillations in current were a transient effect of temperature change on a frozen-in electric polarization, since Plexiglas is known to form electrets³, and that maintenance of a zero potential difference at an elevated temperature permitted the polarization to dissipate.

Measurements of the charging and discharging currents of Plexiglas at room temperature for intervals from one millisecond to one hundred seconds were finally obtained with a vacuum tube electrometer and dc oscilloscope (Tektronix 535). The factors which made the vacuum tube electrometer particularly suitable for this experiment were its rapid response (about 3μ sec rise time, 5μ sec fall time) and its large, negative feedback factor (about 100), which helped to reduce the time constant when the insulator specimen and current-measuring resistor were connected to the electrometer. The transients on the oscilloscope screen were photographed with a Polaroid Land camera. An example of the data obtained is displayed in Figure 7 together with currents from the same specimen for times from ten to eighty-thousand seconds observed with a vibrating reed electrometer and Brown recording potentiometer. The entire curve of current versus time cannot be represented by a single function of the form t^{-n} (t is time, n a constant).

3. H. H. Wieder and S. Kaufman, J. Appl. Phys. 24, 156 (1953); Elec. Eng. 72, 511 (1953).

97

Fig. 7. Logarithm of current vs logarithm of lapse of time from change of potential difference across Plexiglas M3 at about 25°C. Dots represent positive current from application of 310 volts. x's represent negative current from removal of 310 volts. Data taken with oscilloscope and vibrating reed electrometer overlap between 10 and 100 seconds.

A paper entitled "Electrical Conduction in Plexiglas", which was mainly concerned with the conduction currents described in the first few paragraphs, was presented at the Chicago meeting of the American Physical Society on November 26, 1955.

Writing was continued on an article based on results previously obtained for Lucite, Fluorothene, polyethylene, polystyrene and Teflon.

149-2

A Dynamic-Condenser Magnetometer (5200-02)

S. Bradley Burson, Robert C. Doerner
and David W. Martin
Reported by S. Bradley Burson

The shop work on the rotating coil and condenser has been completed and the mechanical parts assembled. A number of problems encountered in attempting to get the system into operation are deemed noteworthy.

The rotating coil which extends into the magnetic field to be measured is housed in an aluminum tube and supported at its outer extremity by a bearing. Since this assembly is in the magnetic field, it was considered advisable to use only non-magnetic materials. The first effort was to turn and polish the micarda rod which extends from

the end of the coil assembly and allow it to rotate in an oilite bronze bushing. This appeared satisfactory at first, but during a test of about an hour, developed sufficient heat to freeze the bearing. Additional lubrication was tried without remedying the defect. The oilite bronze was replaced by a smoothly polished brass bushing and tried. Heating was reduced but still present. The micarda shaft was then turned down and fitted with a solid nylon sleeve to form the journal and then polished allowing about 0.002" diameter clearance. When lubricated with light oil, this bearing proved satisfactory.

The two stator sections were originally held in place within the condenser housing by means of four machined micarda blocks about six inches long and one inch square. After assembly it was found that the leakage resistance between the two stators was of the order of 100 megohms. Since this material exhibits very high internal resistance, the leakage was attributed to surface effects caused by the machining. The insulators were replaced with 3/4" polystyrene rods and after re-assembly, the leakage resistance was too great to be measured with the available apparatus -- in excess of 10^9 ohms.

Preliminary tests show the calculations to have been fairly accurate. The wave form of the 30 cycle signal generated by the dynamic condenser was examined with a wave analyzer and found to contain measurable amounts of odd-order harmonics. About 4% 90 cycle and about 0.8% 150 cycle were considered intense enough to be capable of over-riding the error signal when the instrument is near the balanced condition. The harmonics will be preferentially attenuated by selective filter networks. The amplifier and voltage supply for the magnetometer are now being constructed by the Electronics Division.

150-1 High Vacuum Valve (5200-01, 5220)

Robert E. Holland and F. Paul Mcoring
Reported by Robert Holland

A note entitled "A High Vacuum Butterfly Valve", describing a simple large aperture valve has been accepted for publication in the Laboratory and Shop Notes section of the Review of Scientific Instruments.* This closes the project.

152-1 Radiation Damage to Dielectrics (5200-03, 5230)

Raymond J. Murlick

This is the start of a program to find out the effect of radiation from radioactive sources or charged-particle accelerators on the electrical properties of insulating dielectrics. Such knowledge may lead to a better understanding of the electrical properties of

*Rev. Sci. Instr. 26, 989 (1955).

insulators.

A literature survey on this subject has been made during the past five years.

Although it is planned to try all types of radiation, a beta emitter was selected for the first experiments in order to avoid difficulties associated with the use of more penetrating radiation, such as protecting the experimenter and apparatus from the radiation and avoiding extraneous currents produced from the surroundings of the insulator specimen. Strontium-90 was selected as being a gamma-free beta emitter of half-life short enough to allow a large amount of activity to be obtained, and long enough to avoid appreciable changes in activity during the course of an experiment. Additional reason for the choice of Strontium-90 is that its daughter, Yttrium-90, is also a gamma-free beta emitter, which decays to a stable isotope, Zirconium-90. A Strontium-90, Yttrium-90 source with an activity of about 110 microcuries, consisting of active material on the face of an aluminum disk one-half inch in diameter and one-sixteenth inch thick, was prepared by Raymond F. Barnes of the Chemistry Division. After the first experiment a drop of Zapon lacquer was spread over the active face to keep material from being rubbed off, as the source is placed in direct contact with the insulator specimens.

In the experiments that have been done with the beta source, a brass adapter connected the Plexiglas specimens to the converter unit of a Metallurgical Laboratory Model 3 vibrating reed electrometer. Current from the guarded electrode of the insulator produced a voltage drop across a 10^{11} ohm resistor that shunted the electrometer input. Connection to the high voltage electrode on the top side of the insulator was made by a flat brass ring and insulated wire. The source was roughly centered within the brass ring with the active side down on the high voltage electrode. A brass plate that merely rested on top of the holder provided electrical shielding sufficient to permit the detection of currents of 10^{-15} amperes. Specimen M4 had evaporated aluminum electrodes, which were estimated to be one- to two-tenths mg/cm^2 thick from weighings on other specimens and therefore thin enough to transmit most of the beta particles. The thickness of the electrodes of Plexiglas M1, which consisted of sprayed-on Rubalt, a colloidal suspension of carbon in a volatile solvent, was not known.

When the source was placed on M4 or M1 with the high voltage electrode grounded, the currents obtained were $-1.2 \mu\mu\text{a}$ from M4 and $+1.7 \mu\mu\text{a}$ from M1. If this current is that of the beta particles themselves, it should be negative and not greater than about $0.34 \mu\mu\text{a}$ in magnitude, since it should not exceed the rate at which electrons are being projected into the insulator. That this current is too large to be

merely the beta particle current and that the sign is wrong in the one instance may somehow be connected with the generation of x-rays, which has recently been pointed out as a possible source of confusion in an experiment of this type¹.

When 308 volts were applied to either specimen, with the no-voltage current balanced out at the electrometer input if the source was on the specimen, the conduction current did strange things both in the absence and presence of the source. In some instances it oscillated, apparently following oscillations in room temperature, and in other instances it increased with time after the charging current had become small. Because the results were inconclusive, measurements with this crude setup were discontinued.

1. J. C. Firmin and C. W. Oatley, Proc. Phys. Soc. (B) 68, 620 (1955).

II. MASS SPECTROSCOPY

10-10

(A Search for Rare Naturally Occurring Isotopes)
(5200-01, 5220)

David C. Hess

Nothing has been done on this program for the past six months. The search, however, will not be abandoned, but will be continued from time to time as circumstances permit.

17-5

Long-Lived Activities

(5200-01, 5220)

David C. Hess

A number of samples have been sent for neutron irradiation in the MTR. Some of these were to be loaded early in September and the others at intervals thereafter.

Several of the sample units were rearranged by MTR personnel for the purpose of reducing the total volume required. In this process one of the samarium samples was broken. A replacement was supplied from ANL.

18-2

Lead Ages of Meteorites

(5200-01, 5220)

George Edwards and David C. Hess
Reported by David C. Hess

There is an apparent correlation between the purity of

a small lead sample and the useable data obtained from the mass analysis. Iron impurities appear to decrease the ion emission and made the run more inaccurate. To decrease the iron contamination the sulfide precipitation described previously¹ was replaced by an ion exchange purification. The solution is passed through Dowex Anion resin 1 x 10 in 1N HCl and the column is further washed with 1N HCl. Essentially all the iron and calcium elute with the 1N HCl while the lead does not. The lead is then eluted with 6N HCl and further treated as before, including the electrolysis.

Normal lead contamination was reduced to about 1 μ g. This was determined by analysis of the various reagents or products using the isotopic dilution method.

Three different amounts of Wilberforce Zircon were run and showed about 1 μ g of contamination.

Several meteorite samples were then run. The results indicated a lead content of 0.3 to 0.4 μ g/g. This is somewhat lower than some previously reported values. A sample of Nuevo Laredo meteorite (kindly supplied by C. C. Patterson) was run. Lead from this meteorite has an unusual composition for lead from a stony meteorite as was shown by Patterson. Our results should show a mixture of the 1 μ g or less contamination lead and the 7.0 μ g of lead to be expected from the 10 g sample used. Instead our results indicate a much higher relative contamination. When this result and the low lead yield for

1. ANL-5497

2. C. C. Patterson, Beochim. et Cosmochim. Acta. 7, 151 (1955).

the Modoc meteorite are considered, it appears that there is either much more contamination than indicated by our blank runs, or there is loss in the initial evaporation process. Since the radioactive and isotopic tracers are added subsequent to this evaporation, loss could be occurring in this part of the procedure. Working on the theory that perhaps the evaporation temperature was too high so that a glass was being formed, evaporations were carried out over a range of temperatures from 1200° to 1650° C. There was no trend in the yield values although there was a considerable variation.

An alternative possibility is that some of the lead chloride is lost through the glass wool filter before it has become sufficiently "clogged" to retain fine particles.

At this point, G. Edwards went to Houston. Further investigations at Argonne will depend on: (a) rebuilding MA-15B, work now in progress, and (b) further work by Edwards for which he will need lead analyses (pending his completion of a mass spectrometer in Houston), or (c) continuation of this lead work by Marshall in Urey's group with assistance from Argonne. The experiments require the services of a chemist and a mass spectroscopist.

19-1

The Capture Cross Section of Potassium 39
for EBR Neutrons (5200-01, 5220)

David C. Hess and David Okrent (Reactor
Engineering)
Reported by David C. Hess

A sample of potassium chloride which had been especially depleted in K^{40} by the Stable Isotopes Division at Oak Ridge was placed in Hole No. 208 in the EBR for a number of months. It was irradiated by fast neutrons of energies in the region of hundreds of kev. The starting material and the irradiated material were compared in the 60° 12 inch magnetic analyser, MA-15. Ions were produced from a tungsten filament which had been heated in a vacuum to decrease natural potassium contamination, then heated in air to produce an oxide coat. The sample in the form of chloride solution was then deposited on the filament.

The separated ions were detected by an electron multiplier followed by an Argonne vibrating reed electrometer. The output was recorded on a Speedomax recorder that has a response time of one second.

Several runs were made and the second runs were usually made on a used filament in an attempt to establish equilibrium.

The statistical spread of the data (partially due to a multiplier effect discussed elsewhere) is such that only an upper limit can be placed on the cross section of K^{39} for EBR neutrons.

The results of the mass analyses are:

Original Material	9.98×10^{-1} ³⁹	5.0×10^{-6} ⁴⁰	1.8×10^{-3} ⁴¹
		$\pm 0.4 \times 10^{-6}$	$\pm 0.07 \times 10^{-3}$
Irradiated Material	9.98×10^{-1}	5.2×10^{-6}	1.6×10^{-3}
		$\pm 0.4 \times 10^{-6}$	$\pm 0.07 \times 10^{-3}$

(No errors are given for the 39 abundances; they are about equal to the absolute error on the 41, i. e., $\pm 0.0007 \times 10^{-1}$. Nothing is gained by giving the value for 39 to a percentage accuracy greater than that achieved in the measurement of the increase of the 40).

The fact that the 41 content of the original material is higher than that of the irradiated sample, if a real effect, could be ascribed to two causes:

(a) The cross section of K^{41} for EBR neutrons is rather large (≈ 1 barn). This is not consistent with other cross section measurements at these energies. A much more logical explanation is:

(b) The "original" sample was contaminated with normal potassium more than the irradiated one in handling after the aliquots were separated.

If this is assumed one can calculate the amount of contamination that would account for the difference. This amounts to about 1.5% of normal potassium added to the original sample. Of course,

if both samples, or the total original sample before division, were contaminated with a certain amount of potassium, this would not affect the results.

Since the total apparent change in K^{40} , if no deduction for contamination is made, is 4%, and the mean deviation is 8%, no definite value can be assigned to the cross section. If allowance is made for contamination in the reference sample, there is practically no net change in the K^{40} (mean value). The apparent change, $\Delta 40$, is $-1.0 \times 10^{-6} \leq \Delta 40 \leq 1.0 \times 10^{-6}$.

We can therefore say that the maximum change could be 10^{-6} .

The total neutron flux time for this sample was determined from a measurement of the fission burnup in a uranium 235 monitor as measured by the cesium 137 yield, and the assumption that the effective fission cross section of uranium 235 in hole 208 is 1.4 barns. I am indebted to G. R. Ringo for this cross section. The fission measurements were made by the Chemical Engineering Division.

The value of ϕt obtained from the above is 2.3×10^{20} neutrons / cm^2 . Taking the extreme value of $1. \times 10^{-6} \times (K-39)$ as the change in the potassium 40, the cross section of potassium 39 is:

$$4.3 \times 10^{-27} \text{ or } 4.3 \text{ millibarns}$$

As this is based on the extreme probable value of the change it is an upper limit, so for EBR neutrons near the outer edge of the core:

$$\sigma_{K39} < 4 \text{ millibarns.}$$

29-4

Gaseous Species in Equilibrium with Metal-Metal
Oxide Systems (5200-02, 5230)

Mark G. Inghram, William A. Chupka and
R. F. Porter (University of Chicago)
Reported by William A. Chupka

The gaseous species in thermodynamic equilibrium with La (*l*) - La₂O₃ (s) mixtures in the temperature range 1650° K to 1900° K have been studied. Positive ions were produced by electron bombardment of vapor effusing from a Knudsen cell and were analyzed by a mass spectrometer. The major ions observed were La⁺ and LaO⁺. These ions were shown to be formed predominantly from La (g) and LaO (g) respectively. A thermodynamic treatment of ion currents yields a value of $\Delta H_o^\circ = 100 \pm 4 \text{ kcal/gm atom}$ for the heat of vaporization of La (s) and a value of $\Delta H_o^\circ = 189 \pm 8 \text{ kcal/mole}$ for the reaction LaO (g) = La (g) + O (g) or $D_o (\text{LaO}) = 8.15 \pm 0.35 \text{ e.v.}$

A mixture of B and B₂O₃ was studied in a similar manner in the temperature range 1300° K to 1500° K. Ion currents of B₂O₃⁺, B₂O₂⁺, BO⁺ and B⁺ were observed. The mixture, B - B₂O₃

was shown to vaporize mainly as the gaseous molecule B_2O_2 . The heat of vaporization of B_2O_2 (g) from the condensed phases is $\Delta H^\circ_{1400} = 94 \pm 8$ kcal/mole. The BO^+ and B^+ ions observed were found to be formed mainly by dissociative ionization. The concentration of BO (g) in the vapor is at least an order of magnitude lower than that of B_2O_2 (g). Results obtained with pure B_2O_3 liquid in the Knudsen cell agree with earlier published work.

A study of the oxides of titanium has begun. The initial results indicate that TiO_2 (ℓ) vaporizes mainly as TiO_2 (g) in agreement with other workers. Work on this system is continuing.

32-1

Electron Multipliers in Mass Spectrometry; Effects of Molecular Structure (5200-02)

Henry E. Stanton, William A. Chupka and
Mark G. Inghram
Reported by Henry E. Stanton

The following short paper will appear in the Review of Scientific Instruments (Feb. 1956) under Laboratory Notes.

The uses of electron multipliers in mass spectrometry have been summarized by Inghram, Hayden and Hess.^{1,2} One effect noted was that the number of secondary electrons produced by an impinging ion is dependent on the chemical nature of that ion. As an example they showed that the polyatomic ion CH_2^+ gives on the average about 10% more secondaries than does the monatomic ion N^+ of the

1. Mark G. Inghram, R. J. Hayden and D. C. Hess, Mass Spectroscopy in Physics Research. Nat'l. Bur. of Standards Circular No. 522, pp. 257, 1951.
2. M. G. Inghram and R. J. Hayden, A Handbook on Mass Spectroscopy Nuclear Sci. Series Report No. 14; Nat'l Res. Council Publ. No. 311, 1954.

same mass and kinetic energy. The explanation advanced depends on the assumption that on collision with a surface the molecule breaks up and acts as a group of unbound atoms. At higher masses one would expect the effect to be much larger than the 10% observed by Inghram et. al. and perhaps sufficient to be useful for discriminatory purposes.

As an example, consider the ion $C_{14}H_{10}^+$ at mass 178 as compared to Hf^{178+} at the same mass and moving with the same kinetic energy. Assuming that secondary electron production varies linearly with ion energy and as the inverse square root of the ion mass, the gain for the $C_{14}H_{10}^+$ mass is calculated to be 4.3 times that for Hf^{178+} .

The discrepancy between this calculation and experimental results is due to failure of the two above assumptions. Since the fragment energy in the case of the hydrogen atoms is only 1/178 of the initial energy the linear energy relation is not rigorous³ and we should expect an effect smaller than the above calculation.

The actual discriminatory effect has been determined by measuring pulse-height distributions due to the ions $C_{14}H_{10}^+$ and Hg^{204+} . Ions of different mass were selected in order to minimize background effects. Thus, the molecular impurity peaks under Hg^{204+} were much less than 1% of the atomic ion and the atomic ion impurities under mass 178 were much less than 1% of $C_{14}H_{10}^+$. The secondary electron production by the atomic ion of mass 204 can be extrapolated to that of an atomic ion of mass 178 by the inverse square root approxi-

3. Hagstrom, H. D., Phys. Rev. 96, 325 (1954); 96, 336 (1954).

mation which is reliable over this small mass range.

The comparisons were made by directing the appropriate ion beam from a mass spectrometer onto the first dynode of a multiplier of the type shown in Reference 1. The individual ion pulses from the final stage of the multiplier were introduced into a high gain linear amplifier and pulse shaping system and finally into a pulse-height analyzer and scaler. The pulse-height analyzer used had a base line of 0-100 v and was operated with a window of 0.5v.

The results of the analysis are shown in Figure 8. The average pulse-height, and hence, secondary electron production rate for $C_{14}H_{10}^+$ is 2.3 times that for Hg^{204+} . Table VII gives the apparent ion current for the two ion beams under different operating conditions.

TABLE VII

<u>Method of Detection</u>	<u>$C_{14}H_{10} / Hg^{204}$</u>
A. Direct electrical collection	1.000 (by definition)
B. Direct integration of multiplier output	2.3
C. Integration of pulses in a 0-3v. window	0.5
D. Integration of pulses above 20 v.	5

Correcting the direct discriminatory effect to Hf^{178} predicts a differential effect for $C_{14}H_{10}$ and Hf^{178} of 2.2 which as expected is smaller than the

PHG-899
9-13-55
B.G.

Fig. 8

4.3 calculated. As one goes up in mass or energy one would expect the effect to become greater.

The pulse-height distribution shown could probably be sharpened by increasing the efficiency of the first few stages of the multiplier. The shape of the pulse-height distribution in the case of $C_{14}Hg_{10}^+$ indicates that the gain may be a function of molecular orientation on striking the surface.

The above experiment shows that pulse counting with pulse-height analysis can be used to vary the sensitivity of a multiplier to ions of different types. In the particular case studied, a factor of 10 was realized between cases C and D of Table VII. An illustration of the usefulness of this phenomenon in isotopic analysis of heavy elements is the following:- If the apparent isotopic abundance of a heavy element is changed by $\sim 10\%$ in shifting from condition C to condition D one can be sure that the hydrocarbon errors are much less than 10% ($\sim 1.0\%$) when one is operating with the pulse cutoff of C.

35-6

(Studies of Negative Ion Emission)

(5200-02, 5230)

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

Nothing has been done on this project during this period.

36-6

Field Emission Studies

Mark G. Inghram and R. Gomer (University of
Chicago)

Reported by Mark G. Inghram

A paper summarizing our results to date is being published in Zeitschrift Fur Naturforschung 109(11) 863-872 (1955). This work is being published in this German journal in honor of Dr. J. Mattauch.

37-2

Ion Bombardment of a Solid Target (5200-02, 5230)

Henry E. Stanton

Since the last report period, the experiments with the ion bombardment source have been continued. The bombarding voltage has been increased from 540 previously used to 3500 by introducing an extra power supply into the bombardment source. The spectrometer was also changed from the energy-selecting mode of operation to the approximate "double focussing" mode. This increased the beam intensity by a factor of three to four.

With the higher bombarding voltages, a search was made for the components of the stainless steel target used, but without any success. It is quite possible, however, that the various iron, chromium, etc. peaks were lost in the hydrocarbon background which was strong in this region, as discussed below. Other regions were also searched for bombardment peaks, and potassium peaks were observed together with the background. The intensity ratio of mass 39

to mass 40 was only approximately the correct value for potassium. The mass 23 peak was also quite prominent, and from this one can infer with fair certainty that Na^+ ions are emitted from a target under ion bombardment.

The spectrometer was then opened and a target of different composition was installed. One third of the target was covered with a heavy lead foil, one third was brass, and the final third tin. With voltages of the bombarding ions up to the limit of 3500 v. and down to a few hundred, a search was made for the isotopes of Cu and Zn, but with nothing that could be identified as such.

The machine was then tuned for lead, and the peaks very readily observed. Their intensities were controllable from zero to ten or more times the background peaks, and these background peaks could be independently measured approximately.

Having obtained positive results for the first time with these peaks, some effort was made to determine some of the properties of their formation. A galvanometer was installed to measure the target current, and various types of gases were used to form the bombarding ions.

It was found that with the gases used, which were the rare gases with the exception of neon, the intensity of the lead peaks for 2500 v. bombardment energy was substantially independent of the mass of the bombarding ion, for a given target current. In other words, He^+

was just as effective as Xe^+ as nearly as could be determined, provided the target current was the same. It did require a considerably larger pressure of helium, from volumetric considerations, to produce the same target current as Xe, but this was apparently due to the poorer ionization efficiency of electrons for the production of helium ions. This effect also showed up in the ion gauge readings of the source pressure. Curves were obtained giving the intensity of the Pb^{208+} peak as a function of the target current, and also of the pressure at the source (measured by an ion gauge) as a function of the target current. There was considerable scatter in the data, as is generally characteristic of lead analysis, but for a given bombarding gas, both curves were approximately linear. Furthermore they were approximately the same curves for the various rare gases tried.

From these results the conclusion is drawn that the intensity of the lead peak is approximately independent of the mass of the bombarding gas, and is proportional to the current of the bombarding ions. Some preliminary observations with air and CO also indicate that with the bombardment voltages used, few, if any, effects of surface chemistry are observable.

With a fixed pressure of Xe in the source, the yield of lead ions was determined as a function of the energy of the bombarding ions. The observations were complicated because the bombarding source had to be tuned for each voltage in order to re-focus the ions on the target. Because of this difficulty and the fact that wide enough voltage

variations for the intermediate electrodes in the bombardment source were not available, maximum target currents could not be obtained above 2500 v. Below this voltage, however, the variation in the height of the lead peaks was linear with the energy of the bombarding ions.

The next ions sought were those of the isotopes of tin. Here, again, the background was troublesome as it had been for the other lighter ions. There were, however, indications that tin was being emitted under bombardment, since the mass 120 peak was increased in height about five times over the background. The other peaks for lower masses could also be separated from the background (which was independently measurable) to indicate the presence of tin. The peak at mass 115 (a common contaminant of tin) changed its appearance under bombardment; this could possibly indicate that indium was being driven out under ion bombardment.

The mechanism for the emission of ions under bombardment by other ions is not clear at this point. Ionization from a hot surface occurs as $\exp(\phi - IP) / kT$ where ϕ is the work function of the emitting surface, and IP is the ionizing potential of the ion emitted. If a billiard ball model of the impact is used, a bombarding ion of energy E_1 will deliver the energy E_2 to the target atom on a direct impact where $E_1 = 4 m_1 E_2 / m_2$, with m_1 the mass of the impinging ion and m_2 the mass of the target atom. This equation gives the energy transferred by an electron of 1000 ev. to a lead atom as 0.01 ev so the lead atom could

certainly not pick up a sufficient amount of energy to rupture the metallic bonds. No lead peaks were observed under bombardment by electrons (or any other negative ions) although the target currents were generally some five times larger than those used for bombardment by positive ions. A 1000 v. He^+ ion, however can transfer 100 ev to a lead atom, which is ample to break it loose from the target. No attempt was made to observe the helium threshold, which should occur at about 10 v. bombardment energy. If one applies the exponential formula for the emission of ions, one would assume T to become nearly infinite, which would reduce this term to unity, and all ions should be copiously emitted, with approximately equal probabilities. Such, however, has not appeared to be the case, but unfortunately the background is high for all but the heaviest ions, and any possible emission may have been buried in it.

In the future, a beryllium target will be put in the spectrometer to study its emission. There are, of course, no hydrocarbon impurities at this position and one can presumably distinguish between the process suggested above and one of melting and evaporation.

V. THEORETICAL PHYSICS, GENERAL

1-10 (Interpretation of the Energy States of Light Nuclei)
 (5200-01)

David R. Inglis

No work was reported for this quarter since the author was on a Leave of Absence at the University of California.

2-10 Excited States of Light Nuclei (5200-01, 5220)

Dieter Kurath
Reported by Dieter Kurath

The computation of energy levels and static electromagnetic moments for the lp-shell nuclei has been completed. The results and their interpretation are contained in an article accepted for publication in the January 1, 1956 issue of the Physical Review.

Comparison of the results with experiment is encouraging, especially in the most complicated case, that of mass number ten, where the agreement is excellent. This leads to a search for further tests of the model. One feature of nuclei which depends more strongly on the nuclear wave functions than does the energy level order is the width of an excited state for radiative transition. The transitions observed in this region are mostly magnetic dipole (M1) and electric quadrupole (E2). Since they provide a sensitive test of the model, computation of these gamma transition widths is being undertaken. At present the AVIDAC codes of the previous calculation

have been studied and the necessary modifications for computing transition widths have been made.

10-6 The Effect of Inelastic Scattering in the Analysis
of Scattering Resonances (5200-01, 5220)

H. Hausman, Raymond O. Lane, James E.
Monahan, F. Paul Mooring and Sol Raboy
Reported by James E. Monahan

A preliminary measurement of the inelastic cross section of Na^{23} for neutrons in the energy range 440 kev to 700 kev has been carried out by comparing the yield of 439 kev γ -rays from Na^{23} (n, n') with that of the 478 kev γ -rays from B^{10} (n, α) Li^{7*} . The cross section of the latter process has been determined by Petree, Johnson, and Miller.¹ A conventional ring geometry was used, the NaI detector being shielded from the incident neutron beam by a shadow-cone.

The results are shown in Figure 9. The uncertainty in the ordinate reflects the uncertainty of the B^{10} (n, α) Li^{7*} cross section. In Table VIII the resonance values of the total cross section² and the inelastic cross section are given. These are compared with the corresponding quantities calculated using a square well model for evaluating the ratio of partial widths, $\sqrt{\Gamma_{n'}}/\sqrt{\Gamma_n}$, and assuming a spin and parity of $5/2 +$ for the first excited state of Na^{23} . It might be noted

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

2. Stelson and Preston, Phys. Rev. 88, 1354 (1952).

Fig. 9

that this ratio, for all practical purposes, is independent of well - parameters.

The $i = 5/2^+$ assumption for the 439 kev state of Na^{23} can be made plausible from the data in the following way: The low value of the inelastic cross section at 542 kev makes an assignment of 1^+ for this compound state quite certain. This excludes the possibilities $i < 5/2$ since the 1^+ virtual state should decay with much larger probability to either of these states. Similarly, the assignment 0^+ for 633 kev resonance seems to be the only explanation of an "unobservable" total cross section at this energy. This would exclude the values $i > 5/2$, since these larger values would also make an observable inelastic cross section quite improbable.

We are attempting to repeat this experiment with better shielding and improved resolution. We hope also to be able to make the necessary corrections for anisotropy of the γ -ray from Na^{23} and for the contribution of slow neutrons to the $\text{B}^{10} (n, \alpha) \text{Li}^{7*}$ yield.

TABLE VIII

The total and inelastic cross sections of Na^{23} at the resonance energies E_r . The second and third columns are the measured values of the cross sections. The fifth and sixth columns give the corresponding calculated cross sections based on the assignment $5/2^+$ for the first excited state of Na^{23} . The fourth column gives the spin and parity of the resonance. The energies are in kev; the

total cross sections in barns, and the inelastic cross sections in millibarns.

$(E_r)_{\text{lab}}$	σ_t	σ_{in}	$J\pi$	σ_t	σ_{in}
542	2.1	30 ± 10	1^+	1.8	5
602	1.4	200 ± 70	1^-	1.5	120
633	-	70 ± 30	0^+	0.3	30
710	~ 5.3	> 200	5^-	5.4	200

12-3 Investigation of Neutron Scattering under the Feshbach - Porter - Weisskopf Nuclear Model (5200-01, 5220)

Morton Hamermesh and Jack Sokoloff
Reported by Jack Sokoloff

The code of the square-well problem appears to be completely debugged. R. G. Thomas of Los Alamos furnished us some machine calculations using the FPW model which had been confirmed by W. S. Emmerich of Westinghouse. Our calculations are in excellent agreement with the Los Alamos calculations.

Besides test runs, the following calculations have been completed:

<u>Nucleus</u>	<u>V_0</u>	<u>ξ</u>	<u>Energy</u>
Complete mass spectrum	42 Mev	.03, .05, .1	.06-1.5 Mev
C, Zn, U	42, 50, 60	.0001 - 10	.35, .5, 1.5
C, Zn, Pb	10 - 100	.03	.5

The results are too tentative for comment at this time.

The harmonic oscillator code is in the final debugging stage.

13-3

(Multipolarity of Neutron Capture Gamma Rays)

(5200-01, 5220)

Morton Hamermesh and Jack Sokoloff

Reported by Morton Hamermesh

This work has been temporarily discontinued until data are available from measurements with the bent-crystal spectrometer.

34-10

Quantized Space Time

(5200-02, 5230)

Robert H. Bryan and Katsumi Tanaka

Reported by Robert H. Bryan

The effect of introducing the commutator

$$\left[x_{\mu}, p_{\nu} \right] = i \hbar \left\{ \delta_{\mu\nu} + (\hbar^2 / \hbar^2) p_{\mu} p_{\nu} \right\} \quad (1)$$

into the equation of motion of the free electron has been investigated.

The Hamiltonian as given by Dirac is

$$H = -c \underline{\alpha} \cdot \underline{p} - \alpha_m mc^2 \quad (2)$$

and the x_1 components of velocity are

$$\dot{x}_1 = \frac{-i}{\hbar} \left[x_1, H \right]. \quad (3)$$

Employing the commutator (1) in Equation 3, we obtain

$$\dot{x}_1 = -c \left\{ a_1 + (\ell^2 / \hbar^2) p_1 \underline{p} \cdot \underline{a} \right\}$$

as compared to the value $\dot{x}_1 = -c a_1$ obtained by Dirac. Following the general method used by Dirac but employing the commutator (1), we can write

$$\begin{aligned} \dot{x}_1 = & - (i c \hbar / 2) \left\{ \dot{a}_1 + (\ell^2 / \hbar^2) p_1 \underline{p} \cdot \dot{\underline{a}} \right\} e^{-2 i H t / \hbar} \\ & + \left\{ 1 + (\ell^2 / \hbar^2) p^2 \right\} c^2 p_1 H^{-1} \end{aligned} \quad (4)$$

which agrees with the result obtained by Dirac when $\ell = 0$.

In the case $p_2 = p_3 = 0$, we have

$$\dot{x}_1 = (1 + \ell^2 p_1^2 / \hbar^2) \left\{ - (i c \hbar / 2) \dot{a}_1 e^{-2 i H t / \hbar} H^{-1} + c^2 p_1 H^{-1} \right\} \quad (5)$$

From this result we see that the adoption of the fundamental length introduces a correction factor $1 + \ell^2 p_1^2 / \hbar^2$ in the value of the velocity. Since experimental evidence for electron velocities in the neighborhood of $(v/c)^2 = 0.99$ substantiates Dirac's expression, we must expect the

correction term $\frac{\ell^2 p_1^2}{2 \text{tr}}$ to be small compared to unity for these velocities.

Then the fundamental length must be the Compton wave length by more than two orders of magnitude.

39-8

Applications of the Theory of Angular Correlation
(5200-01, 5220)

Melvin Ferentz and Norbert Rosenzweig
Reported by Norbert Rosenzweig

The computations for the table of F coefficients were completed and the results were published as ANL-5324. As no further work in the field of angular correlation is contemplated, this is our final report.

43-6

The S-Matrix

(5200-02, 5230)

Hans Ekstein and Katsumi Tanaka
Reported by Katsumi Tanaka

One of the workers (H. E.) has given a definition of the S-matrix in terms of rigorous one-particle states. It is conjectured that this S-matrix is insensitive toward a replacement of the rigorous one-particle states by any approximate state which, by adiabatic switching-on of the interaction is carried into a rigorous one-particle state. This conjecture, first suggested by the fact that the usual form of the S-matrix contains bare particle states, is supported by the proof that the S-matrix element between one bare and one "real" particle (e. g. bare meson and real nucleon, bare nucleon and real meson, one bare and one real nucleon) is exactly correct. The equivalence with Low's form of the S-matrix element for nucleon-meson scattering is one case. It is pointed out that great simplifications in calculations would result if the conjecture were correct.

Katsumi Tanaka

In order to avoid energy dependent and non-hermitian potentials that occur in the ordinary T-D method, Feldman (Phys. Rev. 98, 1456 (1955) and Okubo (Prog. Theor. Phys. 12, 603 (1954)) introduced a unitary transformation on the state vector Ψ of the Schrodinger equation, after taking the T-D approximation, to partly diagonalize the Hamiltonian. The result is not covariant, with the consequence that one cannot perform a renormalization of the divergent terms.

We obtain a covariant formulation of the Schrodinger equation of Feldman. This is done by finding the state vector in the interaction representation corresponding to the Feldman state vector in the Schrodinger representation. Extension of the covariant formulation to the new T-D method is also considered. Comparison with the ordinary energy dependent T-D method and Okubo's results is made. An article entitled "Tamm-Dancoff Methods" has been submitted to the Physical Review.

45-3

Renormalizable Field Theory

(5200-02, 5230)

Y. Nambu (University of Chicago) and Katsumi Tanaka

Reported by Katsumi Tanaka

The Lee Model and meson pair theory have the common interesting features that they are both renormalizable and soluble in closed form.

We have solved the Low equation given as

$$T_q(p) = \sum_n \left[\frac{T_p^+(n) T_q(n)}{E_n - \omega_p - i\epsilon} + \frac{T_q^+(n) T_p(n)}{E_n + \omega_p} \right]$$

in the one meson approximation for the above cases, where the transition rate from state q to state p is given by

$$2\pi \left| T_q(p) \right|^2 \delta(\omega_p - \omega_q).$$

However, for the cases above, there can appear states whose probability for transition is negative (ghosts). The properties and interpretation of the ghosts and renormalized coupling constants are being examined.

VII. ELECTRONIC DIGITAL COMPUTERS

2-10 The AVIDAC

1. The Use of the AVIDAC - Jean F. Hall

Many of the programs mentioned in previous reports continued to use machine time.

A new speeded up reactor kinetics program was run. Other new reactor programs included making tables of excess reactivity as a function of other reactor constants, a multigroup fundamental mode calculation and a P_3 spherical harmonic calculation for a two region slab.

Two accelerator programs were used. One is the calculation of the phase acceptance of an accelerator for an arbitrarily programmed oscillator. The other calculations were made for an FFAG type of accelerator having magnetic fields of opposite signs in alternate half sectors. For a given geometry and operating point in the stability diagram, the variation of the field and the momentum of the equilibrium particle were calculated as functions of the radius.

Two new data processing routines were run. One uses the grating law to compute wavelengths from plate-readings taken on the concave grating spectrograph-the other is an analysis of angular distribution data obtained from the Van de Graaff machine. The quantities

calculated are the differential and total cross-sections for neutron scattering.

A program using the "Cloudy Crystal Ball" model was run. This program calculates the cross-sections for differential scattering and total scattering and the total cross-section for the formation of the compound nucleus, on the basis of a model which uses a complex potential.

A table of Slater Integrals was computed.

2. Preventive Maintenance - Carl J. Bergstrom and Stanley Hanson

The tube rotation program is being carried out on schedule.

Marginal checks have been devised, so far, for the A, Q, and S toggles and gates, the adder, and the digit resolver. In these marginal checks, filament voltage is used as the marginal parameter.

These two measures have proven very useful, as the failure rate in the arithmetic unit is now quite low.

Kardex file records on each vacuum tube in the AVIDAC are now 60% finished.

a. Improvements

(1) Photodiodes for the Ferranti Readers.

Several brands of photodiodes have been procured and tested. Only one has been found to be satisfactory for installation into the Ferranti readers. These are to be delivered and installed

in the next quarter.

(2) Double Reader Chassis

A circuit has been designed, constructed, and installed to allow the use of two Ferranti readers on the Avidac. It is so arranged that information can be read-in from either reader, depending on the order.

(3) New Clear and Transfer Drivers

It was decided to replace the paralleled 5687 drivers with one large tube of the 6336 type. So far one chassis has been designed and built but not installed and another is now in the design process.

(4) Super Dot

The super dot used in writing zeros which was re-installed last quarter has shown no apparent gain in either read-around ratio or writing over the old pulse system.

(5) Address Stop Selection or Transfer Control

A circuit has been designed and 80% constructed which will allow the machine to stop whenever the address part of the current order agrees with a similar address set up on a set of switches located on the console.

Also it will be possible to have the machine transfer control only when the address agrees with an address set up on the console switches for certain transfer control orders.

(6) New Video Memory Amplifier

A new video memory amplifier has been designed for the AVI-DAC. Several models were built and are being tested in the machine.

7-10 The Auxiliary Memory for the AVIDAC (4520-02)

David H. Jacobsohn, Raymond F. Kramer and Leslie Merrill
Reported by Raymond F. Kramer

The auxiliary memory for AVIDAC will be connected to the computer GEORGE when it is finished rather than to AVIDAC. Forty-four read/write units were constructed by Eder Engineering Company. The electrical design of the control is in progress. Testing of GEORGE will be completed before undertaking tests of the Auxiliary Memory.

13-7 Computer GEORGE (4520-02)

Jeffrey C. Chu, Leslie Merrill, David Jacobsohn
James Whalen and Raymond F. Kramer
Reported by Raymond F. Kramer

1. Magnetic Core Memory

Delivery of the Memory being built by International Telemeter Corporation for us has been delayed to November 30, 1955. Two digit planes were added to the memory making it a storage of 4096 words each 42 bits long. The two extra bits were thought necessary to provide a parity check. The Rand Memory which was also built by International Telemeter has just completed 6 months of operation with a very good performance record. The mean error free time was 59.5 hours. The contract requirement was for at least 5 hours. The total maintenance time, scheduled and unscheduled, was 3.8% of the total computing hours. The contract required that the maintenance time be held to less than 12% of the computing hours. The Core Memory being built for us has essentially the same electrical and magnetic design as this Memory.

2. Arithmetic Unit and Control

The electrical design of this portion of GEORGE has been completed except for the Auxiliary Memory Control. Construction of the chassis is 85% complete. About 50% of the chassis have been individually tested. Frame wiring is underway and is about 20% completed. Minor modifications have been made in the logical design which increases the flexibility of the machine.

3. Power Supplies and Input-Output Equipment

Delivery of the Power Supplies, being manufactured by Magnetic Research Inc. has been delayed to November, 1955. A design change was requested to provide for a relatively slow rise in voltage with the voltage ratios being maintained from one-third of full voltage to full voltage. The supplies will be shut down in a like manner. The rise or decay would be accomplished in a few seconds. This manner of applying voltage to the machine was specified by International Telemeter Corporation, manufacturer of the Core Memory. It is necessary in order to prevent damage to components of the Memory. It should increase the reliability of the arithmetic and control unit as well as the Memory.

The Data Preparation Equipment being manufactured by Soroban Engineering has been delayed also. This equipment will be used to prepare, verify and compare punched paper tape, also it will print from such a tape. One of the typewriters will be used as a console

typewriter. Delivery of this equipment is expected in mid November, 1955.

4. Modifications and ventilation of Room C-221 of Building 203 and the adjacent area are essentially complete. Plenums for the Arithmetic Unit are in their permanent positions. The supporting structure and ventilation ducts for the Core Memory are in place waiting the delivery of the Memory.

A brief description of GEORGE was prepared for publication in "Computer Newsletter" which appears as a supplement to the "Proceedings of the Association for Computing Machinery".

VIII. APPLIED MATHEMATICS AND COMPUTATION, GENERAL
(4520-02)

13-5 REAC Problems

Nye F. Morehouse, Jr.

A study was made of the effect of variations of parameters on the behavior of a mathematical model for radiation damage to cells. The results are being reported by G. Sacher.