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Physics Progress Report

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PHYSICS DIVISION
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Louis A. Turner, Division Director

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Preceding Quarterly Reports:

ANL-5032 December, 1952, January, February, 1953 (Secret)
ANL-4982 June through November, 1952
ANL-4983 June through November, 1952 (Secret)
ANL-4981 March, April, and May, 1952 (Secret)
ANL-4963 March, April, and May, 1952

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FOREWORD

This report is the first of a series of Quarterly Reports from the Physics Division of the Argonne National Laboratory which are to be different in content and style from the Quarterly Reports previously issued. It is intended that the reports of this new series will summarize all the work of the Physics Division every quarter. Every program will be reported on regularly until the work is ended with appearance of a paper in one of the journals, or by issuance of a special ANL report, or by being discontinued. These quarterly reports are not intended to constitute publication in any proper sense of the word; they will contain much that is preliminary and tentative and will omit much detail that would be necessary for a definitive report or journal article. Their principal purpose is to provide information to interested co-workers in the Division and elsewhere as to what is being done and to stimulate useful discussion.

Since some of the work of the Division is classified, the quarterly report will appear in two parts, one unclassified and one classified. The classified part that supplements this report is ANL-5032.

A system of numbering and indexing has been adopted that will make it possible to add new programs as new work is started and still have them appear in proximity to related topics. The final digit of the index number is the serial number of the report on the given program, and is therefore 1 for all parts of this report. Further reports on these same programs will have the final digit 2 in the next quarterly report, and so on, whereas new programs reported on will begin with 1 when they first appear. The numbers for all program reports in the classified part will be preceded by the letter C.

I. EXPERIMENTAL NUCLEAR PHYSICS

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

L. M. Bollinger, R. R. Palmer, G. E. Thomas
Reported by L. M. Bollinger

A description of the basic operation of the Argonne fast Neutron velocity selector and its use for neutron transmission measurements has been given by W. Selove.[1] During the period since this report was written, the original equipment has been almost entirely replaced. A new rotor which focuses its six neutron beams along its axis is being used. A new 100-channel time analyzer of great reliability has operated successfully for over a year. The stability of the time analyzer has made it possible to operate the velocity selector on a 24-hour-a-day basis, with the rotor and detection system being continuously monitored as a protection against mechanical failure or the accumulation of false data. The present emphasis in the developmental program of the velocity selector is on improvements in the neutron detection system in general and on the application of the methyl borate-containing liquid scintillation neutron detector in particular.

In striving for greater resolution for transmission measurements, three permanent detector stations have been established, giving flight paths of 10, 20, and 40 meters. The 10-meter station contains the original detection equipment. This equipment has been mounted on a rolling table to allow it to be easily removed from the neutron beam when a longer flight path is required.

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[1] W. Selove, Rev. Sci. Instr. 23, 350 (1952).

The 20-meter station has been used periodically throughout the past year, using the equipment from the 10-meter location. A new set of amplifiers and a new neutron shield has now been installed at 20 meters, so that measurements may be made with a 20-meter flight path without disturbing the 10-meter equipment unduly. However, because of difficulty in procuring counters, the same set of BF_3 counters must be used for both the 10 and 20-meter stations. The 20-meter equipment is also mounted on a rolling table.

The 20-meter flight path, as compared with the 10-meter distance, has the advantage of improved resolution. It has the disadvantages, however, of reduced counting rates and of a second order effect. The second order effect consists of an ambiguity as to whether a neutron that is detected is a fast neutron or a slow neutron from the preceding cycle. A careful determination of the magnitude of the second order contribution has been made; it was found to be a monotonically decreasing function that falls from a value of about 10 percent of the first order at zero time of flight to zero at a time of 65 percent of the time between slit openings. The data are, therefore, easily corrected for the second order if there is no structure in the neutron cross section within the energy range that is included in the second order.

A highly efficient methyl borate-containing liquid scintillation neutron detector system has been installed at a distance of 40 meters from the chopper. A helium pipe which has a high transmission for neutrons connects this 40-meter station with the vacuum pipe that ends at the 10-meter position. Removable sections of pipe carry the beam through the 10 and

20-meter stations.

A typical example of the high resolution transmission data that have been obtained with a 40-meter flight path is given in Figure 1. The figure shows the uncorrected numbers of counts per channel as a function of time of flight for 16 hours of running time with 0.98 gm/cm^2 of manganese in the beam. The background level is shown as a dashed line, and the open beam counting rates are indicated by the monotonically decreasing solid line.

The most important result that is demonstrated by the figure is the fact that the liquid scintillation neutron counter has become a useful tool for transmission measurements with the chopper. Only its high efficiency makes a 40-meter flight path feasible. Of equal importance for use with the Argonne chopper is its slow variation of efficiency with energy. For a constant efficiency and a 1/E pile spectrum, the neutron counting rate per unit time of flight τ varies as $1/\tau$. Thus, even without the influence of the chopper cut-off function, the higher order counting rates are small relative to the first order for the early part of a chopper cycle; the cutoff function reduces the higher orders to an almost negligible level.

The major drawback of the liquid neutron counter for use with the Argonne chopper is its high background counting rate. A discussion of the sources of this was given in ANL-4982. Because of the high background and the $1/\tau$ counting rate distribution, there is effectively a lower neutron energy limit beyond which the liquid counter is not useful. This limit is about 200 ev. for a chopper rotor speed of 15,000 rpm. The upper energy

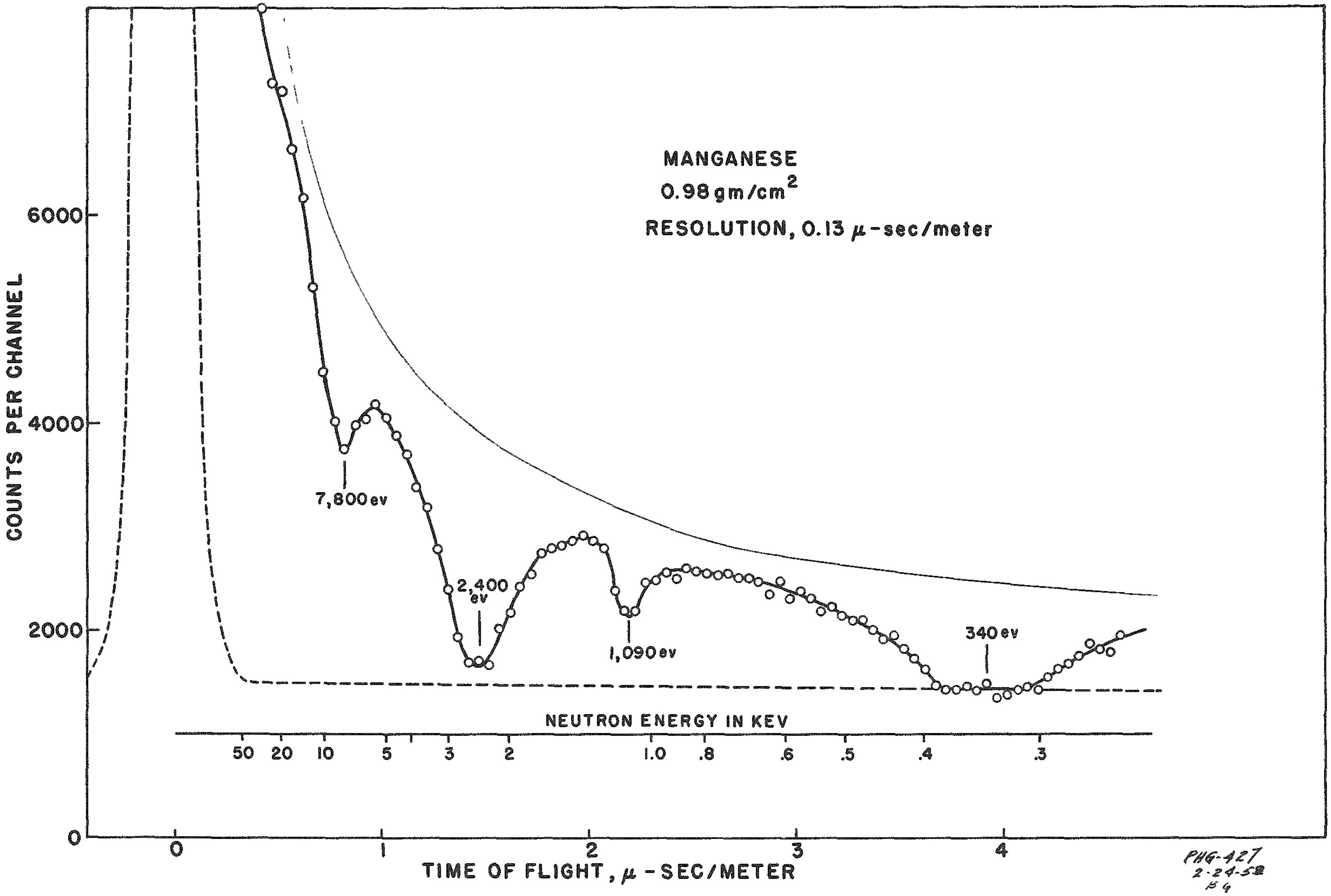

FIGURE 1.

NEUTRON TRANSMISSION DATA OBTAINED WITH A LIQUID NEUTRON COUNTER.

limit to the system is determined by the energy at which the $1/\tau$ rise in counting rate becomes so rapid as to introduce serious distortions in the measurements. This limit is in the neighborhood of 15 kev for a rotor speed of 15,000 rpm.

It is believed that the background rate of the liquid counter is roughly proportional to its volume. It is, therefore, important to have the counter as thin as possible without sacrificing too much efficiency. A Monte Carlo calculation of the slowing down and capture of neutrons in the counting medium is being undertaken to provide information concerning the optimum counter thickness as a function of energy. It is hoped that a thinner liquid counter than is now used will extend the energy range over which such a counter is useful.

Further improvements in the relative background rates are expected to result from the development of more efficient counters along the following lines:

a. Use of enriched methyl borate.

b. Construction of systems of greater surface area, thus reducing edge losses.

c. Use of scatterers to reflect neutrons that would otherwise be lost.

2-1 Liquid Scintillation Neutron Detector (5261-01 and 5211-01)

L. M. Bollinger and G. Thomas

The efficient detection of neutrons by liquid scintillators containing alkyl borates has been reported in the quarterly report for March, April, and May, 1952 (ANL-4963) and also in an article by Muehlhause and Thomas in the January, 1953, issue of Nucleonics.

We are developing a liquid scintillation neutron detector for use with the Argonne fast chopper. Progress has been reported in the quarterly report for June - November, 1952 (ANL-4982).

Construction and Properties - Reported by G. Thomas

Table I is a summary of the various coincidence counters used to date and their properties. The improved performance of the latest counter is mainly attributable to two features, the use of 2, 5-diphenyloxazole and the use of a quartz cell. Pyrex cells are unsatisfactory. Also, a powdered MgO-zapon mixture painted on the quartz has been found to make an excellent reflecting surface.

A beam of neutrons 1/4" wide was passed through various segments of the 4" long cell containing the liquid scintillator. The counting efficiency with the beam at either end of the cell was 96% of that in the center. This indicates that it would be feasible to construct a larger cell to correspond to an effective diameter of the neutron beam from the chopper at 40 meters of 6".

Phenylcyclohexane has been tested for light transmission with the following results for a layer 1 cm thick:

Wave Length - Angstroms	% Transmission
2800	0
2900	60.5
3000	81.3
3100	90.0
3200	93.7
3300	95.7
>3400	→97.0

Enriched boron prepared by R. Barnes of the Chemistry Division has been tested with Co gamma-rays and found to give pulses 20% higher than those given with the normal boron now being used. This may be attributed in part to the purity of the enriched material.

The quantity of the 2, 5-diphenyloxazole used in the scintillation liquid has been optimized and found to be 4 gms/l solution.

During the next quarter a new mechanical design will be put into use, a cell with enriched boron will be used, and the detector will be put to use with the chopper.

Test Procedures - Reported by L. M. Bollinger

Counter No. 6 is being throughly tested. A complete differential pulse-height distribution of the pulses caused by thermal neutrons has been obtained for this counter. The pulse distribution rises rapidly from a rate of zero at zero pulse height, passes through a maximum, and has a long tail toward greater pulse heights.

The primary drawback of the liquid counter as compared with a gas BF_3 counter is its high sensitivity to γ radiation. It is, therefore, essential that it count neutrons with as high an efficiency as possible. Tests with five different coincidence counters have shown that a serious loss of efficiency may be caused by the failure of the neutron to produce a light pulse that is large enough for at least one electron to be released at each photo-cathode. An approximate estimate of the average number of electrons released by a scintillation at each photo-surface can be made as follows.

If R_{1s} and R_{2s} are the single counting rates of the two photo-multipliers, respectively, and R_c is the coincidence rate, $R_{2s}-R_c$ gives the rate at which photomultiplier No. 1 misses scintillations counted by photo-multiplier No. 2. $(R_{2s} - R_c)/R_{2s}$ is thus the probability that such a count will be missed. If we assume that the numbers of electrons produced at one photo-surface for each scintillation are distributed according to the Poisson distribution, that a count will be made for one or more photoelectrons produced, and that missed counts correspond to zero electrons produced, it follows that

$$(R_{2s} - R_c)/R_{2s} = e^{-\bar{n}}$$

in which $\bar{n}$ is the average numbers of electrons per scintillation produced at the photo-surface of photomultiplier No. 1. For the best scintillation counter produced, No. 6, $\bar{n}_1$ and $\bar{n}_2$ are found to be 1.8 and 2.8, respectively. The smallness of these numbers emphasizes the importance of having a good optical system.

TABLE I

Summary of Properties of Coincidence Counters Tested

(All Are Coincidence Counters with Two 5819 RCA Photomultiplier Tubes Facing Each Other)

Counter No.	Construction	Scintillator	Ratio of Coincidence Rate to Av. Single Counting Rate	Average No. of Electrons Produced at a Photo-Surface Per Scintillation
1	Quartz cell - 2" diameter, 2" long; aluminum foil reflector.	4 gms/l terphenyl 8 mgs/l diphenylhexatriene in equal volumes of phenyl-cyclohexane and methyl borate	Not Measured	Not Measured
2	Aluminum cell - 4" diameter, 2" thick; quartz windows for photo-tubes; polished aluminum reflector.	Same as Counter No. 1	0.3	0.3
3	Quartz cell - 2" diameter, 4" long; painted MgO reflector.	Same as Counter No. 1	0.7	1.2
4	Pyrex cell - 2" diameter, 4" long; powdered MgO reflector; expansion bulb on top of cell.	Same as Counter No. 1	0.55	0.8
5	Pyrex cell - 2" diameter, 4" long; painted MgO reflector; expansion bulb on top of cell.	4 gms/l 2,5-diphenyloxazole 16 mgs/l diphenylhexatriene in equal volumes of phenyl-cyclohexane and methyl borate.	0.7	1.2
6	Quartz cell - 2" diameter, 4" long; painted MgO reflector; expansion bulb on top of cell.	Same as Counter No. 5	0.90	2.3

An upper limit for the efficiency of the whole device in counting scintillations is given by the ratio of the coincidence rate to the rate for all separate scintillations counted. This latter rate is $R_{1s} + R_{2s} - R_c$ since $R_{1s} + R_{2s}$ involves counting the coincidences in twice. One has, thus,

$$\mathcal{E} < R_c / [R_{1s} + R_{2s} - R_c] \text{ or } \mathcal{E} < 1/[(R_{1s} + R_{2s})/R_c - 1]$$

The inequality arises from the uncertainty as to the small number of scintillations producing no count at all in either photomultiplier. From a probability argument we can conclude that

$$\mathcal{E} > R_c^2 / R_{1s} R_{2s} \sim (R_c/R_s)^2$$

where R_s is the mean single counting rate. The inequality arises here because a scintillation counted in photomultiplier No. 1 is somewhat less likely to produce a count in photomultiplier No. 2 than is a random scintillation. (Scintillations produced close to No. 1 are more likely to be counted in No. 1 than a random one produced anywhere in the tube and correspondingly less likely to be counted in No. 2.) Using the data for counter No. 6 in these inequalities, we can estimate that its efficiency is close to 81%.

The Argonne fast chopper is being used to measure the over-all efficiency of the liquid counters as a function of neutron energy. Preliminary results have been obtained for counter No. 6. The thermal efficiency, obtained by comparing its counting rate with that of a BF_3 counter of a known efficiency, is found to be 75 ± 20%. The relative efficiency over the energy range 1 to 1000 ev varied as $E^{-0.12}$ when the counter was uniformly irradiated with neutrons. The measurements for linking the relative efficiencies for the epi-cadmium region to the thermal efficiency are not yet completed.

In the near future the efficiency of counter No. 6 will be measured over the energy range from 0. 01 to 10,000 ev. These efficiencies will then be compared with those of a counter of similar construction filled with enriched methyl borate.

3-1 Transmission Measurements with the Fast Neutron Velocity Selector

(5261-01 and 5211-01)

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

Cadmium

Sample used: Cadmium metal, 1 inch thick; 19.9 gm/sq cm.

Resonances observed:

840 ev*
400 ev
234 ev*
163 ev*
122 ev*
88.2 ev**
66.6 ev
27.2 ev**
18.0 ev No other resonances observed down to 1.0 ev.

* Resonances obtained using a 20-meter flight path with its consequent gain in resolution, approximately 0.3 microseconds per meter (full width at half maximum) compared with 0.55 microseconds per meter at 10 meters.

**The 88.2 and 27.2 ev transmission dips are fairly deep and are the only ones for which we are able to make isotopic assignment.

Runs With Partially Separated Isotopes (cadmium oxide)

Isotope	Sample weight	Resonance Assignment
108	1.14 gm/sq cm	none
110	.72	probably the 88-ev resonance
111	.85	quite definitely the 27-ev resonance***
112	.69	none
113	.85	none
114	.71	none
116	1.30	none

*** $\sigma_0 \Gamma^2$ for the 27-ev resonance is about 40 barn - $(ev)^2$.

Gadolinium

Samples used: A. 1/4-inch metal bars, 5.00 gm/sq cm
B. Metal chips, 0.81 gm/sq cm

Resonances observed	Resolution
740 ev	Approx. 0.55 microsecond/meter
355 ev	"
109 ev	"
81 ev	"
49 ev	"
33.2 ev	"
29.8 ev	"
22.2 ev ** ***	0.38
20.6 ev * ***	"
16.6 ev **	"
14.4 ev	"
11.6 ev **	0.55
7.74 ev **	"
6.26 ev *	"
2.85 ev ** ***	"
2.58 ev * ***	"
1.93 ev **	"

(no other resonances observed down to 0.2 ev)

*Quite deep transmission dips.

**Fairly deep transmission dips.

***Each of these two pairs of adjacent resonances illustrates the value of increased resolution gained by using a 20-meter instead of a 10-meter flight path. At 10 meters each pair appears as a single transmission dip.

Manganese

Sample used: Metal powder, 0.98 gm/sq cm

Resolution: 0.13 microseconds per meter (40-meter flight path).

See the report, The Fast Neutron Velocity Selector, for a curve of neutron count as a function of time of flight. (See preceding section of this report.)
Significant features from point of view of neutron transmission:

a) New resonance (Brookhaven) at 1.08 kev confirmed.

b) Our energy assignments for resonances are intermediate between the Brookhaven and Argonne accelerator values:

Argonne Chopper	Brookhaven Chopper	Argonne Accelerator
1.09 ± .05 kev	~0.95 kev	--
2.40 ± .15	1.8	2.8 kev
7.8 ± 1.0	7.1	8.2

Mercury

Samples Used	Weight	Resonances Observed
Liquid mercury	22.5 gm/sq cm	See table below
Isotope 204 (Hg_2S)	1.38	None due to 204
Isotope 202	1.48	None at all
Isotope 198	1.40	At 23 and 311 ev

Resolution: 0.3 microseconds per meter.

Resonances in Liquid mercury:	Isotopic Assignment:
1230 ev	----
437 ev	----
311 ev *	198; possibly another isotope as well
204 ev	----
175 ev *	Most probably 201; possibly 199 or 200
127 ev	----
91 ev	----
71 ev	----
42.8 ev	----
33.3 ev *	Most probably 201; possibly 199 or 200
23.1 ev *	198

* Deep transmission dips at these energies.

Runs to be made:

200 sample

201 and 199, if samples can be obtained.

Zinc

Sample: Metal discs, 14.7 gm/sq cm.

Resolution: 0.14 microsecond per meter.

Resonances	Comments
17,000 ev	Must be extensive system of resonances in this vicinity to show up so large
4,400	New resonance
2,800	
510	
227	

Prospective Work and Work in Progress

Some data have been obtained on gallium. Cross sections will be calculated for it as well as for the elements reported upon above.

4-1 Resonances in Separated Mo Isotopes (5211-01)

S. P. Harris

Six separated Mo isotopes in all have been run to date in the neutron velocity selector (chopper) to attempt to assign the Mo resonances (see AECU-2040). The results for Mo^{92}, Mo^{95}, Mo^{96}, Mo^{97}, and Mo^{98} were reported in ANL-4982.

Recently a $Mo^{100}O_3$ sample was received from Oak Ridge, and a transmission curve covering the region from about 15 ev to a few thousand ev has been run. This curve shows no resonances except for a slight effect at 44 ev caused by the resonance in the Mo^{95} impurity.

Mo^{94} has not been available in sufficient quantity so far. About 900 mg of $Mo^{94}O_3$ would be required to make a good run. A summary of the isotopic assignments of Mo resonances made so far is given below. No resonances have been assigned to Mo^{92} (closed shell of neutrons), Mo^{98}, and Mo^{100}.

Resonance Energy (ev)	Isotope
44	Mo^{95}
70	Mo^{97}
130	Mo^{96}

A calculation of $\sigma_o \Gamma^2$ for the 44-ev Mo^{95} resonance using the thick sample formula of Havens and Rainwater[1] gave $\sigma_o \Gamma^2$ = 1100 b-(ev)^2.

[1] W. W. Havens, Jr. and L. J. Rainwater, Phys. Rev. 83, 1123 (1951).

11-1 Installation of the Van de Graaff Generator (5211-01 and 5261-02)

Those who have spent some or all of their time on this work since October, 1951 are: M. T. Burgy, R. J. Culp, R. C. Dahleen, R. E. Holland, E. F. Hupke, T. H. Kirby, A. Langsdorf, R. E. Malm, F. P. Mooring, R. G. Nobles, J. C. Wallace, and R. R. Weeks.
Reported by A. Langsdorf on the basis of notes supplied by T. H. Kirby.

The new installation is different from the one at Palos Park in almost every respect except the basic design of the machine's tank and frame and the scheme of control. A complete new report should be prepared describing all phases of the mechanical and electrical installation to supercede the original report written by Rolland Perry (which was never published). Since the machine is not yet in operation, changes may be made in the near future, and it is not yet time to write the complete report. A brief statement concerning major items of the machine is appended:

Vacuum System

There are now a large Dry Ice trap and shut-off valves between the oil vapor diffusion pump and the accelerating tube. The vacuum attained is about 1×10^{-6} mm with liquid nitrogen on a side tube as well as Dry Ice in the main trap. This is to be compared with the old value of 3×10^{-6} mm. Low volatility oils formerly accumulated on the liquid nitrogen trap. Now only highly volatile material accumulates on this trap, as judged by the speed with which it pumps out when this trap warms up. (The old installation had a liquid nitrogen trap on a side-arm, but no Dry Ice trap in the main pumping line.)

Cooling Water

Because of the shortage of water, it is recirculated in a cooling tower. Although the water is cleaner than the water was at Palos Park, there is still trouble from slimy sludge clogging lines, and simple filters in the supply become clogged too rapidly. Self-cleaning filters may have to be installed. Except for this difficulty, the system seems to be adequate.

Pressure Gas Handling System

A piping and valving system is installed similar to the one at Palos Park, but better built. The only screwed joints remaining in the piping are those at valves and a few other units; the remainder are welded joints, and unions are flanged. The pipe fitters were completely unsuccessful in making screwed joints non-leaky, so the goal of a tight system was not achieved even though most screwed joints were eliminated. Where necessary screwed joints have been soldered, so the system is adequately serviceable although leaky in several places. The piping system is completed and in use.

External Electrical Instrumentation and Wiring

The control table and relay rack installations and terminal-to-terminal cableway wiring are essentially finished, and most important parts are in working order. Much work must still be done to compile complete wiring data in suitable permanently recorded form.

Beam System

One beam line system is set up consisting partly of old components from Palos Park, with some new or modified components. More new parts are being built and can be added when they are needed. Enough parts are installed now to permit some experimental work as soon as the machine can be used. The most important single new component is a 90-degree, 40-inch radius electrostatic analyzer for high precision control of the machine. It has remained in half-finished condition for the whole re-installation period. It is expected it can be finished and put into operation next summer.

Interior Parts of Machine

A new accelerating tube made by High Voltage Engineering Company is now installed. Only one tube is installed instead of two as at Palos Park, because differential pumping has been eliminated.

Differential pumping has been eliminated by converting to an R-F ion source system (installed by F. P. Mooring), which is now undergoing testing. This ion source uses much less gas than the old one, which was a Zinn-type arc source.

In the place where the old differential pumping tube was located, there is now an optical system for viewing meters that are in the high voltage electrode. This system is so designed that it is possible (by a periscope system) to read these meters at the control table. The periscope, designed by the Remote Control Division, is almost finished.

A beam of ions at low energy has been brought out of the machine and focused. No further data of interest is available as yet concerning performance.

12-1 R. F. Ion Source for the Argonne Van de Graaff Generator (5211-01 and 5261-02)

F. P. Mooring

In the past a Zinn-type ion source has been used in the Argonne Van de Graaff generator. This source, which operates at a relatively high gas pressure, requires the use of differential pumping. Hence, in addition to the conventional accelerator tube, a pump-out tube of identical construction was used. Sparking and electron loading in the pump-out tube limited the maximum voltage at which the Argonne machine could successfully be operated, approximately 3.5 Mev. Two effects are thought to have caused the voltage instability of the pump-out tube. In time the tube became coated with a thin film of pump oil, which is apparently a copious source of secondary electrons. Unlike the accelerator tube through which the ion beam passed, the pump-out tube did not have a chance to "clean up" due to continuous ion bombardment. The dirty interior coupled with the relatively poor vacuum conditions under operating conditions probably caused its poor voltage behavior at elevated voltages.

The differential pumping tee in the high voltage shell forced the installation of the ion source at a considerable distance from the mouth of the accelerator tube. Thus the positive ions passed through a long field-free region between the ion source focussing assembly and the entrance to the accelerator tube. This long field-free path necessitated the use of excessive focus voltages.

For these and other reasons it was decided to use a different type of ion source at the new site. After the development by Moak *et al.*[1] of a particularly simple R. F. ion source capable of delivering large ion beams, it was decided to use such a source with the Argonne Van de Graaff generator. The source which has been installed is identical with the one described by Moak[1] except for a few minor alterations as follows:

The probe canal has been reduced in diameter from 0.060 inches to 0.040 inches. In the Argonne source, the magnetic field is produced by a permanent magnet rather than an electromagnet.

The ion focussing assembly at present installed is similar to the one previously used in conjunction with the Zinn source. However, it has been so designed that the focussing geometry can be changed to be more nearly like that used by Moak.[1] A third geometry, a hybrid between the first two, can also be used if one so desires.

A hydrogen ion beam of the order of 20 microamperes has been obtained with the new source. As yet no information concerning the ratio of the mass one ion yield to the mass two and mass three yields has been obtained. It is hoped that the total ion current can be improved somewhat over its present value. Experiments with this in mind are currently in progress.

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[1] C. D. Moak, H. Reese, Jr., and W. M. Good, *Nucleonics*, Vol. 9, No. 3, 18-23, (Sept. 1951).

13-1 A High Vacuum Plug Valve (5211-01 and 5261-02)

J. A. Stark* and A. Langsdorf
Reported by A. Langsdorf

A high vacuum plug valve using "O" rings that is simple to make has been developed. A description of the valve and the procedures for making it has been submitted for publication in the Review of Scientific Instruments.

* Now at Berry Bearing Company, Chicago, Illinois.

20-1 Energy States of Light Nuclei from Charged Particle Reactions (5211-01)

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

A high resolution magnetic spectrometer has been constructed for use in conjunction with the Van de Graaff Generator in the study of the excited states of light nuclei by means of charged particle reactions. This spectrometer is capable of focusing, in two dimensions, protons of 12 Mev energy emitted in a solid angle of approximately 0.1%. It is so mounted that any angle of observation between 0 and 135 degrees with respect to the direction of the bombarding particles can readily be obtained.

The present status of the spectrometer and associated apparatus is as follows:

1. Spectrometer

   Magnet, cooling system, and vacuum system have been tested and found to be satisfactory. The gas regulating system for the proportional counters has been installed but has not been tested. Assembly of the vacuum system awaits the availability of a beam from the Van de Graaff Generator.

2. Power and Control Systems

   The Lincoln Welding Generator, which is used to feed the magnet, has been installed and tested. The installation of the power distribution leads has been completed. Further work is required on the magnetic field control and stabilizing circuits.

3. Proportional Counter Detection System

   Five proportional counters are provided for detecting the particles traversing the spectrometer. The circuitry required for these counters is complete except for four preamplifiers.

It is expected that the unfinished work listed above will be completed during the next quarter. In addition, plans are being made to initiate an experimental program in the event that a beam from the Van de Graaff Generator becomes available. One of the first experiments to be carried out will be a further investigation of the first excited state in Li^6 by means of the Be^9 (p, γ) Li^6 reaction. Preliminary results on the experiment were obtained sometime ago and reported in the quarterly report for June, July, and August of 1951 (ANL-4680). Reference was made to these results by Ajzenberg and Lauritsen in their review article on the energy levels in light nuclei which appeared in the Reviews of Modern Physics 24, 347, (1952).

30-1 Scintillation Coincidence Spectrometer (5211-01)

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

To facilitate the assignment of the radiations from radioactive isotopes into correct and consistent decay schemes, an instrument for determining coincidences between gamma-rays and between gamma- and beta-rays, has been constructed. This instrument, constructed by the Electronics Division of ANL in accordance with our specifications, is now in use. We are greatly indebted to Mr. Thomas Brill, Director of the Electronics Division, and to James McMahon for their cooperation in designing and constructing this machine.

The instrument consists of a two-channel coincidence circuit, the two inputs of which are fed by scintillation type detecting probes. Type 5819 photomultipliers are used in conjunction with either NaI (Tl) or anthracene crystals, depending upon whether gamma-rays or beta-rays are to be detected. The anthracene crystal is provided with a 0.0004-inch Al window. The photomultiplier-crystal assemblies were prepared by R. Swank and J. Moenich of the Argonne Instruments Division.

One input, after being fed through its linear amplifier, passes through a single-channel differential pulse-height analyzer before entering the coincidence circuit. The other arm of the system passes through a ten-channel differential pulse-height analyzer before entering the coincidence circuit.

The ten-channel analyzer is provided with a window amplifier to *facilitate inspection of different regions of the spectrum.*

With the coincidence circuit off, the ten-channel analyzer can be used to investigate the "normal spectrum" of gamma-rays. The single channel may then be set to accept any particular region, and an analysis of the coincidence gamma-rays obtained with the ten-channel analyzer.

To date, conclusive results have been obtained regarding the decay schemes for ${}_{66}Dy^{166}$, ${}_{64}Gd^{159}$, and ${}_{64}Gd^{161}$. The details of these measurements are reported by W. C. Jordan in sections 32-1 and 33-1 of this report.

31-1 The 1.42-Min Isomeric State in $_{77}Ir^{192}$ (5211-01)

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

The 1.42-minute isomeric state in $_{77}Ir^{192}$ is characterized by two radiations, a gamma-ray of 57.0 kev and another uncharged radiation of approximately 26 kev. Early experiments by other investigators indicated the possibility that the lower energy radiation was comprised of a continuum of quanta, associated with a two-quantum transition process. The purpose of this investigation is to ascertain the nature of this radiation and to fit it into a consistent energy level scheme for this activity.

To facilitate normalization of measurements being made with the scintillation spectrometer, new matched sources have been prepared by moulding the Ir powder into 1/2-inch lucite discs which will be activated in the "rabbit". A new holder has also been made for holding the sources in the same position. By thus standardizing the sources and holding the activation time constant, it is hoped that comparative absorption measurements can be made without having to rely entirely upon the magnitude of the lower 57.0-kev peak as a means of normalizing the data taken on the lower energy radiation. It is hoped that under these conditions the critical absorption measurements will be more readily interpreted.

32-1 Decay Schemes of $_{66}Dy^{165m}$ (1.2 min) and $_{66}Dy^{165}$ (2.3 hr) (5211-01)

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

Previous work by others has shown that neutron capture in Dy^{164} produces metastable Dy^{165} (1.25 min), which decays via a 109-kev E3 transition to the ground state. This in turn beta decays with a 2.3-hr half-life to various states of the Ho^{165} nucleus. Three beta transitions have been resolved and found to have energies of 0.42, 0.88, and 1.25 Mev. Gamma-rays of 0.091, 0.275, 0.36, 0.76, and $\sim$1.0 Mev have been detected. Proposed decay schemes have either required an undetected beta transition or have made use of energy sums which are known from preliminary results of the present investigation to be inconsistent.

The 1.25-min metastable state has been studied with the 180° conversion electron spectrographs. A transition energy of 108.0 ± 0.2 kev is found. The observed internal conversion electrons are listed in the following table.

Electron Energy (kev)	Relative Intensity	Proposed Interpretation	Transition Energy (kev)
54.2	3	K (Dy)	108.0 ± 0.2
99.4	10	L_2	
100.3	10	L_3	
106.3	5	M	
107.8	1.5	N	

The K/L ratio is $\sim$ 0.15 in good agreement with empirical relations of K/L versus $\frac{Z^2}{E}$ for an E3 transition.

The gamma radiations of the 2.3-hr activity have been studied with the 180° conversion electron spectrographs and with a scintillation coincidence spectrometer.

The observed conversion electrons are listed in the following table.

Electron Energy (kev)	Proposed Interpretation	Transition Energy (kev)
38.8	K (Ho)	94.4 ± 0.2
85.0	L_1	
92.2	M_1	
93.9	N	
223.8	K	279.4 ± 0.8
270.0	L_1	
305.9	K	361.2 ± 1.0
351.6	L_1	
578	K	634 ± 3
~623	L	

Studies with the scintillation spectrometer have shown the definite presence of other gamma-rays of 710 ± 20 and 1020 ± 30 kev and possible presence of additional ones of ~180 and ~550 kev. The results of coincidence studies indicate the 279-kev transition is coincident with the 710-kev, while the 361-kev is coincident with the 634-kev. The 94-kev gamma-ray is coincident with a beta transition of ~1.3 Mev. Coincidences between the 94-kev and other gamma radiation have not been detected.

Further coincidence studies will be made and the results compiled for publication in the Physical Review.

33-1 Decay Schemes of $_{64}Gd^{159}$ (18 hr) and $_{64}Gd^{161}$ (3.7 min) (5211-01)

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

Among the activities produced by neutron capture in gadolinium are an 18-hr and a 3.7-min activity which have been assigned to mass numbers 159 and 161, respectively. Both of these undergo beta decay to terbium. The 3.7-min activity is the parent of a second beta decay to dysprosium. Absorption measurements have indicated that a beta transition energy of $\sim$0.9 Mev and electromagnetic radiation of $\sim$0.055 and $\sim$0.35 Mev are associated with the 18-hr activity. A beta transition of $\sim$1.5 Mev, gamma radiation of 0.37 Mev, and internal conversion electrons of $\sim$0.066 Mev have been reported to be associated with the 3.7-min activity.

In the present investigation the radiations of these activities are studied with 180° electron conversion spectrographs and with a scintillation coincidence spectrometer.

Results for Gd^{159} (18 hr)

Internal conversion electrons which may be identified with the 18-hr activity are listed in the following table.

Electron Energy (kev)	Proposed Interpretation	Transition Energy (kev)
48.8	L_1	57.5 ± 0.2
50.0	L_3	
55.5	M_1	
56.9	N_1	
312	K	364 ± 2
$\sim$353	L	

Using the binding energies of terbium, these electrons are interpreted as corresponding to transitions of 57.5 ± 0.2 and 364 ± 2 kev.

Pulse-height distributions obtained with the scintillation spectrometer exhibit several peaks. Those which decay with the 18-hr half-life may be identified with the 364-kev and x-ray transitions ($\sim$45 kev). The contribution of the unconverted portion of the 57.5-kev transition is not resolved and is apparently small compared to the x-ray intensity. Other peaks corresponding to transitions of 120, 860, and 970 kev are present. However, these decay with a half-life of $\sim$10 hr and are assumed to be due to contamination of 9.3-hr Eu^{152}. (K, L, and M conversion lines of the 122-kev transition following K capture in Eu^{152} are observed. Also, the x-ray peak of the pulse-height distribution shows evidence of this activity.) The 860 and 970-kev transitions have not, to our knowledge, been previously reported.

Coincidence experiments failed to reveal any x-ray-gamma or gamma-gamma coincidences involving the 364-kev transition. X-ray - x-ray coincidence experiments are complicated by the presence of the K capture activities of Gd^{153} and the 9.3-hr Eu^{152} contaminant.

Beta coincidences are observed with both the x-ray and the 3.64-kev transition. The former are alternated by aluminum absorbers with a half-value thickness of 43 mg/cm^2 while the latter have a half-value thickness of 29 mg/cm^2. These correspond to beta energies of $\sim$1.1 and $\sim$0.9 Mev.

Results for Gd^{161} (3.7 min)

Measurements of the half-life of Gd^{161} result in an average value of

3.74 ± 0.10 min. Aluminum absorption measurements of the beta radiation indicate a maximum beta energy of ~1.6 Mev. Conversion electrons associated with this activity are listed in the following table.

Electron Energy (kev)	Proposed Interpretation	Transition Energy (kev)
~55	K^1	~107
264.0	K^2	316.0
~310	$K^3 + L^2$	
350	L^3	355 ± 5

With the exception of the 264-kev line these are very weak lines even on spectrograms subjected to more than 100 iterated exposures.

The pulse-height distribution obtained with the scintillation spectrometer has peaks corresponding to energies of ~45, 100, 164, and 360 kev. The "360" kev is broad and distorted, suggesting it is composed of two unresolved peaks of ~320 and 360 kev. The conversion electron data definitely established the presence of a 316-kev transition and also indicate the existence of a 355-kev transition. Coincidence studies confirm the presence of both of these transitions. The two peaks are well resolved in coincidence pulse-height distributions. The 316-kev transition is found to be coincident with the 107-kev, while the 355-kev is coincident with the x-ray.

In the ensuing quarter, the 3.7-min activity will be further studied by means of the coincidence spectrometer. In particular, beta-gamma coincidence work will be done. The results will then be compiled for publication as an article in the Physical Review.

34-1 Decay Schemes of $_{45}Rh^{104m}$ (4.3 min) and $_{45}Rh^{104}$ (44 sec) (5211-01)

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

A study of the decay of neutron-activated rhodium has been reported in Section IX of the Physics Division's Quarterly Report for June through November, 1952 (ANL-4982). The results of this study have now been submitted for publication in the Physical Review. A summary of this work is given below.

The radiations of neutron-activated rhodium are studied with a 180° constant field conversion electron spectrometer and a gamma-ray scintillation spectrometer. Internal conversion electrons are observed to be associated with 4.3-minute activity. These are interpreted as arising from two isomeric transitions of 51.1 ± 0.2 and 77.2 ± 0.2 kev in rhodium. By coincidence studies, these two transitions are shown to be in cascade. The character of the radiations, as determined from K/L ratios and lifetime considerations, appear to be Ml and E3, respectively. Additional gamma-rays of energy 550 ± 10 kev and ~1.2 Mev (weak) are observed with the scintillation spectrometer. The 550-kev transition is associated with both the 44-sec and 4.3-min periods and is assumed to follow the beta decay and hence be in Pd^{104}.

35-1 Decay Schemes of Long-Lived Rare-Earth Isotopes (5211-01)

E. L. Church

There exist a number of long-lived ($T_{1/2} = 6$ mos.) isotopes in the rare-earth region, the decay schemes of which have not yet been adequately investigated. This lack is due in part to their low activation by direct neutron capture. The present studies are made feasible through the use of fission products (A = 151, 154, 155) and sources prepared by long-term neutron bombardment (152, 153, 155).

Preliminary results of the examination of the low-lying levels of these isotopes are included in the table below:

Parent	Daughter	Lifetime	(kev)
$_{62}Sm^{151}$	$_{63}Eu^{151}$	73 yr	6.8 ± 0.5* 21.4 ± 0.4*
$_{63}Eu^{152}$	$_{62}Sm^{152}$	13 yr	121.6 ± 0.5
$_{64}Gd^{153}$	$_{63}Eu^{153}$	236 d	69.4 ± 0.4 97.3 ± 0.4 103.1 ± 0.4
$_{63}Eu^{154}$	$_{64}Gd^{154}$	16 yr	122.8 ± 0.5
$_{63}Eu^{155}$	$_{64}Gd^{155}$	1.7 yr	59.8 ± 0.4 86.3 ± 0.4 105.1 ± 0.4

* Measured by means of a proportional counter.

With the exception of A = 151, the energy values quoted above have been determined by means of a permanent magnet 180° focusing β-ray spectrograph. Cursory examination by means of a scintillation detector has revealed traces of Eu contamination in all the samples studied.

The 21.4-kev transition associated with Sm^{151} is below the threshold for conversion in the K shell. The 6.8-kev radiation, measured by Be absorption, is undoubtedly the x-radiation arising from conversion in the L shell.

The $\sim$122-kev radiations following the decay of Eu^{152} and Eu^{154} are probably the electric quadrupole ground state transitions in their even-even daughters. These multipolarity assignments and the structure of the L conversion groups are borne out by K/L measurements. The assignment of the 122.8-kev transition to Eu^{154} is in disagreement with the earlier work of Keller and Cork (Phys. Rev. 84, 1079 (1951)) and in agreement with that of Katz and Lee (Phys. Rev. 85, 1038 (1952)).

No positrons have been detected in the long-lived K capturer Gd^{153}. Of the three γ transitions observed, only one (103 kev) has been previously detected in this activity.

The 132-kev transition previously associated with the decay of Eu^{155} by Rutledge et al. (Phys. Rev. 86, 775 (1952)), is missing in the fission product. The conversion lines observed by these authors have been shown to be due to a misinterpretation of the lines associated with a trace of Eu^{156} (2 wks) in an incompletely aged source.

36-1 The Decay Schemes of Mass 48 Nuclei (5211-01)

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

It has recently been shown* in the case of the decay of Sc^{48} that whereas only two gamma-rays are observed in a scintillation spectrometer, suggesting the simple cascade emission of two gammas, there is a possibility that the cascade consists of three gammas, with two of them having almost the same energy.

The purpose of the present work is to investigate this and other similar cases by means of triple coincidence methods, and insofar as possible, to determine the multipolarity of the emitted radiations by looking for angular correlations among them.

During the past quarter, a relatively slow triple coincidence set-up (resolving time of the order of several microseconds) was assembled and put into operation. It consists of three sodium iodide scintillation detectors followed by three single-channel pulse-height analyzers whose outputs were fed into the coincidence circuit. By means of a switch, one of the channels could be disconnected and the set-up used to measure two-fold coincidences. With each of the gamma-ray sources used, pulse-height distributions for each detector were obtained, and before the triple coincidence work was begun, the discriminators were biased to register only pulses greater

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* B. Hamermesh, V. Hummel, L. Goodman, and D. Engelkemeir, Phys. Rev. 87, 528 (1952).

than one-half of the highest gamma pulses involved. In this way, the effect of Compton scattering from one crystal to another, producing spurious coincidences, could be eliminated. For checking purposes, Cs^{137} and Co^{60} were used as one-gamma and two-gamma sources, respectively. Sc^{48} was obtained by bombardment of titanium metal with 20-Mev neutrons from the cyclotron. Triple coincidences were obtained in this case in far greater numbers than the accidental rate observed and calculated for Co^{60}. The results confirm the conclusion of Hamermesh, et al., with regard to the decay involving three-gamma cascade. A further investigation showed that two of them had the energy 0.99 Mev and the third was of energy 1.32 Mev.

An investigation of the decay of Sc^{46} indicated that only two gammas were involved.

A chromium-plated copper strip has been bombarded with high energy deuterons in the cyclotron and will shortly be chemically separated to yield the radioactive V^{48}. The decay of V^{48}, producing information about energy levels in Ti^{48} (the same element to which Sc^{48} decays), will be similarly investigated.

An angular correlation study of the Sc^{48} decay is contemplated after completion of the V^{48} measurements. This will require faster coincidence circuits to get sufficient counting rates with stronger sources without being troubled with accidentals. The construction of such a faster coincidence set-up is being planned.

50-1 Internal Conversion of Capture Gamma-Rays Associated with Gd (5211-01)

C. T. Hibdon

Four additional internal conversion electron lines associated with capture gamma-rays from Gd have been identified by use of the internal conversion beta-ray spectrograph. Seven lines have been reported previously.[1] The identification of the four new lines was made possible by the use of better samples and longer exposure times, which in some cases amounted to three weeks.

The results obtained to date are summarized in the following table. The new lines are indicated by an asterisk. The 148.8-kev electrons do not appear to be produced by any of the other previously known gamma-rays. They are presumably to be attributed to K-conversion of another gamma-ray which will, acccordingly, have an energy of 199.1 kev.

A further study of Gd will be carried out when the separated isotopes become available.

TABLE II

Line Energies, Work Functions, and Gamma-Ray Energies

$H\rho$	E_β	K	L_{II}	L_{III}	M	E_γ (kev)
575	28.3	50.3				78.6
667	37.8	50.3				88.1
927	70.7		7.9			78.6
932	71.3			7.3		78.6
969	76.8				1.9	78.7
992	80.3		7.9			88.2
1030	86.0*				1.9	87.9
1298	131.2	50.3				181.5
1392	148.8*	50.3				199.1
1522	173.8*			7.3		181.1
1546	179.0*				1.9	180.9

[1] C. T. Hibdon and C. O. Muehlhause Phys. Rev. 88, 943, (1952).

51-1 Characteristics of a Scintillation Counter Spectrometer (5261-02)

B. Hamermesh and V. Hummel
Reported by B. Hamermesh

The work on capture γ-ray[1] spectra using a 3/8" x 1-1/2" right cylinder of NaI showed that only the most prominent lines of such spectra could be detected. The counting rate rises very rapidly with decreasing energy because of the Compton electrons formed in the crystal by the higher energy γ-rays. The lower energy lines are located on top of this background of pulses.

In order to reduce this effect, a 3-1/2" x 3-1/2" right cylinder of NaI has been obtained. It was hoped that any degraded photons formed as a result of a Compton process would be absorbed by photoelectric effect and a full height pulse would result. The crystal was packaged by R. Swank and J. Moenich of our Instrument Research Division and has been used with a 5819 photomultiplier. A lucite light pipe is needed in order to conduct the scintillations from the 3-1/2" face of the crystal to the 1-1/2" face of the phototube.

The resolution has been measured as 18% for the 662-kev line from Cs^{137}. It has been found that the Compton process followed by absorption of the degraded photon is greatly enhanced so that in the case of Cs^{137} there is no Compton distribution of pulses present. For a Na^{24} source, the Compton

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[1] B. Hamermesh and V. Hummel, Phys. Rev. 88, 916 (1952).

distribution due to the 1.38-Mev line is very weak compared to the photoelectric peak. The distribution of pulses caused by the 2.76-Mev line shows hardly any pulses caused by pair production with both annihilation quanta escaping, whereas the peak caused by capture of one of these quanta is intense. There is very little contribution to the pulse distribution caused by Compton effect of the 2.76-Mev line, but the full energy absorption peak is intense. One may summarize by saying that all double processes are greatly enhanced by use of the large crystal.

In order to use the crystal at CP-3', the shielding had to be increased, since the sensitive volume of the large crystal is over 50 times greater than the volume of the small crystal. By adding 8-10" of lead on all sides and 6" on top to the original shielding used (See Fig. 1, loc. cit.), the background was reduced to a count comparable to that present in the work done with the small crystal.

It is planned to try to improve the resolution of the crystal by eliminating the light pipes. This is to be done by making a compact bundle of three 5819 tubes which will be mounted in a single holder next to the crystal. The three tubes will cover nearly 75% of the 3-1/2" diameter face of the crystal.

52-1 Neutron Capture Gamma-Ray Studies with the Scintillation Spectrometer (5261-02)

B. Hamermesh and V. Hummel
Reported by B. Hamermesh

Chlorine

The large crystal has been used to restudy the spectrum of chlorine. The suppression of the Compton effect made it possible to search the energy region between 2 and 4 Mev, where Kinsey's[1] data indicated that some lines would be found. A line at 2.90 Mev was found, and another very weak line at 2.4 Mev seemed to be present.

It is planned to use the large NaI crystal to restudy the elements covered with the small crystal spectrometer.

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[1] Kinsey, Bartholomew, and Walker, Phys. Rev. 85, 1012 (1952).

60-1 8-Meter Bent Crystal Spectrometer (5261-02)

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

Design of an 8-meter (focal circle diameter) bent crystal spectrometer of the DuMond type has begun. The instrument is to be used primarily for the study of capture gamma-rays. In addition, gamma-rays following β decay or from isomeric transitions can also be studied. The source of gamma-rays is to be placed in the center of hole H5 in the CP-5 reactor. The high flux in CP-5 should make it possible to study capture gamma-rays from elements with cross sections as low as 0.1 barns.

An optical flat of monocrystalline quartz 6 mm in thickness and between 9" x 9" and 12" x 12" in area is to be prepared. The large faces are to be perpendicular to the 310 planes.

The design of the shielding for the NaI (Tl) crystals which will be used to detect the diffracted gamma-rays has been completed. The shielding will weigh nearly 10 tons.

It is planned to complete the mechanical design and begin construction during the next quarter.

70-1 Measurements of Nuclear Moments by Angular Correlation (5211-01)

S. Raboy

A magnetic field applied perpendicular to the plane of emission of two γ-rays emitted in cascade will decrease the angular correlation between them if the intermediate state has a sufficiently long half-life. This change in the angular distribution is a function of the magnetic moment of the intermediate excited state, the life time of this state, and, of course, the field itself. Qualitatively one can imagine the spin of the intermediate state to be precessing about the field while the state is decaying exponentially at the same time. The net effect is to shift the angular distribution and also to attenuate the coincidence rate. By measuring this shift, one can obtain the moment of the excited state. This method was used by Aeppli, Albens-Schonberg, Frauenfelder, and P. Scherrer to determine the magnetic moment of the intermediate state of Cd^{121} (Helv. Physica Acta 25, 339 (1952)). The theory is given by Alder, (Helv. Physica Acta 25, 235 (1952)).

This method is limited to nuclei with half-lives of the intermediate state of order 10^{-7} to 10^{-9} seconds. Hg^{197} was selected as a first possibility. An isomeric state of Hg^{197} is formed by neutron capture in Hg^{196}. This isomeric state decays with a 23-hour half-life to the ground state by emission of two gammas (133 and 165 kev). The intermediate state has a half-life of 7×10^{-9} secs. The ground state subsequently decays with a 66-hour half-life by K capture to an excited state of Au^{197} which emits a 77-kev γ-ray to get to the stable ground state. Hg^{197} has the further advantage that the gammas of interest originate from an isomeric state and are not the result of a β transition. Thus, one avoids difficulties which may be caused by fields of excited atoms.

Preliminary trials have been made on irradiated HgO (enriched to 1.9% in Hg^{196}). The 77-kev level in Au^{197} and the 80-kev Au x-rays have caused some difficulty. Apparently the ground state of Hg^{197} is also formed in neutron capture to a much greater intensity than the isomeric state, and at this time it is not too clear that the interferences of the 77-kev can be overcome. There is some hope for this, however, since the pulse-height analyzers are operated with windows from 110 kev to 190 kev. It is thought that there will be few coincidences from the 77-kev and x-rays in this range.

It is planned to continue this work next quarter. The HgO sources will be irradiated for much longer times, and one hopes to get better counting rates so as to make the experiment feasible. In addition, other methods of measurement will be investigated, as will other nuclei. For example, for nuclei with intermediate state half-life of the order of 10^{-5} to 10^{-7} seconds, an R. F. scheme has been planned. A steady magnetic field applied parallel to one of the gamma-rays and an R. F. field applied perpendicular to the two γ's will combine to wash out the angle correlation at the resonant R. F. frequency. This resonance frequency will give the magnetic moment directly.

For nuclei with intermediate half-life of 10^{-9} to 10^{-10} sec another scheme is proposed, and this scheme is still very tentative. One can measure delayed coincidences, i.e., delayed by 3 or 4 half-lives, with a fast coincidence circuit. Then one can study the effect of a magnetic field on these delayed coincidences in a manner similar to the scheme described in the first paragraph.

71-1 Angular Correlation of β-Rays and Delayed Neutrons from Kr^{87} (5211-01)

L. Goodman

The exact decay scheme of Kr^{87} is somewhat in doubt. It is not known for sure just what maximum energy β-ray precedes the delayed neutron. The first step of the experiment will be to search for coincidences between the delayed neutron and the β-ray using a methyl borate counter for the neutrons and a thin organic crystal for the β-ray. A pulse-height distribution from photons in the organic crystal in coincidence with the pulses from the neutrons should provide the β spectrum and end point of the β-ray which precedes the delayed neutron.

If this coincidence technique proves feasible, angular correlation of the β-ray and the delayed neutron will be studied.

No work has been done in the past quarter.

If the methyl borate counter development proceeds to the point where it is no longer an experimental instrument, and its electronic circuitry is standardized, some preliminary work may be done in the ensuing quarter.

72-1 The Angular Distribution of Photoneutrons From Be Produced by 2.185-Mev Gamma-Rays (5211-01)

B. Hamermesh and C. Kimball
Reported by B. Hamermesh

The angular distribution of the photoneutrons from Be has been measured at various energies. Near threshold the distribution is spherically symmetric. At higher energies the distribution is of the form $a + b \sin^2 \theta$ where the value of a/b decreases with energy. Guth and Mullin[1] have calculated values of a/b as a function of energy using the valence neutron model. The model consists of a Be^8 core plus a single valence neutron. The Be^8 is unstable against decay into two alpha particles by about 120 kev, but its lifetime is very long compared with the time required for the emission of a neutron from Be^9.

Using a sample of Ce^{144} whose daughter product Pr^{144} emits a 2.185-Mev gamma-ray following β emission, we have begun a study of the angular distribution of the photoneutrons from beryllium. Since good geometry is required in order to limit the possible angles between the gamma-ray direction and the direction of motion of the neutron, the counting rates are very low compared with those available in a cross section measurement. Measurements are being made in the 0° and 90° directions.

A very stable counter has been set up, and preliminary counting has begun. It is planned to obtain sufficient statistics so that a value of a/b accurate to about 20% is obtained. This will require several weeks of counting.

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[1] E. Guth and C. J. Mullin, Phys. Rev. 76, 234 (1949).

80-1 <u>Molecular Beam Studies</u> (5211-01)

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

A molecular beam apparatus to measure nuclear spin, magnetic dipole, and electric quadrupole moments of radioactive isotopes is under construction.

Neutral atoms diffuse from a furnace and pass through two transverse inhomogeneous magnetic fields and thereby are deflected so as to miss the detector. Between these inhomogeneous fields lies a uniform transverse field, which induces a Larmor precession without causing deflection. A radiofrequency magnetic field of this Larmor precession frequency is applied in the region of the uniform field but transverse to it; this causes a change of magnetic substate, so that the deflection in the second inhomogeneous field is reversed and the particle strikes the detector.

All mechanical parts have recently been constructed and are undergoing assembly and test. Much of the electrical equipment is at hand; only the secondary frequency standard remains to be designed.

90-1 Cross Sections for 14-Mev Neutrons (5211-01)

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

The aim of the present program is to study the neutrons elastically scattered from various materials to determine both their angular distribution and the total cross section for the process.

The 14-Mev neutrons are to be produced by the reaction $T(d,n)He^4$ using a low-voltage (0 to 300 kev) Cockcroft-Walton type positive ion accelerator, whose construction has been basically completed but is still in need of some modification and development work before it can be considered a stable working tool.

Very little work has been reported in the literature regarding the angular distribution of scattered fast neutrons, in view of the difficulties of obtaining adequate collimations so that only the desired neutrons scattered from the target are detected.

Because of the large Q of the $T(d,n)He^4$ reaction, the neutrons are emitted in the laboratory frame of references at approximately 180° with respect to the alpha particles. By counting neutrons in coincidence with alpha particles in a narrow beam, we can measure scattering of only those neutrons that were originally in a corresponding narrow beam opposite to the beam of alpha particles.

During the present quarter, the following progress has been made on this project:

1. A magnet has been designed to bend the deuteron beam through 90° into the horizontal plane so that the target, alpha detector, etc., may be more suitably located.
2. A fast coincidence circuit has been ordered.
3. A plastic scintillator for detection of the scattered neutrons is being prepared at our request by W. Buck.
4. The accessory electronic equipment has been decided upon.

During ensuing quarter, it is hoped to get the neutron source into satisfactory operation, set up and check the various pieces of equipment as they are completed, and to begin doing the experiment.

91-1 Neutron Transport Cross Sections (4110-22)

A. Langsdorf

The determination of the angular distribution of scattered mono-energetic neutrons and transport cross sections is of interest from various points of view. The present lack of agreement between theory and experiment, in discussions of the average behavior of total neutron cross sections of the elements as a function of neutron energy, may well be improved by the determination of angular momenta at various energies.

Early experimental work on this problem, using the Van de Graaff generator as a source, was reported in early 1952 in ANL-4798, pages 5 to 18, and in earlier reports. This work showed the feasibility of the method but indicated that considerable refinement in technique would be required for extensive or accurate work in this field.

This early equipment employed a bank of 63 boron trifluoride proportional neutron counters embedded in a "spool" of paraffin which itself was in a large shield; the counting efficiency for neutrons released in the central hole of the spool was about 15%. For angular scattering work, the whole device could be rotated about the scattering sample placed near the mouth of the hole; the source of primary monoenergetic neutrons (the Li target of the Van de Graaff generator) was a few inches from the scatterer A.

The newly planned equipment will afford better definition of the scattering angle, while maintaining the same geometrical efficiency; will greatly reduce background counts; will obtain data over a wider spread in scattering angle, both forward and backward, and with greater accuracy as to relative absolute yields.

This will be accomplished by abandoning the rotating detector and replacing it with five fixed detectors, three accepting neutrons scattered in the forward quadrant and two in the backward quadrant; thus, data on all five angles will be obtained simultaneously, without the introduction of calibration errors necessary with the older in-sequence method. Each detector will consist in a trapezoidal water tank containing a bank of proportional neutron counters surrounding the base of an air-filled collimating tube in the water. The primary source of neutrons will be a lithium target mounted in a collimating tube inside a similar water tank. Monitoring of the primary neutrons (unsatisfactory in the older apparatus) will be accomplished by locating counters close to the wall of this collimator. The scattering sample will be mounted at the center of the circle about which the six water tanks will be grouped. Thus, the scattering target will be illuminated by a collimated beam of neutrons from the primary source, and each detector will be exposed only to neutrons coming from the scatterer.

Present work is still limited to early design conceptions; in the ensuing quarter, drawings on all the shielding and collimating system will be completed and construction started and electronic equipment and accessories will be planned in detail and placed on order.

92-1 Neutron Scattering Cross Sections of the Titanium Isotopes (5211-01)

C. T. Hibdon

The sub-cadmium and epi-cadmium scattering cross sections of the various titanium isotopes have been measured with the annular scattering chamber. Scattering foils of TiO_2 were used for the various separated isotopes and a metal foil for unenriched titanium. The scattering cross sections in barns are summarized in the following table.

Isotope	Percentage Enrichment	σ_s Sub-Cd	σ_s Epi-Cd
Ti^{46}	82.7	2.1	3.2
Ti^{47}	63.1	4.1	5.0
Ti^{48}	99.2	3.9	8.7
Ti^{49}	77.6	0.7	2.7
Ti^{50}	84.6	2.8	3.2
Ti	----	4.2	8.1

93-1 Be (γ,n) Cross Section at 2.185 Mev (5211-01)

B. Hamermesh and C. Kimball
Reported by B. Hamermesh

The cross section for the photodisintegration of Be^9 at 2.185 Mev has been measured using γ-rays which follow the β-decay of Pr^{144}. A value of 3.9×10^{-28} cm^2 was found in reasonably good agreement with the valence neutron model. This value is lower than the values at 1.81 Mev and 2.50 Mev, in agreement with the theoretical predictions that a minimum value of the cross section should be found near 2.2 Mev.

An article describing the experiment has been sent to the Physical Review.

94-1 The Cross Section for the Capture of Thermal Neutrons by Hydrogen

(5261-01)

B. Hamermesh, G. R. Ringo, S. Wexler
Reported by B. Hamermesh

The analysis of the results of the experiment to determine σ_a (H) has been completed (ANL-4982). The cross section at 2200 meters/sec was found to be 0.329 ± 0.004 barns.

An article describing the experiment has been sent to the Physical Review.

95-1 Activation Cross Sections Measured with Antimony-Beryllium Photoneutrons - II (5211-01)

C. Kimball and B. Hamermesh
Reported by B. Hamermesh

Additional measurements of activation cross sections using Sb-Be photoneutrons have been made using the technique described by Hummel and Hamermesh.[1]

The table contains a list of these cross sections relative to Seren's[2] thermal cross section for the given element.

TABLE III

Activation Cross Sections Obtained with Sb-Be Neutrons

Isotope (A+1)	Half-life	Natural Atom Cross Section (millibarns)	Percent Error
Co^{60}	10.7 min	* 7.7	30
Cu^{64}	12.8 hrs	85	25
Ge^{75}	82 min	14	10
Ba^{139}	85 min	53	10
W^{187}	24.1 hrs	119	15

* This value is an upper limit. The very small number of counts above background made it difficult to obtain good half-life values. Assigning to the 10.7-minute activity all counts above background corresponding to a half-life of less than thirty minutes yields the value in the table.

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1 V. Hummel and B. Hamermesh, Phys. Rev. 82, 67 (1951).

2 Seren, Friedlander, and Turkel, Phys. Rev. 72, 888 (1947).

These results are given in a Letter to the Editor appearing in the Phys. Rev. **89**, 1306 (1953).

This work will be discontinued for the immediate future. It will be continued later if circumstances allow.

96-1 Pile Absorption Cross Section of Na^{23} (5261-01)

S. P. Harris, D. Rose, H. P. Schroeder
Reported by D. Rose

The pile absorption cross section of Na^{23} was measured in CP-3' by the technique of the pile oscillator method using the 2200 m/sec capture cross section of boron (755 barns) as the standard. For a description of the pile oscillator technique see ANL-4746, p. 17. Two samples of Na_2CO_3 weighing 40.43 and 84.86 gm, respectively, were used. The smaller sample was contained in a quartz bottle identical to those used for the standard boron solution, the other in a Dowmetal sample can.

Three sets of runs were made with each of the two samples and with empty sample containers as blanks. The weighted mean of the average value obtained for each sample after subtraction of the carbon and oxygen contribution to the cross section gives

$$\sigma_{pile}\,(Na) = 0.503 \pm 0.005 \text{ barns.}$$

110-1 Crystal Spectrometer For 0.1-to 100-ev Neutrons (5211-01)

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

The neutron crystal spectrometer is a useful instrument for investigating scattering resonances and activation cross sections. There are in addition many other problems for which the spectrometer lends itself more readily than the chopper. Sailor (Phys. Rev. 87, 1612 (1952)) has used a Be neutron crystal spectrometer to provide beams up to about 50 volts.

In order to get the higher energy neutrons, one must use crystal planes of small lattice spacing. The (311) plane in copper (1.09 Å) and the (120) plane in beryllium (0.7 Å) are planes suitable for such purposes. Narrow collimation is also necessary, and the collimation used at CP-3' is such that the present detector swings through an angle of half of a degree when in the main beam. This allows a Bragg deflection of about a half degree, which determines the upper limit of the energy of the neutron beam.

The crystal itself should not contribute more than 30 minutes to the width of the beam.

Two Cu crystals grown and oriented at ANL were tried. Both of these crystals had natural widths greater than one degree. The peaks at about 1 Å were examined for different parts of each crystal, and structure of these peaks was observed. The net effect when the entire crystal was studied was a fat peak, too fat for the purposes stated above.

The conclusion was that the ANL-grown crystal had more lineage than was desired. Negotiations were started with the Virginia Institute for

Scientific Research which culminated in the loan of two unoriented crystals of copper. These turned out to have natural widths within the requirements, one having a natural width of about 15 minutes and the other about 30 minutes.

On the basis of the above results an oriented copper crystal was purchased from the Virginia Institute for Scientific Research. This crystal will be studied during the next quarter. A crystal holder is now being constructed in the shop, as is also a fission chamber for monitoring purposes.

Some Be crystals have been obtained from M. I. T., meanwhile, and so it is planned to examine these for lineage also.

Up to now only superficial attempts have been made to get close to the main beam. The background from the main beam must be reduced considerably if Bragg reflection at 30 minutes is to be achieved. It is quite possible that the present detector will be modified to some extent for this reason.

111-1 Neutron Spectroscopy in the 0.01-to 10-Mev Region (4110-22)

V. E. Krohn and G. R. Ringo
Reported by V. E. Krohn

A survey has been made of methods which might be suitable for measurements of the energies of neutrons in the range from 0.01 to 10 Mev, with special emphasis on the 50-to 500-kev region. The methods considered can be classified as follows:

A. Methods for use with neutron beam extracted from the reactor

1. Proton recoils in a cloud chamber.
2. Proton recoils in a nuclear emulsion.
3. Proton recoils from a thin radiator detected by thin scintillating crystals.
4. He^3-filled counter.
5. Nuclear emulsions "speck"-loaded with Li^6.
6. Threshold detectors.

B. Methods for use within the reactor

1. Nuclear emulsions "speck"-loaded with Li^6.
2. Proton recoils in nuclear emulsions.
3. Threshold detectors.
4. Proton recoils from a radiator in the reactor, the recoils extracted for energy analysis.

Emphasis in the near future will be on the cloud chamber, lithium-loaded emulsions, and possibly the radiator with thin scintillating crystals. Each of these techniques is applicable in all or part of the 50-to 500-kev region.

112-1 The Neutron Spectrum of a Standard Ra-Be Photo Source (5261-01)

C. Eggler

A photoneutron source has been prepared by the National Bureau of Standards as a possible primary and permanent standard for the measurement of neutron fluxes. A Ra-Be photo source as described by Wattenberg[1] has tentatively been adopted as this primary standard. It is proposed here to measure the neutron spectrum of this source in a more precise manner than previously used by the writer.[2] It is proposed to substitute for proton recoils the use of the He^3 (n,p) H^3 reaction. He^3 has been ordered from Oak Ridge. To assist in measuring the reaction energy an anti-counter is being incorporated in the chamber. It is hoped that this will be a self-triggering device for horizontal tracks that will eliminate the necessity of stereoreprojection. The counter has been installed in cloud chamber and found to give counts. So far, however, the signals obtained with condensible vapor in the chamber are so small as to be lost in the noise of the pre-amplifier. An amplifier with better S/N ratio is being sought.

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1 A. Wattenberg, NRC Report No. 6 of Nuclear Science Series.

2 C. Eggler, ANL-4476, pp. 42-49, 1950.

120-1 Calibration of a Ra-Be Neutron Source (5261-01)

S. P. Harris

It is proposed to measure the number of neutrons emitted per second by a source by a method differing somewhat from those previously used. The neutrons will be absorbed in a solution of sodium acetate, $NaC_2H_3O_2$, in which the source will be placed. After the Na is activated to saturation and the solution is thoroughly mixed, a small sample (about 2.5 gm) of $NaC_2H_3O_2$ is extracted by evaporation of a portion of the solution to dryness. This sample is pressed into a thin circular pellet. This pellet will be counted in a β-γ coincidence arrangement described below to find the absolute decay rate. $NaC_2H_3O_2$ is chosen as the material to be activated for six reasons: (1) it is a 1/v absorber; (2) it has high solubility; (3) Na has a convenient half-life (14.9 hr); (4) the cross section is well determined; (5) the decay scheme is simple; and (6) the compound is stable, pure, and available. The decay scheme consists of a 1.39-Mev β-ray followed in succession by 1.38-and 2.76-Mev γ-rays (in Mg^{24}).

The β-γ coincidence technique to be used is similar to that described by Putman,[1] except that a NaI scintillation counter is used as the γ-ray counter because of its higher efficiency. An end window counter is used for the β-rays. These two counters are on opposite sides of the active

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[1] J. L. Putman, Brit. J. Radiol. XXIII, 46 (1950).

pellet in an Al-lined lead shield. The distance from the β counter to the γ counter is about 1.7". The pellet is placed as close as possible to the β counter so that the efficiency of the γ counter will be as constant as possible with distance over the thickness of the pellet. This is required because a 2.5-gm pellet (thickness about 2 mm) is almost equal in thickness to the range for 1.39-Mev β-rays, so that the β-ray efficiency is far from constant over the pellet thickness. In order for the coincidence method to be valid for finding the absolute decay rate of the pellet, one or the other counter must have constant efficiency over the whole pellet.

The γ sensitivity of the β counter is corrected for by taking counts with about 1/8" Al between the pellet and the β counter to remove all β-rays. For a pellet such as described above, the residual count is about 8%. This is attributed almost wholly to γ-rays.

Approximate efficiencies have been found by counting coincidences visually on an oscilloscope for a pellet of the above size activated in the pile. They are about 4% for the β counter and about 1% for the γ counter for the above-described set-up. The efficiency of the β counter is

$$E_1 = \frac{C}{\gamma}$$

where C is the coincidence rate, and γ is the γ-counting rate. The efficiency of the γ counter is

$$E_2 = \frac{C}{\beta}$$

where β is the β-counting rate.

Coincidence circuits are under construction.

121-1 <u>Calibration of Neutron Sources</u> (5261-01)

C. Eggler

A 100-mg Ra-Be neutron source is to be calibrated for John S. Laughlin of Memorial Center, New York, by comparing it with ANL source No. 312 by the sub-critical pile technique.

This method has not been published in full. A paper submitted to Review of Scientific Instruments for publication has been returned for minor additions and revisions and is now in the hands of A. Wattenberg, one of the authors.

130-1 Absolute Measurements of the Energies of Alpha Particles (5211-01)

R. L. Platzman (Consultant from Purdue University)

An error has been found (and acknowledged by the author) in the authoritative paper[1] on the absolute determination of alpha-particle energies. The error is very small but is believed worth reporting here because of the possible future importance of the precise energies. For the standard, which is the main group of RaC', Briggs' values[1] for the energy and velocity should be changed from E = 7.6802 ± 0.0005 Mev to E = 7.6797 ± 0.0005 Mev, and from V = 1.92148 ± 0.00009 x 10^9 cm/sec to V = 1.92141 ± 0.00009 x 10^9 cm/sec. All other measurements using magnetic deflection have been made relative to RaC', so that the values in the standard compilations, such as that of Holloway and Livingston,[2] should be changed accordingly. The results are not given here because the time is apt for all energies to be recalculated using contemporary values of the fundamental constants. This is being done by Briggs, and it is expected that he will publish a new compilation some time next year.

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1 G. H. Briggs, Proc. Roy. Soc. (London) A 157, 183 (1936).

2 M. G. Holloway and M. S. Livingston, Phys. Rev. 54, 18 (1938).

131-1 The Average Charge of Daughter Atoms After Nuclear Transitions
(5211-03)

S. Wexler

The program of measuring the average charge of daughter atoms after nuclear transitions was continued with the study of the positron decay of 10-min N^{13}. A detailed account of the technique has been described in the quarterly reports from March through November, 1952 (ANL-4963 and ANL-4982). A preliminary summary of the results of beta decay and isomeric transition studies was published in Physical Review 88, 1203 (1952).

The procedure for preparing N^{13} (as N_2 and NO) in the very high specific activity necessary was worked out after many tests. The N^{13} was formed by deuteron bombardment of anhydrous Na_2CO_3 in the Argonne cyclotron and separated from the salt by vacuum fusion. The data obtained thus far indicate quite definitely that greater than 90 percent of the daughter atoms from β^+ emission of N^{13} carry a negative charge. This result is to be expected from the decrease in nuclear charge in positron decay, and suggests that orbital electron ionization does not accompany the β^+ process to a significant extent. Experiments are being performed to gain a quantitative measure of the average negative charge per disintegration. By suitable variation of the experimental conditions, it is hoped to separate the negative ion current formed by the β^+ emissions from the secondary electrons produced by the positrons at the walls of the ion collection chamber.

In addition, measurement of the average charge after K-capture of A^{37} is planned. A procedure for making A^{37} in very high specific activity by vacuum fusion of neutron-irradiated calcium metal has been worked out. Also, considerable testing of scalers and proportional counters was done to obtain a combination suitable for internal gas counting of the argon activity.

132-1 Chemical Service Work (4110-22 and 5261-01)

S. Wexler

A sample of $Li^6_2SO_4$ was converted to Li^6NO_3 in better than 95% yield. This lithium nitrate is to be incorporated into a glass to be used by V. Krohn in his study of neutron spectroscopy in the 0.01-to 10-Mev region.

The separation of V^{48} from deuteron-bombarded chromium is in progress. This activity is to be used by H. Casson and V. Krohn in a study of a decay scheme.

Several solutions of boron and uranium were prepared for pile oscillator measurements performed by D. Rose.

133-1 Design Study of Multibillion-Volt Proton Synchrotron (5211-14)

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

In anticipation that Argonne National Laboratory may join forces with universities located in the Midwest in a cooperative effort to build a multibillion-volt proton synchrotron, general studies of the strong-focusing principle are under way. (See Courant, Livingston, and Snyder, Phys. Rev. 88, 1190 (1952).)

II. MASS SPECTROSCOPY

1-1 Mass Spectrometric Techniques (5211-08 and 5261-01)

W. Chupka (Consultant from Harvard University), R. J. Hayden,
D. C. Hess, M. G. Inghram, H. Stanton, C. Stevens
Reported by M. G. Inghram

One of the most important jobs confronting the mass spectroscipist working on atomic energy is that of increasing the sensitivity and accuracy of the spectrometric equipment which serves as the basis of his work and which limits the number of problems which can be solved. Of the three major components of the machine, source, analyzer, and detector, the major limitation on sensitivity is the efficiency of the source; the major limitations on the accuracy are stability of the source and the accuracy of the detector. No major improvements are necessary in the resolving power of the analyzer or the sensitivity of the detector, the latter being able to detect single ions. The most recent report on improvement of the source is given as a note on "Surface Ionization Source Using Multiple Filament", which has been submitted for publication in The Review of Scientific Instruments.

During the last quarter, the properties of the multiple filament source were studied, and it was applied to the analysis of milligram samples. The major difficulty encountered is surface ionization of free radical hydrocarbons, which are not completely accommodated at the hot surface.

Preliminary studies have been made of ion bombardment sources. It has been found that the efficiency of the lead ionization is better when a surface containing lead is bombarded with Na^+ ions than when lead is evaporated in the surface ionization source. The difficulty with this method of "solid" analysis is that the ion beam produced has a spread in energy such that "good" resolution is not possible with a direction-focusing machine.

During the next quarter, we hope to study the effects of gases on surface ionization efficiencies. Results to date have been "erratic". In addition, we hope to test a multiple filament source designed to get rid of the free radical hydrocarbons, which limit the sensitivity of the present assemblies.

A paper on "The Multiple Filament Surface Ionization Source" was submitted to the Review of Scientific Instruments and accepted for publication.

2-1 Construction of Ma-17 (5211-08)

H. E. Stanton

In order to study the masses of nuclei with improved precision, the construction of a double-focusing mass spectrometer was undertaken. The versatility of such a machine can be improved by the insertion of an auxiliary accelerating slit system between the electrostatic and magnetic deflection systems. This modification would permit the study of numerous physical chemical problems, especially those involving carbon.

As the construction is still proceeding, no results of scientific interest have as yet been obtained. The electrostatic system has been virtually completed, and adjustment is being undertaken. Singly charged ions have been generated, deflected, and detected, with 4000 V acceleration, and the system performs roughly as expected. Serious electrical breakdown difficulties have appeared at higher accelerating voltages.

During the next quarter, it is hoped that the magnetic deflecting and detecting systems can be installed. This would permit final adjustment of the machine, at which time some studies of interest may be undertaken.

10-1 A Search for Rare Naturally Occurring Isotopes (5211-08)

D. C. Hess

At present atoms of most mass numbers which might be expected to be found for a given element have been identified either as occurring in nature or as having been produced artificially. There are, however, a few nuclides not yet discovered that in the light of beta systematics might be expected to be stable; for example, Gd^{150} and Sm^{146}. Furthermore, the proved existence of an active artificially produced nuclide of a given mass number does not preclude the possibility that the observed activity is that of an isomer of a stable nucleus.

It is to be presumed that all as yet undiscovered stable isotopes have low abundances, else they would have been discovered already. Further, such isotopes often differ in mass number from relatively abundant ones by only one unit. In general, the beam in a mass spectrometer for a given mass number is found to have weak but measurable wings that spread through the locations of the beams of adjacent mass numbers, presumably by scattering in the analyzer. Thus, the detection and measurement of a rare isotope is hampered by the presence of these backgrounds from nearby ones of much greater abundance.

Our successive single-focussing mass spectrometer, MA-16, that should make it possible to detect a beam having an intensity only 10^{-9} times that of an adjacent beam, has been built. After one magnetic deflection, the ions of the mass number of interest pass through a slit, are given further acceleration, and are again magnetically deflected. The second deflection thus analyzes the greatly "enriched" beam that emerges from the exit slit after the first deflection. The detector is a multi-stage electron multiplier. With the auxiliary equipment it gives a 10^{10} range of beam strength that can be measured.

The adjustment and testing of the machine and associated equipment has been completed, and it is ready for use.

11-1 Technetium in Nature (5211-08)

J. M. Miller, (Brookhaven National Laboratory), M. G. Inghram,
R. J. Hayden
Reported by R. J. Hayden

Old ores containing a relatively high percentage of rhenium have been found. Had technetium existed in nature at the time of their formation, it would probably have been relatively prevalent in these ores. The small molybdenum content of these ores has been extracted and will be analyzed isotopically. Excess Mo^{97} or Mo^{98} would indicate that technetium of corresponding mass existed in the ore at the time of its formation. Subsequent determination of the half-life would enable the time from the creation of the element until the formation of the ore to be estimated.

One of the three samples has been analyzed roughly. Deviations from normal, if any, were less than 3%. To set lower limits on this and on the other samples, improved methods of molybdenum analysis must be devised, but this result is good enough to be discouraging.

12-1 The Double Beta Disintegration of Te^{130} (5211-08)

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

A measurement of the double beta half-life of Te^{130} may help to decide between the Majorana and Dirac neutrino theories. To measure the half-life, xenon is extracted from old tellurium ores. The excess Xe^{130} extracted, as measured by a mass spectrometer, allows the double beta half-life of Te^{130} to be calculated. Previous work by members of this group indicates the half-life to be of the order of 10^{21} years, but in each of the experiments performed to date questionable points exist. It is hoped that a definitive experiment can be made using MA-18, the newly constructed gas analysis mass spectrometer.

Work on this problem is still in the stage of tuning up the recently completed mass spectrometer. When completed, the resolution of the machine (mass 1801 can be completely resolved from 1800) was adequate to resolve most mass 130 hydrocarbons from Xe^{130}. However, the sensitivity of the machine was low, and enormous background peaks appeared at every mass number. The sensitivity was improved by enlarging the size of the gas leak and by placing "pusher" plates to push the ions formed out of the ionization region and into the accelerating region. It is now such that 10^{-13} cc of gas at atmospheric pressure can be observed. To eliminate the background peaks, the instrument was baked out at 400° C. During this baking two flaws in the vacuum system appeared. These are now being repaired. George Wetherill, student at the University of Chicago, is helping with the instrument tuning.

It is hoped that, in the coming quarter, the instrument can be made vacuum-tight and that the high background peaks can be reduced. After this, xenon will be extracted from tellurium ores, and the Xe^{130} will be measured.

30-1 The Heat of Vaporization of Carbon (5211-08)

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

The problem is to study the fundamental thermochemistry of graphite by mass spectrometric techniques. The problem was outlined, and the state of the problem up to November, 1952, was given in ANL-4982.

Accent this quarter has been on extension of the work reported in ANL-4982. The ratio of C/C_2 from a hot graphite surface was reinvestigated using a new type source where the secondary effects were quite different. The ratio was unchanged. The ratio was studied while C_2H_2, H_2, C_2H_6 were introduced into the machine to see if the free radicals formed by the hot surface would affect the ratio; i.e., if part of the C_2 might be coming from fragmentization of C_2H. No change in ratio was observed. It is still felt that the results reported for this ratio in ANL-4982 are correct.

The measurements were extended to look at the C/C_3, C/C_4 ratios. No evidence could be found for C_4. There is tentative evidence that C_3 comes off hot graphite in amounts comparable to C. This must be checked again while varying pertinent parameters.

During the next quarter we expect to extend the work on C_3; to redetermine the activation energy of C; and determine that for C_2 and C_3. In addition, work will be started on a study of the ratios from an almost closed furnace in order to get data on accommodation coefficients, etc.

A letter summarizing our results to date has been published in Journal of Chemical Physics <u>21</u>, 371 (1953).

31-1 Studies of Electron Impact (5211-08)

W. Chupka and R. J. Hayden
Reported by R. J. Hayden

By measuring differences in appearance potentials, ionization potentials and electron affinities for atoms or for diatomic molecules and radicals may be measured. This problem is best attacked by using a mass spectrometer with a variable energy electron bombardment source and with a very sensitive ion detector. MA-18 is ideally suited to this work.

Due to the present vacuum difficulties with MA-18, no work has been done recently on problems of this kind. The first problem to be tackled is that of the electron affinity of carbon. This may lead indirectly to information as to the heat of sublimation of graphite.

32-1 Complex Ion Studies (5211-08)

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

The existence of ions of the form $NaKCl^+$, $NaCl_2^-$, etc., in a mass spectrometer equipped with a surface ionization source indicates that the thermal chemistry of such ion dipoles can be studied quantitatively. Such ions as NaH_2O^+ are of interest in wet chemistry. The present state of this subject was summarized by W. A. Chupka in ANL-4680.

No progress was made in the last quarter, due to interest in the heat of vaporization of carbon.

We hope to study the equilibrium of alkali ions in various gases, H_2O, Xe, etc., at near room temperatures. A new source has been completed which will enable the use of high gas pressures so that large ion clusters should be readily produced in thermal equilibrium. The older work on alkali halide equilibrium has been written but has not yet been accepted for publication.

33-1 Molecular States in Rare Gases (5211-08)

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

The noble gases form ionic molecules of the form A_2^+ or $KrNe^+$ when subjected to electron bombardment. The appearance potential and the variation in number with pressure for such ions indicate that they are formed by collision of an excited atom with a neutral atom. Since this is a second-order process, relatively high pressures are required in the source to produce a measurable number of the molecular ions. This high pressure causes considerable scattering of atomic ions in the analyzer, which in turn tends to mask the presence of the molecular ions. For this reason, we are not yet certain of the existence of some combinations of He, Ne, A, Kr, and Xe such as $XeHe^+$.

Since the production of these molecules depends on transition from excitation of the atoms to vibration of the molecule, the transition probability should be influenced by the mass of the nucleus. This effect may be detectable in the case of He^3 and He^4.

Future studies in this experiment will use either MA-18, a single deflection 12-inch radius 60° magnetic analyzer which has much better isolation between the source, where the high pressure is required, and the analyzer tube, where undesirable scattering occurs, or MA-16, which uses double magnetic deflection and extra acceleration to overcome the effects of gas scattering.

34-1 Argon Age Determinations (5211-08)

G. J. Wasserburg, (University of Chicago), and R. J. Hayden
Reported by G. J. Wasserburg

Since the discovery of a long-lived activity in K^{40}, there has been considerable interest on the part of geologists and physicists in the possibility of establishing a dating scheme based on A^{40}/K^{40} ratios. Because of the ubiquitous nature of potassium, it would be possible to date a considerable number of "old" geological events using small samples of primary rock-forming minerals. Furthermore, stony meteorites can be dated, which was hitherto not possible. These latter dates are of considerable cosmological significance, particularly since the discovery of He^3 contamination in iron meteorites has invalidated all of the earlier age determinations of interplanetary materials. Careful age determinations of meteorites would be of considerable aid in understanding the genesis of the solar system.

For this purpose a high vacuum line has been built for the extraction and purification of the rare gases contained in rocks and meteorites. Because of the micro-quantities of argon produced in stony meteorites ($\gtrsim 10^{-5}$ cc (STP) per gm), it is necessary to use an isotopic dilution technique. The purified gases are run on MA-18, a mass spectrometer of high resolution and sensitivity, and the A^{40} content determined. Since the A^{40} content of the atomsphere is approximately 1%, the contamination problem is critical.

The potassium analyses will also be done using an isotopic dilution technique. The K content of chondritic meteorites is $\gtrsim 0.1\%$ to 0.01%; it is therefore preferable to use this mass spectrometric method over standard wet chemical procedures. This will also be an independent check on the optical spectrographic determinations of K in meteorites done by other workers.

III. CRYSTALLOGRAPHY

1-1 Crystal Structures of Technetium Compounds (5211-11)

H. A. Plettinger and W. H. Zachariasen
Reported by W. H. Zachariasen

A study of the crystal chemistry of technetium carried out in collaboration with Dr. Sherman Fried, who did all the chemical work, was completed a considerable time ago. The work led to the determination of the chemical identity and the crystal structures of a number of compounds of technetium. Most of these individual results were included in earlier progress reports.

A paper for journal publication giving an account of the individual crystal structure determinations and a discussion of the crystal chemical properties of technetium is being prepared.

2-1 Structural Studies of Boric Acids (5211-11)

H. A. Plettinger and W. H. Zachariasen
Reported by W. H. Zachariasen

There is nothing new to report on the structural studies of HBO_2 and of H_3BO_3, as the Fourier synthesis calculations on the Pennsylvania State College XRAC computing machine have not as yet been completed.

V. THEORETICAL PHYSICS, GENERAL

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

D. R. Inglis

As a part of the general problem of trying to understand the structure of nuclei and the forces between nucleons, an attempt is being made to answer the question, "Why does the (jj)-coupling shell model not apply to the light nuclei, and what is the nature of the deviations from it?" In view of the fact that the mechanics of the light nuclei should be simpler than heavy nuclei because of their fewer particles, although empirically it appears to be more complicated, perhaps partly because of a lack of statistical averaging, this promises to be a fruitful region for obtaining a further understanding of the fundamental laws of nuclear structure. An indication of the general approach to the problem is given in a recent publication, "Intermediate Coupling as Encountered in Some of the p-shell Nuclei", Phys. Rev. 87, 915 (1952).

Among the heavy nuclei of the p-shell, from B to O, the general distribution of excited states may be accounted for fairly successfully by interpreting the states having the same parity as the ground state as arising from intermediate coupling of the ground configuration, intermediate between the (jj) and (LS) extremes, and noting that the states of the opposite parity arise from excitation of one of the p-nucleons to the sd-shell. For example, of the first three excited states in C^{13}, the two with even parity consist primarily of a closed $P_{3/2}$ shell plus an s or d nucleon, and are essentially single particle states. The state with odd parity is similar to a $^2P_{3/2}$ but extended into intermediate coupling in such a way that many p-nucleons are involved. The distinction between these single-nucleon and many-nucleon states is apparent in the very disparate intensities of the scattering resonances involving them.

The application of nuclear models to light nuclei is on firmer ground as a result of the recent clearing up of the sign of the quadrupole moment of Li^7, which is now known to be negative, as it should be according to the models. One of several indications of this fact has involved a rough qualitative understanding of the molecular quadrupole coupling constant in alkali halide molecules. Reason can be seen for believing that the dominant contribution at the nucleus of one ion comes from the simple coulomb potential of the charge of the other ion.

An article reporting progress to date and giving a good deal of the background for understanding the nature of the problems involved is scheduled to appear in the Reviews of Modern Physics for April, 1953.

During the following quarter, it is expected to polish up the final details of the publication in the Reviews of Modern Physics and to look into some of the unexplained "queer" facts, such as the frequent equality of first excitation energies of neighboring pairs of even-even nuclei.

2-1 Excited States of Light Nuclei (5211-07)

D. Kurath

The order of energy levels for 1 p-shell nuclei (He^5 through O^{16}) as given by the jj-coupling model has been reported[1] for configurations where the individual nucleons are all in the lowest possible shells. Some of the low excited states should arise from configurations wherein a nucleon is excited from the 1 $p_{3/2}$-shell to the 1 $p_{1/2}$-shell. It is proposed to investigate the level order of states arising from such configurations and to attempt correlation of results with recent experimental data.

Results have been obtained for some of the simple configurations with static, central-force interactions of the Majorana and Bartlett types. Many of the results have been used by D. R. Inglis in his studies of energy states of light nuclei.

Very little work has been done on this project in the past quarter, but resumption of calculations is anticipated in the next quarter.

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[1] D. Kurath, Phys. Rev. 88, 804 (1952).

3-1 Angular Correlation in the 3-Gamma Cascade in Ti^{48} (5211-07)

M. Brachman and E. J. Hellund
Reported by E. J. Hellund

There are reasonable grounds for the belief that the decay of Sc^{48} by beta emission leads to an excited state of Ti^{48} with a spin of 6. This state decays via three successive γ emissions into the ground state with spin 0. According to D. Kurath, Phys. Rev. 87, 528 (1952), the two intermediate states have spin, 2 and 4, respectively. Experiments now underway seek to correlate these conclusions by a check on the angular correlation of the three γ quanta.

Since there is no likely possibility of a parity change, one should expect to find that the angular distributions observed experimentally agree with those calculated theoretically for electric quadrupole radiation. Using Wigner's notation, one finds for the correlation function $W(\theta_1, \theta_2, \phi_2)$,

$$W(\theta_1, \theta_2, \phi) = \sum_{m_1, m_3, \mu_0, \mu_1, \mu_2} \left(S^{6,2}_{4, m_1 - \mu_0, \mu_0} \right)^2$$

$$\left| \sum_{m_2} S^{4,2}_{2, m_1, m_2 - m_1} D^2_{m_2 - m_1 \mu_1}(0, \theta_1, 0) \; S^{2,2}_{0, m_2, m_3 - m_2} D^2_{m_3 - m_2, \mu_2}(\phi_2, \theta_2, 0) \right|^2$$

where the $S^{j_1 j_2}_{j, m_1, m_2}$ are the Clebsch-Gondon coefficients and the $D^2_{\mu_1, \mu_2}(\phi, \theta, 0)$ represent the elements of the rotation matrix. θ_1 and θ_2 are the polar angles of γ_1 and γ_2 with γ_o defining the polar axis. ϕ_2 is the azimuthal angles of γ_2 with respect to the plane formed by the directions of emission of the first two quanta.

A very minor complication is injected by the experimental inability to discriminate on the basis of energy between all three quanta. Mathematically, this is expressed by averaging formula (1) over a suitable permutation of the angle variables.

The rather lengthy computations are not yet completed.

Investigation of advantages of the triple correlation over double correlation will be undertaken.

4-1 Investigation of Nuclear Shell Structure (5211-07)

M. G. Mayer

The shell model of the nucleus has been able to explain a number of experimental facts. However, there are a number of experimental data for which the explanation is still outstanding. For instance, one is as yet unable to predict spins of odd-odd nuclei; the very large quadrupole moments certainly must influence the shell structure.

In connection with Mr. Morris Scharff, methods were set up to deal with nuclei of even A in which neutrons and protons are not in the same shell. The influence of various types of forces on the coupling between neutrons and protons is investigated.

Calculation of spins of odd-odd nuclei will be continued. The influence of the quadrupole moments on various nuclear phenomena will be studied in greater detail than previously (ANL-4963, Sec. X).

Most results will probably be incorporated in the book on Nuclear Shell Structure to be published by John Wiley and Sons.

5-1 Book on Nuclear Shell Structure (5211-07)

M. G. Mayer

The book "Nuclear Shell Structure" by J. H. D. Jensen and M. G. Mayer attempts to summarize all experimental data which bear upon the proposed nuclear model. It will be written for experimentalists rather than theoreticians, and be no more that 150 pages long.

Since the shell model was first proposed, many more experiments have been performed which are significant. In view of this, the empirical evidence had to be reviewed carefully. Tables were prepared of spins, magnetic moments, and quadrupole moments of all nuclei of odd A. The occupation numbers of the shells were assigned according to this evidence.

β decay systematics, which were discussed by Mayer, Moszkowski, and Nordheim (Rev. Mod. Phys. 23, 315 (1951)), were again reviewed. New tables were prepared, which contain many more, and more accurate, data than those available at the earlier time.

The significance of the deuteron stripping experiments with respect to nuclear model was investigated.

The book may be finished within the next quarter. The chapters still to be written are those on quadrupole moments, light nuclei, and odd-odd nuclei. The book will be published by John Wiley and Sons.

6-1 Inner Bremsstrahlung and the Magnetic Moment of the Neutrino (5211-07)

E. J. Hellund

A particle emitted from a nucleus decay will radiate, provided it has a net electric charge or magnetic moment. The amount of radiation is dependent on the velocity with which the particle is ejected and on the specific electromagnetic properties of the particle. A significant feature of this radiation is the following. If the energy of the emitted beta particle be regarded as fixed and the mass of the particle be regarded as variable, then on letting the rest mass approach zero, the probability of radiation approaches infinity. The importance of this observation lies in the fact that experimental measurements on the H^3 spectrum demand that the neutrino mass be less than 100 ev. However, the neutrino energy can be in many cases well over 1 Mev. This suggests that inner bremsstrahlung observation may be a good means of establishing an upper limit on the magnetic moment of the neutrino.

Since, in the beta emission, the bremsstrahlung is quite insensitive to the details of the beta emission, the method employing the singular solutions of the Dirac equation was used in the calculations (J. K. Knipp and G. E. Uhlenbeck, Physica, 3, 425 (1936). The result, using the Born approximation, yielded for the total cross section for photon emission,

$$\Phi \cong \frac{2}{\pi} \frac{m_0}{\mu_0} g^2 k' \alpha\left(\frac{p'}{p'e}\right) W' W'e$$

where μ_0 = rest mass of neutrino
m_0 = rest mass of electrons
g = ratio of neutrino magnetic moment to 1 Bohr magneton

k' = momentum of photon in units of m_0c
$p'e$ = momentum of ejected neutrino in units of m_0c
p' = momentum of neutrino after photon bremsung
$W'e$= energy of emergent neutrino in units of m_0c^2
W' = energy of neutrino after photon bremsung

Publication is intended after a thorough check for possible errors has been completed.

7-1 Collective Description of Nucleon Interactions (5211-07)

M. Ferentz and D. Pines (University of Illinois)
Reported by M. Ferentz

The success of the Collective Description in dealing with electron-electron interactions,[1,2] conductivity of metals,[3] and the stopping power of metals for charged particles,[4] led to the investigation of the application of the Collective Description to nucleon-nucleon interactions.[5]

Work in the last quarter has consisted principally of numerical calculations on the IBM equipment of the dispersion relations for collective oscillations with various choices of nuclear parameters and interaction potentials. To date, calculations have only been done for self-mirrored nuclei, and in the next quarter it is hoped that the calculations for the more interesting case of unequal numbers of neutrons and protons will be done.

A paper is being prepared on this subject for submission to the Physical Review.

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[1] D. Bohn and D. Pines, Phys. Rev. 82, 625 (1951).
[2] D. Pines and D. Bohn, Phys. Rev. 85, 338 (1952).
[3] T. Staver, Ph. D. Thesis, Princeton University (1952).
[4] D. Pines, Phys. Rev. 85, 931 (1952).
[5] M. Ferentz, Ph. D. Thesis, University of Pennsylvania (1953).

8-1 Monoenergetic Neutrons from Charged Particle Reactions (5211-07)

A. Langsdorf and J. Monahan
Reported by J. Monahan

Hanson and Taschek (A. O. Hanson and R. F. Taschek, National Research Council Nuclear Science Series, Preliminary Report No. 4) give the formula for the energy, E_3, of a neutron emitted in a (p,n) reaction in terms of the energy of the incident proton and the masses involved. The purpose of this investigation is to obtain the following: (a) the corresponding expression for the relativistic kinetic energy, T_3, of the emitted neutron; (b) the magnitude of the spread and shift in E_3 due to the Doppler effect; and (c) the change in E_3 due to the ionization of the residual atom. These results are to be used in a detailed numerical analysis of the Li^7(p,n) reaction.

Preliminary calculations indicate that $\frac{|T_3 - E_3|}{T_3} \simeq 0.001$ for back angle scattering from Li at proton energies less than 5 Mev. This is the same order of magnitude as the experimental uncertainty in T_3 expected by the Argonne electrostatic generator group. For angles less than 90°, the relativistic correction is somewhat greater.

If the recoil velocity of the Be nucleus is greater than the velocity of its orbital electrons, the Li(p,n) reaction must be treated as

$$H^1 + Li^7 \rightarrow (Be^7)^{\nu + 1} + n + \nu\beta + Q,$$

where $\nu + 1$ is the degree of ionization of the residual atom. Because the definition of Q as the difference in rest energies enters more naturally, the relativistic treatment of this reaction is simpler than the corresponding classical calculation. In general, however, this correction seems to be an order of magnitude less than the initial relativistic correction.

The motion of the target nucleus causes a spread, or uncertainty, in the energy E_3. For a Li target at room temperature, a spread in E_3 of 120 ev is obtained for $E_1 = 2$ Mev at a scattering angle of 135°. There is also a total shift in the neutron energy due to the Doppler effect; however, this is only 2 or 3 ev.

Plans have been made to obtain the proton energies corresponding to about 700 values of T_3 in the range 100 kev to 6 Mev for scattering angles 0°, 2°, 30°, and 32° and to approximately 125 values of T_3 in the range 0 to 200 kev for scattering angles 119° and 120°. A more detailed program depends on the results of these calculations. The computer group has scheduled these for sometime within the next three months.

30-1 Consultation on Miscellaneous Theoretical Problems (5211-07 and 5211-14)

M. Hamermesh

Be (γ,n) Cross Section at 2.185 Mev

In calculating the cross section for photodisintegration of Be by the 2.185-Mev gamma from Ce, one must correct for the disintegrations which are produced by the bremsstrahlung which is produced by the 3-Mev beta spectrum of Ce. A general procedure, which had been developed earlier for such problems, was applied to this specific case. The results are included in a paper by B. Hamermesh and C. Kimball, Phys. Rev. 89, 1306 (1953).

Direction of Polarization of Neutrons Passing Through Iron

S. Bernstein, *et al.*, at Oak Ridge are doing experiments on neutron capture by aligned nuclei. For the interpretation of these experiments it is necessary to know the direction of polarization of the incident neutron beam. The general theory was checked, and the final result (in agreement with independent work of Jauch) is that the spin of the polarized neutrons emerging from an iron block is opposite to the direction of the applied magnetic field.

31-1 The Configuration Interaction in Iron Group Elements (5211-14)

N. Rosenzweig

The energy terms assigned to the different configurations of an iron group element overlap considerably in many cases. Therefore, it is expected that an adequate theoretical elucidation of many iron group spectra will require the inclusion of the matrix components of the configuration interaction (CI). The matrix components of the CI have been expressed in terms of Slater integrals (N. Rosenzweig, Phys. Rev. 88, 580 (1952)).

We shall try to assess the importance of the CI by attempting to fit the experimental terms to the theoretical eigenvalues as given both with and without CI. The Slater integrals are treated as adjustable parameters, and the best values are determined by a least squares calculation.

Least squares calculations appropriate for investigating CI in the even configurations of FeII have been programmed for the AVIDAC.

A variety of calculations planned for the AVIDAC will be carried out when certain temporary technical limitations connected with the operation of the AVIDAC are overcome.

32-1 Plural Scattering of Electrons at Oblique Incidence (5211-14)

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

Goertzel and Cox (G. Goertzel and R. Cox, Phys. Rev. 63, 37 (1943)) have obtained expressions giving the minimum contribution of plural scattering to the number of electrons deflected from a thin foil through an angle of 45°. They find this effect to be about ten times greater for reflected than for transmitted electrons, a ratio which is much larger than recent experiments seem to indicate. The purpose of the present calculation is to obtain more exact expressions for this effect and to extend the results to scattering angles other than 45°.

Fairly precise expressions for the magnitude of the plural scattering in terms of double integrals have been obtained. However, the complexity of the integrand in these equations seems to rule out any possible method of solution other than a numerical integration.

Yet to be examined is the advisability of using a Gaussian distribution for the electron cross section at small scattering angles. The alternative is to neglect this region of the foil which gives rise to multiple scattering.

33-1 Geometry for Maximum Scattering and Minimum Dispersion (5211-14)

A. Langsdorf and J. Monahan
Reported by J. Monahan

Consider a line drawn from a point source to the center of a target and a second line drawn from the center of the target to the center of a detector. Let the angle between these lines be θ_o. Due to the finite size of the target and detector, particles will be counted which are scattered through angles in the range $\theta_o - \mathcal{E} \leq \theta \leq \theta_o + \mathcal{E}$. This angular dispersion decreases as the sizes of the target and detector are decreased. However, the counting rate is also directly proportional to the product of the effective areas of target and detector. It is desired to obtain the shapes of target and detector which give a minimum dispersion consistent with maximum scattering.

Equations for $\mathcal{E}$ as a function of the areas involved can be obtained rather simply. However, in the formulations already investigated the resultant optimum conditions involve the simultaneous solution of rather complicated algebraic equations.

Plans for any future investigation of this problem are rather indefinite, depending upon the time available for it. Since essentially the same information which would result from the solution of this problem can be obtained experimentally, the problem is somewhat academic.

34-1 Quantized Space-Time (5211-14)

E. J. Hellund and K. Tanaka
Reported by E. J. Hellund

The proposal that space-time coordinates contain a minimum length has been frequently advanced as a means of removing the divergence troubles of quantum field theory. That a minimum length could be introduced without giving up space-time continua was demonstrated by H. S. Snyder. His proposal involved changing over from a c-space to a q-space in such a way that the operators representing configuration space possessed discrete eigenvalues. Snyder's mathematical formulation was awkward in that no simple correspondence could be established between the two spaces.

We have eliminated this defect by showing that a transformation could be written for free particles, as follows,

$$X'_\lambda = X_\lambda - \ell^2 \frac{\alpha}{\alpha X_\lambda} X_\alpha \frac{\alpha}{\alpha X_\alpha} \qquad (1)$$

where primes denote q space always. With the above formulation one could take the momentum and energy to remain invariant under such a transformation,

$$p'_\lambda = p_\lambda \qquad (2)$$

and

$$X'_\mu p'_\nu - X'_\nu p'_\mu = X_\mu p_\nu - X_\nu p_\mu \qquad (3)$$

The principal difficulty encountered in these proposals is the obvious one that initial conditions (at a definite time) can no longer be introduced in the usual manner.

The program at present is concerned with just the question of time localizability.

35-1 Scattering of Photons by Atoms (5211-14)

E. J. Hellund

The decay of resonance radiation by spontaneous emission has been shown not to yield the radioactive decay law, (Phys. Rev. 88, 919 (1953)). The proof of this theorem rested on the assumption that the system could be represented as in an excited state at some definite time, say $t=0_0$. The result has been criticised on just this ground, the contention being advanced that the scheme of excitation of the resonance level should appear explicitly in the calculation. To meet this criticism, the state at t=O was changed to be described as follows: atom unexcited; radiation field of photons with isotropic distribution as to direction of propagation and polarization present. Calculation of the excitation and decay of the resonance level again revealed that the radioactive decay law did not hold. Inclusion of additional atoms, excited or unexcited, did not alter the conclusion.

Publication has been delayed to permit prior appearance in the Physical Review of the calculations based on the boron decay conditions employed by E. Wigner and V. Weisskopf.

VII. ELECTRONIC DIGITAL COMPUTERS

1-1 Report on the Design of the ANL Computer (4520-02)

R. F. Kramer

A report on the design of the AVIDAC (Argonne's Version of the Institute's Digital Automatic Computer) is being prepared. The report will cover both the logical design and the engineering design. Many people, both inside and without the Laboratory, have contributed to the design of the AVIDAC, with each section being treated as an individual problem. This report will attempt to assemble the ideas and designs used in the AVIDAC into a description of the machine and its operation.

To date, some of the drawings have been checked and brought up to date. Also, a tentative outline of the report has been prepared. The outline is shown below:

A. Introduction.

This introduction will give a general description and history of the machine. The principle units will be described.

Arithmetic unit
Control unit
Memory unit
Input and output units

B. A list and description of the arithmetic and control orders.

C. The logical design.

A description of the logical design of the various units used in the arithmetic section, memory section, and control section.

D. Engineering design.

A description of the engineering design of the units described in C.

E. Power supply and protection system.

F. Maintenance procedures and routines.

This is tentative and will probably be revised and expanded.

During the ensuing quarter, a rough draft of at least a few of the sections indicated in the outline will be made.

2-1 The Electrostatic Memory System of the AVIDAC (4520-02)

J. C. Chu, D. H. Jacobsohn, R. F. Kramer
Reported by D. H. Jacobsohn

The present problems of the electrostatic memory system are two-fold: First, obtaining the best possible results from the memory system that is at present part of the AVIDAC; and secondly, the development of a better system as a possible replacement should the present system prove to be inadequate.

The present major cause of errors in the use of the AVIDAC is the electrostatic memory. This system is now operating with a 256-word, 16 x 16 diamond-shaped raster.

The general types of difficulties that have occurred with the system are as follows:

A. Common errors - the same type of error occurring in two or more tubes simultaneously at the same location.

B. Impurity errors - the inability to write a "1" in some specific location of a particular tube.

C. Read-around errors - the changing of a zero to a "1" due to electron refilling caused by repeated consultation of adjacent spots.

D. Random - occasional errors having no apparent cause or regularity.

During the past quarter considerable progress has been made in reducing the error rate of the memory.

A. Common errors have been virtually eliminated by: 1) improved filtering and isolation of the various voltage lines going into the memory; 2) the removal of dust from the deflection bus (this must be done regularly); 3) the grounding of the cans of the by-pass capacitors of the CR tubes that had been previously allowed to float.

B-C. Impurity and read-around errors are being reduced by tube selection.

D. Random errors appear to go down in frequency as the other causes of errors are reduced. This could be due to the need of less marginal adjustment.

Fifty Sylvania CR tubes were tested with a 1024 raster during the past period with the following results:

18 tubes were acceptable with a read-around of 64 or better.

12 of these 18 read around 96 or better.

3 of these 12 had very bad impurities.

32 tubes were of no value.

Some of the 18 acceptable CR tubes undoubtedly have undetected impurities. Attempts at sparking new tubes to eliminate impurities have been started. At present there has been no success.[1]

During the next quarter at least one hundred new CR tubes should be obtained and tested in order to replace all remaining questionable tubes

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[1] National Bureau of Standards Report 5711, p. 3.

that are in the memory and to stock some good spare tubes. At such time as the memory has operated adequately for several weeks on a 256-word raster, investigation should be made into the use of a 512-raster. In line with this investigation, certain things should be kept in mind:

A. The possibility of increasing both the gain and high-frequency cut-off of the video amplifier.

B. The use of a back-to-back twitch.

C. The relative virtues of a 16 x 32 raster vs. a 32 x 16 raster.

Possible investigations of other electrostatic storage systems for replacement purposes will be considered.

3-1 The Operation and Maintenance of the AVIDAC (5420-02)

J. C. Chu, D. H. Jacobsohn, R. F. Kramer
Reported by D. H. Jacobsohn

This report pertains to the transition of the AVIDAC from a machine in construction to a machine in operation. Many different problems are encountered at this stage that will not arise later. These problems include the completion of the control to bring the complete order list, the debugging of both the Arithmetic Unit and the Memory, and the establishment of operating and maintenance procedures.

Operation and maintenance can best be treated if divided in the following manner:

A. Preventive maintenance.

B. Operational checking.

C. Operational problem solving.

D. Corrective maintenance.

During the past quarter, no effort has gone into preventive maintenance, as all effort has been spent on operation and corrective maintenance.

Operational checking has been fairly well established. The following set of tests and procedures for testing the reliability of the machine has been devised:

A. If the machine has not previously been used, a static memory check is made for 1/2 hour.

B. A test tape is used to check the ability of the memory to write zeros and ones in all memory positions.

C. A read-around test is run for 1/2 hour, checking all positions for a read-around of 80.

D. A register test is run until completion. This test tests all operations of the machine repeatedly, checks the total contents of the memory, and then stops.

All the above tests must be successful before the machine can be used. Any troubles located by these tests are to be analyzed and corrected.

In the final operation of the AVIDAC, it is expected that relatively little time will be spent on corrective maintenance, even though the bulk of all time at present is so spent. At present the useful operational problem solving time is about 10%. Most of the errors that have occurred repeatedly have been with the electrostatic memory and the teletype input-output devices. Various aspects of the electrostatic memory system are treated in the separate current report on that subject.

The difficulties that occurred in the teletype input-output system were almost all due to attempting to use moderate speed mechanical devices at higher than normal speeds in conjunction with electronic circuitry. Most of these difficulties were overcome by redesigning some of the circuitry and by more critical adjustment of the mechanical parts. One difficulty that still exists is that our tape reader perforates the tape it reads, preventing repeated use of tapes unless they are reproduced. With our present equipment it is necessary to use the AVIDAC to reproduce tapes. This is highly inefficient. The present input speed is 1 second per word, and the output speed is 2 seconds per word.

During the next quarter it will be necessary to establish a preventive maintenance program based on the analysis of data that have been accumulated from corrective maintenance records. Other procedures should be established using marginal checking by the variation of voltage and timing parameters wherever possible.

An effort will be made to complete the AVIDAC order list in this period.

4-1 Test Routines for the Argonne Computer (4520-02)

J. Alexander, J. F. Hall, J. Sukup
Reported by J. Alexander

In order to locate physical faults (burnt-out tubes, resistors, etc.) it is necessary to have a number of simple, diagnostic, test problems. The following routines have been developed to date:

Teletype Reader Test

Determines that the teletype reader can read zeros and 1's in all positions, and that memory can receive zeros and 1's in all positions.

Memory Reading and Writing Test (Tape T-1.3)

Determines whether the memory can read and write zeros and 1's in all positions.

Memory Consultation Test (Tape T-11.5)

Determines whether the memory can write 1's 160 times in rapid succession at any location without destroying zeros at neighboring locations.

Register Test (Tape T-13)

Determines whether all (?) the gates in the arithmetic unit operate properly for 2^{10} to 2^{16} times in succession, and tests that the adder can obtain the correct result for each of the eight possible input states for 2^{16} times each.

"Random Number Test" (M. Butler of RE Division) (Tape T-5.2B)

Determines whether the machine can compute 6×2^{16} products and 3×2^{16} quotients without error.

Since astronomical times would be required to check all states of the computer, some selection was necessary in constructing these tests. Optimizing this selection will be a continuing project.

5-1 Sub-Routine Library for the AVIDAC (4520-02)

M. L. Butler (Reactor Engineering Division), J. F. Hall, J. L. Sukup
Reported by J. F. Hall

The basic built-in order list of the AVIDAC includes those most frequently used operations which can be made automatic without undue complication of the control (addition, subtraction, multiplication, division, etc.). There are, however, many frequently used operations not included in this basic list, such as computation of square roots, sines, cosines, exponentials, etc. For these, lists of instructions for producing the desired functions by use of the basic order list are prepared. Such lists of instructions are known as sub-routines. Having them available for use in connection with particular calculations is nearly equivalent to adding the corresponding order to the order list. Another type of sub-routine would be called an arithmetic; e.g., the arithmetic of complex numbers. Still another is a floating-point or self-scaling arithmetic, where numbers are represented in what is sometimes called scientific notation. For arithmetics of this sort, additional sub-routines for the frequently required functions again are needed.

In the interest of getting the sub-routine library of the AVIDAC to the point where many short,small computations can be done with a minimum of special preparation, the main effort has been in obtaining sub-routines for floating-point arithmetic. Routines of this sort are now being tried out on the machine. Revised, more final versions will be prepared and reported on at a later date.

6-1 Coding Manual for the AVIDAC (4520-02)

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

It is desired to have a manual that will contain all relevant information concerning the mode of operation of the AVIDAC, the conventions and procedures used by the AVIDAC group in programming and coding problems, and a descriptive list of the standard sub-routines available for use. This manual should serve as a reference for persons expecting to code problems for the AVIDAC, rather than as a text book.

Considerable material has been written up concerning the mode of operation of the ORACLE, and this needs only slight modification to be applicable to the AVIDAC. This material also contains some description of the conventions and procedures adopted by the Argonne and Oak Ridge groups, but is incomplete.

A course of lectures for prospective users of the AVIDAC is planned to begin about April 1. It is expected that at least a rough draft of the manual should be completed by the end of April for use in connection with this course.

7-1 The Auxiliary Memory for the ANL and ORNL Computers (4520-02)

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

A discussion of the magnetic tape auxiliary memory in general is to be found in ANL-4600, pp. 71-103. Current effort is being expended on equipment necessary to connect the two experimental tape units to the AVIDAC and ORACLE.

During the last quarter, the electronic design work on the equipment was started and carried to the point where some construction work can begin.

The 2-inch multiple-channel recording head was completed and tested. The performance is satisfactory except for some obvious construction faults which can be eliminated in future models.

An experimental model of an electrostatically actuated tape clutch has been built. Unexpected difficulties have occurred in the various parts which make a feasibility test meaningless.

During the forthcoming quarter, work on the equipment which will allow communication between the auxiliary memories and computers will be carried forward. Completion and installation of the equipment could be achieved by June 1, given sufficient manpower.

Some experimental work aimed at cutting costs of production on recording heads will be done so that final drawings for production can be had by June 1.

Also, it is hoped that a firm choice on the clutch type (magnetic or electrostatic) can be made by June 1.

The test rig modifications currently being undertaken will be completed as soon as possible (possibly by May 1) so that tapes can be analyzed for reliability, and initial program pulses recorded.

8-1 A Problem in Partitions (5211-14)

D. A. Flanders

The problem, to be solved by the AVIDAC, is the following:

Let n be a positive integer, and let $(p_1, \ldots, p_r)$ be a finite set of distinct ordered pairs of positive integers, say $p_i = (p'_i, p''_i)$ for $1 \leq i \leq r$. We shall say that $(p_1, \ldots, p_r)$ is a partition of n if and only if $\sum_{i=1}^{r} p'_i = n$, and shall denote the partition by p (n). If $p(n) = (p_1, \ldots, p_r)$ is a partition of n, each p_i will be called a part of p(n), and p'_i and p''_i will be called the value and index, respectively, of the part p_i. If also q(n) = $(q_1, \ldots, q_s)$, with $q_j = (q'_j, q''_j)$, is a partition of n, p(n) will be said to be identical if and only if there is a one-to-one correspondence between the parts of p(n) and those of q(n) such that corresponding parts have the same value.

Let p(n) and q(n) be partitions of n. A class $(Q_1, \ldots, Q_r)$ of mutually exclusive subsets Q_i of q(n) will be called a way of filling p(n) from q(n) if and only if Q_i is a partition of p'_i for $1 \leq i \leq r$. If also $(Q^*_1, \ldots, Q^*_r)$ is a way of filling p(n) from q(n), then the two ways will be called identical if and only if for each i the sets Q_i and Q^*_i are identical.

For any n, p(n) and q(n), the number of distinct ways of filling p(n) from q(n) is finite, and will be denoted by $f[p(n), q(n)]$. For any n and p(n) the number of distinct ways of filling p(n) from all possible partitions q(n) is finite and will be denoted by $F[p(n)]$.

The problem is to determine $F[p(n)]$ for every partition of n, where n assumes any positive integral value less than some suitable upper limit N.

A systematic procedure for generating the partitions of an integer n has been found that is applicable to the AVIDAC in its present form. A systematic procedure for computing $f[p(n), q(n)]$ and $F[p(n)]$ has been found that can be applied to the AVIDAC as soon as the machine has auxiliary magnetic tape memory. It has been determined that this procedure is practicable for $n \leq 15$ and that it can be suitably modified for larger n, but that the rapid increase in labor with increasing n makes it unlikely that the computation can be carried out for n as large as 31.

The problem of generating and listing the partitions of n for $1 \leq n \leq 31$ will programmed for the AVIDAC, and the actual listing carried out up to some point beyond n = 15.

20-1 Report on Research, Development, and Design of the ORNL Computer (4520-02)

J. C. Chu and G. Evans II
Reported by J. C. Chu

The major construction work on the ORNL computer was completed in January, 1953. The research, development, and construction of this computer represents the major portion of the time and effort spent by the computer engineering group since early 1950 to date. However, because of the fact that an early operation date of this computer is desired by Oak Ridge National Laboratory, the time schedule has been such that no comprehensive report with some continuity has ever been issued on this computer for the past two years. Inquiries for such a report have been received from time to time from ANL staff members and workers in this field outside the Laboratory.

Inasmuch as the ORNL computer will move to Oak Ridge in the near future, it is desirable to prepare a comprehensive report. The author began work on this report in January, 1953, and was later joined by George Evans.

The tentative table of contents of this report is as follows:

Table of Contents

5.4 The dynamic programmer and carry delay gate

5.5 The clear and transfer selector

5.6 Shift register and end connection control

5.7 The complement gate control

5.8 Transfer control

5.9 Miscellaneous control gates

5.10 The shift counter

5.11 The memory

5.12 The memory order sequence control

5.13 The dispatch counter

5.14 Input and output control

VI. Power supply and protection system

VII. Computer maintenance routine

VIII. Appendix

8.1 Binary representation of real numbers.

8.2 Binary arithmetic used by the computer.

To date, the first draft of Sections I, II, and III has been written.

Work to be done during the ensuing quarter: It is expected that a first draft of the major portion of the report will be completed during the next quarter.

21-1 Operation of the ORNL Computer (4520-02)

E. Burdette, J. C. Chu, W. Gerhard, R. J. Klein, Jr., J. Woody
Reported by J. C. Chu

The major work on the construction and installation of the ORACLE (Oak Ridge Automatic Computer, Logical Engine) was completed in January.

To date, the memory control and the dispatch counter have been checked and operate satisfactorily. The teletype control was designed and is now in production.

It is expected to have the ORACLE in operation during the ensuing quarter.

VIII. APPLIED MATHEMATICS AND COMPUTATION, GENERAL

1-1 IBM Methods and Procedures (4520-02 and 5261-08)

W. Feurzeig

The tab plug-board for the fixed-point general purpose board has been wired. The board has been tested and minor errors corrected. Operating instructions and coding conventions have been written up for distribution to users. The computation of auto-correlation coefficients and other statistical results from series of data on human blood has been coded. Other problems are in process. The board is in constant use and has become a permanent part of the IBM facilities.

2-1 Report on Technical Details of the General Purpose IBM Boards (4520-02 and 5261-08)

N. F. Morehouse

A report on the technical details of the IBM boards is currently being prepared. It is hoped that this report will enable the machine operators to take over all duties connected with the "trouble shooting" of the boards in the event of a machine failure.

3-1 Report on Coding for the General Purpose IBM Boards (4520-02 and 5261-08)

N. F. Morehouse

A report on the operations which are possible with the three general purpose IBM boards is currently being written. This report includes an elementary discussion of general purpose boards and the details of coding problems for the boards currently in use. The first draft has been written and corrected by D. A. Flanders.

4-1 Tabulation of Fermi-Dirac Distribution Functions (5211-14)

E. L. Dershem and N. F. Morehouse
Reported by E. L. Dershem

The Fermi-Dirac distribution functions

$$\int_0^x \frac{t^{1/2}\,dt}{e^{t-\eta}+1}$$

and

$$\int_x^\infty \frac{t^{1/2}\,dt}{e^{t-\eta}+1}$$

have been computed for all $x \geq 0$, over the parameter range $-4 \leq \eta \leq 10$. The final tables will be expressed in terms of the arguments x and $x-\eta$. First differences with respect to $x-\eta$ are being computed. The tabulation will be completed during the next quarter.

5-1 IBM Floating Point Sub-Routines (4520-02 and 5261-08)

E. L. Dershem

A number of floating-point sub-routines have been coded and punched on IBM cards. Decks are now available which will compute the following functions of real arguments:

Function	Range Limitation
10^X	$\|X\| \leq 50$
e^X	$\|X\| < \ln 10$
X^N	$\|N \log X\| < 50$; $X > 0$
log X	$X > 0$
ln X	$X > 0$
sin X, cos X	$\|X\| < 200\pi$
Arc sin X	$0 \leq X \leq 1$
sinh X, cosh X	$\|X\| < 50 \ln 10$
arc sinh X	----
arc cosh X	$X \geq 1$
arctanh X	

The following routines for computation with complex numbers are available:

Operation or Function	Coordinate System
Add	Rectangular
Subtract	"
Multiply	"
Divide	"
Multiply	Polar
Divide	"
Square Root	"
i times (a + ib)	Rectangular
Conversion	Rectangular to Polar
Conversion	Polar to Rectangular
sinh (a + ib), cosh (a + ib)	Rectangular

During the next quarter, we hope to extend the range for arc sin X, develop routines for arccos X and arctan X, and incorporate changes which will enable real number routines to check their own range limitations.

6-1 Computation of Neutron Chopper Results (5261-08)

W. Feurzeig

The calculation of energies, transmissions, and cross sections from data obtained with the neutron chopper has been programmed and coded for the IBM machines, using the fixed-point general purpose board. Instructions on operating procedures have been written up. A report on these calculations is being written. It will illustrate the use of the general purpose board for the numerical analysis of experimental data.