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Physics-General

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Experimental Nuclear Physics Division

D. J. Hughes, Director

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Group #1 - A. Langsdorf, Jr.

1. Progress on Van de Graaff Machine

The stabilizing control systems on the Van de Graaff machine are now in operating order. A beam of about 1 microampere at 3 million volts has been obtained. The electrostatic deflector has been checked against the $\text{Li}(p,n)$ reaction threshold at 1.88 Mev and the design figure for the electrostatic analyzer checked to 1%. Therefore we are certain of the 3 million volt figure for the energy that has been reached. This voltage was reached with 60 pounds nitrogen pressure in the tank. Since the tank is designed to operate up to 150 pounds it appears certain that 4 million volts will soon be exceeded barring only unexpected electrical breakdown in the vacuum tubes.

Group #2 - D. J. Hughes

1. Polarization of Neutrons by Reflection from Magnetized Mirrors
(M. T. Burgy, W. E. Woolf)

In a recent investigation of small angle scattering of neutrons¹ the observed deviations were explained as the magnetic refraction of neutrons at domain boundaries in unmagnetized iron. According to this explanation there should be two indices of refraction for neutrons in iron and the possibility exists of demonstrating this double refraction in a more striking way and of using it for the production of polarized neutrons. During the course of this work a paper by Achieser and Pomeranchuk² was called to our attention in which the double refraction was considered as a means of neutron polarization. Recently O. Halpern (at the Physical Society meeting in Chicago, December 1948) pointed out that studies of the refraction effect could also be used to obtain information on the form of the fundamental magnetic interaction between the neutron and the electron.

In order to study the refraction in a more clear cut way than it had been observed in the small angle scattering, it was decided to make use of critical reflection at mirror surfaces, a technique used by Fermi and Marshall³. The object of the work was first to demonstrate the two indices of refraction in iron by obtaining two critical angles for reflection, and second to investigate the possibility of producing highly polarized beams of neutrons by

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1. D. J. Hughes, M. T. Burgy, R. B. Heller & J. W. Wallace, Phys. Rev. 75, 565 (1949).
 2. A. Achieser & J. Pomeranchuk, J. Exper. & Theoretical Physics, U.S.S.R. 18, 475 (1948).
 3. E. Fermi and L. Marshall, Phys. Rev. 71, 666 (1947).

by reflection. Hamermesh (see theoretical section of this report) has shown that the index of refraction, n , in a ferromagnet is given by

$$n_{\pm} = 1 + \frac{2\pi N}{k^2} \left(C \pm \frac{e^2 \gamma S}{mc^2} \left\{ 1 - \frac{1}{2} \sin^2 \psi \right\} \right) \quad (1)$$

where N = no. of atoms per cc.

$k = 2\pi/\lambda$

λ = neutron wave length

C = amplitude of coherent nuclear scattering

γ = neutron moment in nuclear magnetons

S = uncompensated spin per atom of the ferromagnet

ψ = angle between neutron direction and direction of magnetization

According to this formula there will be two ranges of indices for unmagnetized iron, and hence two ranges of critical angles. For a neutron wave length of $4.4 \text{ \AA}$ the corresponding critical angles range from 14.2 to 19.6 minutes for one spin state, and 27.5 to 30.7 minutes for the other spin state. Thus there will be two clearly separated critical angles. In the work of Fermi and Marshall only one critical angle was observed (corresponding to about 25 minutes for $4.4 \text{ \AA}$) probably because of lack of resolution.

It was decided to use BeO filtered neutrons ($4.4 \text{ \AA}$ cutoff) in order to obtain large critical angles (which are proportional to λ). Although the BeO filtered neutrons are not monoenergetic they exhibit an exceedingly sharp cutoff which can easily be located as a drop in reflectivity at the critical angle. A beam of filtered neutrons $.1''$ wide and $4''$ high was formed by cadmium slits and a polished iron mirror $4''$ high by $10''$ long (the one used by Fermi and Marshall) was placed in this beam $120''$ from the slit, mounted on a spectrometer table. The

direct or the reflected beam was detected in a high efficiency counter placed 120" beyond the mirror, with an aperture sufficiently large to include the entire beam in each case. Fig. 1 shows the positions of the direct and the reflected beams for two mirror angles, the apparent width of the beams being determined mainly by the width of the counter opening. The reflectivity of the mirror is given by the intensity of the reflected beam, taking into account the fact that the mirror intercepts more of the incident beam as the mirror angle is increased. The intensity of the reflected beam as a function of mirror angle is plotted in Fig. 2 along with the theoretical curve obtained from equation 1. The theoretical curve has been corrected for the resolution of the apparatus which is about 3 minutes. The experimental points show the two peaks in the distribution quite clearly, each of which corresponds to one index of refraction (the iron being magnetized with $\psi = 0$). The agreement between the points and the curve show (1) that there are definitely two indices for neutrons in iron, (2) that the magnitudes of the indices agree with the theoretical equation and thus that the field acting on the neutrons is correctly given by the induction B, and that the nuclear amplitude (9.2×10^{-13}) assumed is correct, (3) that the fundamental interaction which is the basis of Eq. 1 is correct; the interaction originally used by Bloch thus being definitely wrong (his interaction actually would predict only one peak for $\psi = 0$).

The neutrons reflected with an incident angle of 30 minutes or greater should possess a polarization of 92%. Experiments are now being performed to demonstrate this polarization by a "double reflection"

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FIG. 1

experiment which is completely analogous to the double transmission effect which we have used to measure neutron polarization in the past. The polarized neutrons reflected from the first mirror at an incident angle of 34° are reflected at a second magnetized mirror set at an angle of 34° with respect to the once reflected beam. The beam reflected from the second mirror should be much more intense when the mirrors are magnetized in the same direction as when they are magnetized in reverse directions. It is of course necessary to insure that the neutrons do not rotate in space as they move from the first mirror to the second which means that the fields between mirrors must be accurately adjusted for a non-adiabatic transition. The preliminary results show a polarization of at least 60% in the beam reflected from the first mirror and steps are now being taken to raise this value to the theoretical 92%.

2. Capture Cross Sections for Fast Neutrons of Isotopes Containing 50 or 48 Neutrons (D. Sherman)

Continuing the measurements of capture cross sections for 1 Mev neutrons, and the testing of the Mayer theory of closed neutron shells, described in CP-2750, p. 27 and ANL-4174, the capture cross sections of nuclei containing 50 neutrons have been measured, using the techniques described in the above references, of radiating samples and observing the resulting beta ray emission. According to the Mayer theory, 50 neutrons constitute a closed shell. As explained in ANL-4174, p. 9, this implies that the cross sections for fast neutron capture by nuclei with 50 neutrons will be lower than those of neighboring isotopes, which in this atomic weight region, have cross sections of about 50 or 60 millibarns. The values obtained

for the cross sections of the 50 neutron isotopes are:

Kr ⁸⁶	2.4 mb
Rb ⁸⁷	1.8 mb
Sr ⁸⁸	1.4 mb
Y ⁸⁹	7. mb

The value for yttrium is somewhat uncertain because the sample radiated contained 15% impurities.

During the measurement of the krypton cross section, it was observed that the activation cross section of the 4.6 hour activity produced from Kr⁸⁴ (48 neutrons) was only 1.9 millibarns, smaller than the cross section of the 50 neutron isotope. The cross section of Kr⁸⁴ consists of a 9.4 year activation as well as the 4.6 hr hence if this isotope is to have the expected 50-60 mb value the 10 yr activity must account for almost the entire value. After an 85 hour radiation with fast neutrons, no trace of the 9.4 year activity could be observed. From this result an upper limit of 10 mb can be established for the capture cross section of Kr⁸⁴. The discontinuity in cross sections at 50 neutrons thus does not seem as marked as at 82.

3. "Fast" Neutron-Chopper (W. Selove, W. Woolf)

The fast chopper, a rotating-shutter time-of-flight neutron spectrometer for the resonance region, has been put into operation, and results are satisfactory, even though preliminary measurements have been made with a counting rate only about 3% of the projected value. The low counting rate is due almost entirely to the temporary use of a makeshift detector, of much smaller sensitive

area than the originally planned detector; the detector situation will be discussed further, below. The counting rate will also be increased by about 50% when the installation of the evacuated pipe along the 10 meter path of the beam is completed.

One principal advantage of the new spectrometer is that it is possible to make measurements with relatively small amounts of material. This advantage has been exploited in the first measurements made, by examining the separated isotopes of tungsten, supplied by the Isotopes Division, AEC. Tungsten, in normal isotopic distribution, has been measured previously¹ and has been found to have resonances at 4 ev, 7 ev, 18 ev and at higher energies. The present measurements show conclusively that the 4 ev resonance occurs in W^{182} , the 7 ev resonance in W^{183} , and the 18 ev resonance in W^{186} . Furthermore, W^{183} appears to have a resonance at about 30 ev and W^{184} one at about 21 ev, which are hidden in the normal element by the very strong 18 ev resonance. The data taken thus far is shown in Figs. 3 and 4.

With regard to the apparent strength of the resonances in the separated isotopes, it should be mentioned that the thickness of the samples used was such that if the enrichment were complete then the strength of a resonance occurring in a given isotope would be the same as in the sample used for the normal element. No analysis of the separated isotope tungsten samples has yet been received from the Isotopes Division, so that we do not at present know just how enriched each sample is.

The Rotating Shutter

The shutter consists of a 16 inch long rotor of high-strength steel, $4\frac{1}{2}$ inches in diameter. This rotor has longitudinal slits,

1. Havens et al, Phys. Rev. 71, 165 (1947).

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essentially parallel to the axis, in the region from 1.2 to 2 inches from the axis along 6 equally spaced radial planes; the sides of the slits fall approximately on radial planes which give a slit width of .007 inches to .012 inches at one end of the cylinder, fanning out to 1/16 inch at the other end. The rotor is very accurately aligned with a collimator of which the last 16 inches is a finely slitted section closely similar to the rotor, and is turned at adjustable speed by a 3 h.p. motor (General Electric Thymotrol unit) coupled to it by a toothed belt. The design speed is 40,000 rpm, which would give a 3 microsecond burst, triangular in time. Preliminary operation has been at 6000 to 10,000 rpm, with satisfactory operation possible higher than 20,000 rpm. We have not tried to operate much at speeds higher than 20,000 rpm, to avoid possible damage to the rotor; there has been a small amount of trouble with bearings at higher speed, although nothing serious. (Precision ball bearings are used on the rotor, two rows at each end).

The Detector

Considerable effort has been exerted to obtain a detector which would have an efficiency as high as possible in the energy region of principal interest - of the order of hundreds of electron volts. The detector is located 10 meters from the shutter, and must be large enough to respond to the full size of the beam, which is about 4 inches in diameter. (The beam is actually larger than 4 inches in diameter, but the detector size is intimately related to the design of the rotor and to the prevention of overlap of neutrons from successive bursts, and in the present apparatus cannot be larger than

4 inches in diameter.) The detector design is also subject to the restriction that its length should be short so as to worsen the resolution of the spectrometer as little as possible.

The detector originally planned was a BF_3 pulse ionization chamber, $3\frac{1}{2}$ inches in diameter and 20 cm effective length, to be filled with 5 atm of enriched BF_3 . On the basis of the data available at the time, it was hoped that this chamber would have a plateau at a voltage considerably below 10,000 (the center collecting electrode was $\frac{3}{4}$ inch diameter); the chamber was built to be usable at as much as 10,000 volts. Tests with the completed chamber, however, showed that the plateau was not reached at 10,000, and that probably about 15,000 would be required. Temporarily, this chamber has been put aside, and an array of chambers is being constructed, each to be $1\frac{1}{4}$ inches diameter, 30 cm long, and filled with 3 atm BF_3 . Meanwhile, the equipment is being operated with a single BF_3 chamber, $1\frac{1}{4}$ inches diameter, 50 cm long, and filled with 2 atm BF_3 .

The Electronic Circuits

Not all of the "channels" to be ultimately available are built, but a sufficient number is finished to permit measurements with fairly good efficiency. The various channels are used for recording counts from neutrons of various energies at each burst. The neutron counts from the detector, which operates continuously, are switched into the various channels at the proper times by means of a "gating" circuit in each channel. The time during which each channel is sensitive is adjustable and is determined by a set of switching pulses, synchronized by means of a photocell system with the time at which the slits are open.

Eventually, there will be 80 channels, which will make it possible to record, with optimum ratio of counting rate to resolution, every neutron passing through the shutter. Preliminary measurements have been made with 16 channels; 8 more are ready, and additional chassis with 8 channels each will be completed at the rate of about one chassis a week.

Samples

Because of the small size of the shutter slits (which are made small to achieve high resolution), comparatively little material is required for measurements. To cover each slit requires that the sample cover an area of about $.06 \text{ cm}^2$. Thus, e.g., 100 mg. of material provides a sample of 1.6 gm/cm^2 . The accompanying curves on tungsten were taken with samples of 80 to 100 mg. of WO_3 . This amount of material is sufficient to measure the resonance characteristics of strong and moderately strong resonances. To measure weak resonances and non-resonance cross sections requires somewhat more material, of course. In addition, the counting rate goes up in direct proportion to the number of slits used. With sufficient amounts of material - e.g., in measurements on normal elements with natural isotopic abundances - all six slits can be used; the accompanying data was taken using only one slit.

Counting Rates

Most of the accompanying data was taken using a resolution of about 4 to 4.5 microseconds/meter (about 2 to 3 times the spacing between the experimental points). Under these conditions the counting rate per channel with no sample in the beam was about 2 to 3 counts per minute. With additional counters and with the use of all six slits the counting rate will be about 20 times larger, and with the 10 meter beam path

evacuated the counting rate will increase by about 50% more. Thus the data shown will be obtainable (if sufficient material is available to use all six slits) in 10 to 15 minutes instead of the 4 to 6 hours used in the preliminary measurements. Or alternatively, using the maximum resolution of the spectrometer, 5 to 6 times as high as that used in the work reported here, the counting rate will even so be about 5 times as high as that in the preliminary measurements, so that data of a few percent statistical accuracy will be obtainable in one to three hours. In addition to these increases in counting rate, the use of more channels will permit the simultaneous measurement of a wider range of neutron energies.

The counting rate can be increased further by about 50% by special design of the rotor slits, and by still an additional factor of 2 or more by use of more neutron-opaque material in the slit system (which would permit greater solid-angle of transmission through the slits in the open position, at no sacrifice in sharpness of definition of the burst). A slight amount of work is being done on such an improved shutter system.

That the low counting rates are usable is due to the small background counting rate. Regular checks are made on the background rate by blocking the beam with several inches of wood, or by stopping the rotor in a closed position. The background rate has been 3 to 5 percent of the timed neutron rate, with only very simple shielding used. The fractional background will decrease by a factor of about 3 when all slits are used; but will increase in proportion to the resolution. In operation with the use of all slits and highest resolution, it is expected that by use of improved shielding the background rate can be kept below a few percent of the open-beam counting rate. With the use

of a single large counter as originally planned, the background rate would then be of the order of one or two percent at the highest resolution.

4. The Beta Spectrum of Tl^{204} (J. Richards, D. Saxon)

The 3 year Tl^{204} activity has been measured in the $180^\circ \beta$ spectrometer. In a previous spectrometer measurement, Peacock, Jones and Overman¹ report the β end point as 0.77 Mev, while Hagemann² found 0.80 Mev by absorption in Al. Fajans and Voight³ report no γ -rays.

Thallium, in the form of the nitrate, was irradiated in the Hanford pile. The particular sample used had been cooling for over 2 years, so that all short lived activities had disappeared. As a further precaution against impurities, a chemical purification was done involving the conversion of the nitrate to the chloride followed by a final extraction. We wish to thank F. Hagemann for kindly providing us with the source material and performing the chemical procedure.

The final source was 0.4 mg/cm^2 , mounted on 0.6 mg/cm^2 nylon. The momentum plot shown in Fig. 5 was taken with a 0.05 mg/cm^2 nylon window on the spectrometer counter. There are no signs of any internal conversion lines at the discrete set of points taken, confirming the previous work of Fajans and Voight. In Fig. 6 is shown the Kurie plot, using the complete relativistic Fermi function for the daughter Pb, $Z = 82$. There are large deviations from the linear plot, starting about 250 kev, such as have been reported by Cook and Langer⁴.

-
1. W. C. Peacock, J. W. Jones and R. T. Overman, Mon-M-432, p. 56 (Dec. 1947)
 2. F. Hagemann, CC-3780, p. 8 (Mar. 1947)
 3. K. Fajans and A. F. Voight, Phys. Rev. 60, 619 (1941)
 4. C. S. Cook and L. M. Langer, Phys. Rev. 73, 601 (1948)

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FIG. 6

If all this deviation were due to the screening effects, then one should get a linear plot after dividing the experimental points by the correct screening coefficients. We have done this using the theoretical data of Longmire and Brown⁵ for RaE, $Z = 83$. The result shows that most of the deviation is not due to the screening effect, rather to source scattering, or a failure of the theory at low energies. The possibility of a low energy β -component is slight, since such a decay scheme would most likely involve a difference γ -ray of which there is no sign.

The β -end point is found to be 775^{+20}_{-10} kev; the large $\pm$ error depends on whether the residual background of Fig. 6 is real or not. We suspect that it is not, but rather due to counter erratic behavior observed during some of the runs. The present data is considered preliminary, and we hope to have better results in the near future. Using 3 years for the half life and our preliminary value for the end point, the ft value is found to be 4.8×10^9 , making Tl^{204} very highly second forbidden. Considering the fact that the spectrum is allowed over most of its range, this high value for ft must be considered a discrepancy to be explained theoretically.

The Beta Spectrum of Tb^{160} (J. Richards, D. Saxon)

In Fig. 7 is shown a summary plot of our runs on the rare earth terbium. The data has not as yet been completely analyzed, there being some question as to the exact value of the half life to use in normalizing the separate runs. Cork⁶ et al give 77.3 days, whereas we find various parts of the spectrum decaying with $\sim$ a 55 day half life.

5. C. Longmire and H. Brown, Phys. Rev. 75, 264 (1949).

6. J. M. Cork, R. G. Shreffler, and C. M. Fowler, Phys. 74, 240 (1948)

24

The source material used was Hilger Tb_2O_3 , the Oak Ridge sample had not yet been made available. It is very possible that part of the spectrum is due to an impurity. Even so a few conclusions can be reached now about the data.

There is a continuous β -spectrum with end point ~ 840 kev. This value is somewhat below the value of 882 kev of Cork⁶ et al. The difference may be due to the K_γ internal conversion line being included in their β -spectrum. Whether the β -spectrum is complex or allowed must await the complete analysis. In addition there are 14 internal conversion lines which have tentatively been assigned to 8 γ -rays of energies 87, 125, 199, 235, 252, 343, 890 and 970 kev. For comparison Cork⁶ et al found 9 lines and assigned them to 4 γ -rays of energies 85.5, 194.8, 212.1 and 296.5 kev. Little as yet can be said about internal conversion coefficients, but it should be pointed out that the 87 kev γ -ray has a K to L ratio much less than 1, and possibly a very small K coefficient like the 85.5 kev γ -ray from Tm^{170} reported previously.

It was thought worth while to look for the Auger electrons following the K shell internal conversion of the 87 kev γ -ray, since they should lie in the valley between the K and L lines. At the right in Fig. 7 is the enlarged plot of the valley region. There is strong evidence for 2 small peaks beyond the statistical errors involved. The first is at the position for both $L_I L_I$ and $L_I L_{III}$ final state configurations, while the second is at the $L_{II} L_{III}$ and $L_{III} L_{III}$ positions. From the relative areas under the peaks as compared to that under the K line, we may estimate the contribution of the Auger effect to the total width of the K level. The relative areas are each $\sim 1\%$. This may be compared to a theoretical estimate of Ramberg and Richtmyer⁷.

7. E. G. Ramberg and F. K. Richtmyer, Phys. Rev. 51, 913 (1937)

For Au, $Z = 79$, they find a total Auger width of 1.2%, of which 0.4% would be in our first peak and 0.8% in the second.

There are two corrections to be made to the total theoretical Auger width, both of which tend to increase it, possibly as high as the measured value. First, it is known that the Auger width⁷ is $\sim$ constant for large Z , whereas the radiation width⁸ goes like Z^4 . The difference between Tb, $Z = 65$ and Au, $Z = 79$, is sufficient to decrease the radiation width a significant amount and accordingly increase the percent Auger width. Second, the theoretical estimate was non-relativistic, and there is evidence that a relativistic one would favor the Auger over the radiation width.⁷ In view of the large errors in the measurements of the Auger peaks, the present agreement is considered satisfactory.

Beta Spectrometer Instrumentation (J. Richards, D. Saxon)

The quick change for counter and source as mentioned in a previous quarterly (ANL-4208) have been completed. However, instead of the modified Crane #440 gate valves originally planned, we have built special all metal vacuum stopcocks through which the counter and source pass. This allows us to change a counter window in a few minutes without breaking the main vacuum. Similarly the source can be placed in the spectrometer in less than a minute, enabling measurements on short half life activities to be started. The new double vacuum manifold was completed some time ago and has worked very satisfactorily. By using a liquid air trap and the new Welch #1397 duo-seal forepump, we are able to get a good enough vacuum without the diffusion pump. The new counter has also been completed and tested, giving a very low background

8. W. H. Zinn, Phys. Rev. 46, 659 (1934)

of only 12 counts/min. In Fig. 8 is shown the schematic for the new counter and its quick change.

5. Inter-Calibration of the Argonne and Los Alamos Standard Neutron Sources (C. Eggler)

Both the Argonne and the Los Alamos laboratories have standard neutron sources which were calibrated in 1944, the former by a helium measurement¹, the latter by a water bath method.² The results of these absolute measurements have been used since 1944 to calibrate various secondary standard neutron sources, but until now no comparison has been made between the two primary standards. This unsatisfactory situation has now been remedied as we have been able to compare our standard source #38 with a Los Alamos source #70 which had been calibrated in terms of the primary Los Alamos source.

The strengths of Los Alamos #70 and Argonne #38 are given as

$$\#38 \quad Q = (5.5 \pm 0.4) \times 10^6 \text{ n/sec}$$

$$\#70 \quad Q = (6.18 \pm 0.3) \times 10^6 \text{ n/sec}$$

both as of October 1944. Since that time the Q's have increased by 0.54% per year because of growth of Po^{210} .

During February of this year we have compared #70 and #38 by means of the usual sub-critical pile method developed by Wattenberg et al³. The results of the comparison are

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1. F. G. P. Seidl & S. P. Harris, Rev. of Sci. Inst. 18, 897 (1947)
 2. R. Walker, MDDC-414
 3. CF-3490, p.9

FIG. 8

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$$\text{Ratio } \frac{\#70}{\#38} = 1.176 \pm 0.002$$

as compared to the expected ratio from the quoted strengths of

$$\frac{\#70}{\#38} = \frac{6.18}{5.5} = 1.122 \pm 0.096$$

It is thus seen that the accurately measured ratio of the source strengths is 5% greater than, but well within the error of, the ratio expected from the absolute calibrations.

6. Studies on the Recoil Energy Spectrum in Radiative Capture of Bromine (T. H. Davies and S. Wexler)

A. Introduction

Previously reported results indicate the existence of positive and neutral recoil bromine atoms as a result of bond rupture in ethyl bromide on neutron capture. Approximately 12 percent of the 4.4 hr. Br^{80} atoms are positively charged, while about 25 percent of the 34 hr. Br^{82} are similarly charged, the fraction of positive 18 min. Br^{80} being intermediate. The presence of charged particles in this nuclear process suggests that a determination of the energy distribution of the recoiling bromine atoms may be feasible. No experimental results on this problem have yet been reported. Only the maximum recoil energy can be calculated, assuming that a single γ -ray is emitted with the binding energy of the captured neutron, and that the recoiling bromine travels away from its bonded carbon partner. Then,

$$E_r = \frac{5.25 \times 10^{-10} E_\gamma^2}{M_{\text{Br}}}$$

30

where E_r is the bromine recoil energy in electron volts

E_γ the γ -ray energy (ev)

M_{Br} the mass of the bromine atom in ordinary chemical units ($M_{Br} = 80$).

Using the value of 7.2 Mev for E_γ given by Dancoff and Kubitschek¹, $E_r = 340$ ev. However, a spectrum of γ -rays may be expected in this process, and consequently a recoil energy spectrum should be found. The value of 340 ev. merely sets the maximum possible energy to be expected.

B. Variation of the Distribution of Bromine Recoils with Applied Voltage

Two approaches to the problem are being taken. In one gaseous ethyl bromide at a few microns pressure is irradiated in the pile between cylindrical electrodes consisting of a 1 cm. radius wall surrounding a rod 0.08 cm. in radius. By study of the distribution of the wall to rod bromine activities after bombardment as the applied voltage across the electrode system is increased, the range of recoil energies may be estimated in an approximate fashion. Furthermore, a negative voltage on the rod is reached above which the ratio appears to remain constant. It is probable that at this voltage the positive recoils of maximum energy are collected by the rod.

The data from this experiment are collected in the accompanying table, and the wall to rod activity ratios are plotted against the applied voltage. With the exception of the two apparently poor points, the distributions lie on smooth curves, one for Br^{80*} and the lower for Br^{82} . The two curves demonstrate again the isotopic dependence of the fraction of positive recoils. The uniform decrease of the ratio with

Variation of Ratio of Wall to Rod Activities with Applied Potential

Voltage	Br ^{80*} Activity ¹		Ratio	Br ⁸² Activity ¹		Ratio
	Rod	Wall		Rod	Wall	
0	145	2825	20	8	175	22
6	174	3670	21			
23	264	4245	16			
45	365	4980	13.7	23	299	13.0
88	384	4640	12.1	22	295	13.4
221	240	3380	14.1			
221	406	3530	8.7			
221	312	3200	10.3	29	186	6.5
270	296	3750	12.7	22	223	10.4
310	342	2870	8.4			
310	286	2670	9.3	29	153	5.4
400	383	3185	8.3	31	192	6.2
503	361	2840	7.9	36	165	4.6
1000	389	2725	7.0	39	166	4.3
1500	694	3900	5.6	119	276	2.3
Blank	14	190		0	11	

¹ Activities are corrected for coincidence chemical yield and blank. Br^{80*} counting was done about 4 hours after irradiation, Br⁸² about 45 hours after bombardment.

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voltage as increasing numbers of the recoils are collected by the rod shows these bromine recoils have energies definitely greater than thermal. Since the ratios for Br^{80*} and Br^{82} at 1500 volts are within experimental error the same as those reported previously at 4000 volts, the indication is that saturation of the positive recoils in the gas phase occurs on the central rod at the lower voltage. However, the interpretation of this saturation effect in terms of the maximum recoil energy awaits development of a theory describing the collection efficiency of the central rod as a function of the initial recoil energy, the direction of recoil, and the point of origin of the recoil, with the perturbation of collisions along the path of the trajectory of the ion toward the rod. Dr. Hellund² has begun study of the problem of ion trajectories in a logarithmic potential field, with a view towards obtaining equations applicable to the experiment described above.

C. Monomolecular Soap Film Technique

A more direct experiment to determine the recoil energy spectrum utilizes a repelling potential, a technique used recently by Kofoed-Hansen and Jacobsen³ for the study of β^- decay. These investigators measured the yield of Rb^{88} positive ions from the β^- decay of Kr^{88} as a function of the repelling potential carried by a grid separating the collector from the source space filled with Kr at very low pressures.

However, considerable modification of the apparatus and procedure

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2. See the section under Theoretical Nuclear Physics Division in this Quarterly Report.
 3. O. Kofoed-Hansen and J. C. Jacobsen, Phys. Rev. 73, 675 (1948)

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used by them is required before application to our own case because of the large obscuring fraction of uncharged bromine recoils present.

We plan to avoid this difficulty by using as before a collecting rod of low "geometry". In an effort to increase precision by accurately locating the source of the recoils we have adopted as source a glass surface carrying a monolayer of the barium salt of ~~the~~ brom undecanoic acid.⁴ In properly layed on layers the Br atoms should be located about 20 Å from the glass surface or well beyond the range of disturbing electron transfer effects. Further, by observing the yield of radio bromine on the collector with increasing numbers of layers, it appears possible to determine the range of the Br recoils in the fatty acid. At present, the brom fatty acid has been prepared, some facility in preparing the monolayers has been acquired, and first designs for an irradiation chamber and a vacuum line for continuous evacuation during bombardment in the thimble have been constructed.

7. The Radiometric Determination of Gold and Rhenium in Iron Meteorites (H. S. Brown and E. D. Goldberg)

Continuing our work on the relative abundances of nuclear species, we have investigated the concentrations of gold and rhenium in a series of iron meteorites. The pile irradiation method, as previously described,¹ was employed. Weighed amounts of meteorite and the element whose concentration is sought are simultaneously irradiated in the thimble of the Argonne heavy water pile. A known amount of inert carrier of the element desired is added to a solution of the radioactive meteorite

4. This use of the techniques of Langmuir, et al was suggested to us by Messrs. R. R. Williams and W. Hamill of Notre Dame.

1. Brown, H.S. and Goldberg, E. Science (In Press) 1949

and to an aliquot of the irradiated standard. The activated atoms of the element along with the carrier are chemically separated from the meteorite. The ratio of the amount of carrier recovered to the amount added gives the chemical yield of the separation. A comparison of the decay curves of the meteoritic and standard samples gives the concentration of the element in the meteorite. Absorption curves along with decay curves of both samples are compared and used as the criterion of completeness of separation.

The Procedure for Gold

The separation of gold from the approximately 80 elements in meteorites depends upon the extraction of gold chloride from a 10% hydrochloric acid solution into ethyl acetate². This quantitatively separates gold from sodium, potassium, magnesium, barium, ferric iron, aluminum, strontium, calcium, chromium, manganese, cobalt, nickel, zinc, mercury, copper, cadmium, lead, bismuth, antimony, arsenic and stannic tin. The gold chloride was then reduced with hydroquinone which provided separation from the platinum metals³.

- 1- Dissolve 0.3 to 0.5 gr. of irradiated meteorite in 20 ml. aqua regia. Add 30 mg. AuCl_3 carrier. Evaporate to near dryness.
- 2- Take up residue in 30 ml. of 10% hydrochloric acid solution and extract the gold chloride into 30 ml. of ethyl acetate. Wash the ethyl acetate layer twice with 20 ml. of 10% hydrochloric acid.
- 3- Evaporate the ethyl acetate layer to dryness on a steambath. Take up the residue in 15 ml. of water and 5 ml. of concentrated hydrochloric acid. Bring the solution to a boil and add 10 ml. of 5% aqueous hydroquinone. Continue boiling for 20 minutes.

2. Lenher, V. and Kao, C.H., J. Phys. Chem. 30, 126 (1926)

3. Beamish, F. E., Russel, J. J., & Seath, J., Ind. Eng. Chem. Anal. Ed 2, 174 (1937)

- 4- Filter the gold metal on #42 paper circles. Wash with two 50 ml. portions of water and 25 ml. of ethyl alcohol. Dry for 15 minutes at 110° C., weigh, and mount.
- 5- Ten to fifteen mg. of irradiated gold metal was dissolved in 10 ml. of aqua regia and diluted to 1000 ml. A 0.5 ml. aliquot of this solution was reduced with hydroquinone as in paragraph 3 above along with 30 mg. AuCl_3 as carrier. The gold was then treated as in paragraph 4.

The meteoritic gold gave the reported 2.7 day⁴ half life of Au^{298} and an absorption that was identical with that of the gold standard.

Gold was analyzed in 45 meteorites and its weight concentration was found to range from 0.135 to 3.65 parts per million. These results are tabulated in Table I. Table II shows the standard deviation and the precision of the results on four meteorites. Spectroscopic iron and commercial aluminum were analyzed for gold following the above procedure as blank runs. The following upper limits were placed on these analyses:

<u>Substance</u>	<u>Gold Concentration in Ppm</u>
Aluminum	0.005
Iron	0.002

4. Seaborg, G. T., Rev. Mod. Phys. 16, 23 (1944)

TABLE I

<u>Meteorite</u>	<u>Gold in Parts per Million*</u>
Fish River	0.135
Pinon	1.20
Tazewell	3.21
Carlton	2.97
Edmonton	2.56
Bear Creek	3.65
Hill City	3.35
Altonah	2.20
Bristol	1.81
Huizopa	1.56
La Grange	1.75
Spearman	2.05
Maria Elena	1.22
Drum Mts.	1.50
Perryville	1.30
Chilcoot	1.71
Institute of Meteoritics #2	1.46
Puerta del Zacate	1.36
Sacramento Mts.	0.986
El Morito	1.04
Navitas	0.874
Henbury	0.790
Costilla Peak	0.845
Clark County	0.677
Coahuila	1.07
Sierra Gordo	1.00
Indian Valley	1.03
Cedartown	1.04
Mejillones	0.909
Mount Joy	1.41
Sandia Mts.	1.69
Chihuahua City	1.44
Horse Creek	2.00
Odesa	2.84
Arispe	1.54
Goose Lake	2.63
Leeds	2.70
Linwood	2.20
Deport	2.93
Willow Creek	1.95
Institute of Meteoritics #6	2.67
Canyon Diablo	2.99
Toluca	2.60
Canyon Diablo #2	2.27
Sanderson	3.19

* Three runs were made per meteorite except for those meteorites listed in Table II, and the value listed represents an arithmetic mean.

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TABLE II

Statistical Data of Analyses of Four Meteorites

Canyon Diablo		Henbury		Toluca		Odessa	
Run No.	Au(ppm)	Run No.	Au(ppm)	Run No.	Au(ppm)	Run No.	Au(ppm)
	$\bar{X}_i$		$\bar{X}_i$		$\bar{X}_i$		$\bar{X}_i$
37	3.03	6	0.701	2	2.25	57	3.66
38	3.13	7	0.700	3	2.63	58	2.82
39	3.00	8	0.665	4	2.34	59	3.14
47	2.88	10	0.692	13	2.64	60	3.24
48	3.22	12	0.757	14	2.31	83	2.63
49	2.90	32	0.774	24	2.80	90	2.91
77	2.84	33	0.809	44	3.10	91	2.74
78	2.66	52	0.954	75	2.76	92	2.72
130	3.02	53	0.910	63	2.57	113	2.31
131	3.19	54	0.936	64	2.44	114	2.24
Arithmetic Mean = $\bar{x}$ 2.99			0.790		2.60		2.84
$\sigma = \sqrt{\frac{(\bar{X}_i - \bar{x})^2}{(n-1)}} 0.17$			0.108		0.24		0.44
$\frac{\sigma}{\bar{x}}$ 5.7%			13.7%		9.23%		15.5%
Precision = $\frac{\sigma}{\bar{x}}$ 0.05			0.034		0.07		0.14

The Procedure for Rhenium

The procedure for separating rhenium in meteorites is based on the Separation of Element 43 from Fission Products⁵. The main isolation from molybdenum is accomplished by the distillation of RuO_4 from a sulfuric acid solution of the meteorite. Separation from arsenic, selenium, germanium, and other constituents with volatile halides is accomplished by repeated evaporations, to dryness, of a hydrobromic acid solution of the meteorite.

- 1- Dissolve 0.3 to 0.5 gr. of irradiated meteorite in 20 ml. of concentrated HBr. Add 10-15 mg. of Re in the form of standardized potassium perrhenate carrier. Evaporate to dryness. Add 10 ml. more of HBr and repeat evaporation.
- 2- Take up the residue in 10 ml. of water. Add 10 ml. of concentrated sulfuric acid and distill in a current of air until 2 or 3 ml. of sulfuric acid remain in the flask. Collect the distillate in 20 ml. of water in a 50 ml. centrifuge tube kept in an ice bath.
- 3- Place the centrifuge tube in a steam bath and pass in H_2S until the coagulation of Re_2S_7 is complete. Centrifuge and discard the supernate. Wash the Re_2S_7 with 10 ml. H_2O .
- 4- Dissolve the Re_2S_7 in 1 ml. of HNO_3 ; add 5 ml. of conc. HBr and evaporate to dryness. Take up residue in 20 ml. of H_2O .
- 5- Add 5 mg. of ferric iron in the form of ferric chloride. Add NH_4OH drop by drop till precipitation of ferric hydroxide occurs. Heat on steam bath. Centrifuge, and discard the precipitate. Repeat $\text{Fe}(\text{OH})_3$ scavenging.
- 6- Add 5 ml. of a 1% aqueous solution of tetraphenyl arsonium chloride. Let the precipitate of tetraphenyl arsonium perrhenate stand for 20 min. Filter, wash with two 25 ml. portions of hot water and 25 ml. of alcohol. Weigh, dry 15 minutes at 110° and mount for counting.
- 7- Ten to fifteen mg. of irradiated rhenium metal was dissolved in 10 ml. of nitric acid and diluted to 1000 ml. A 1 ml. aliquot of this solution was added to the carrier aliquot. The combined solution was diluted to 50 ml. The standard was then treated as in paragraph 6.

5. Glendenin, L. E. PPR 9B 8.11.2

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The 90 hr. rhenium¹⁸⁶ was used as a basis for counting. The meteoritic rhenium gave the reported 90 hr. half life⁴ and an absorption curve that was identical with that of the standard rhenium sample.

Preliminary results on 5 meteorites gave the following values of rhenium content in parts per million:

<u>Meteorite</u>	<u>Rhenium Content (ppm)</u>	<u>No. of Runs</u>
Altonah	1.18	1
Henbury	1.95	4
Goose Lake	0.385	1
Canyon Diablo	0.378	1
Toluca	0.335	4

Group #3 - G. R. Ringo

1. Small Angle Scattering of Neutrons by Powdered Materials (H. H. A Krueger, D. Meneghetti, G. R. Ringo, L. Winsberg)

Small angle scattering of neutrons first appeared in measurements of neutron cross sections of powdered materials using different geometries. Analysis of the measurements of neutron intensity versus sample position by methods described in ANL-4237 has shown that the angular distribution of the scattered neutrons is approximately Gaussian. Investigation of the dependence of the width of the distribution on the energy of the neutrons and on the thickness of the sample has given results typified by the curves of Figs. 9 and 10. The dependence of the scattering on the size of the particles in the powders is not so clear but in general it has been found that for large ($> 1 \text{ mm}^3$) crystals or solids the scattering is inappreciable and that the width of the scattered beam increases as the particle size decreases.

From the dependence of the cross section on sample thickness shown in Fig. 11 it can be seen that the scattering is multiple even for samples as thin as 0.15 gms/cm^2 .

At present there appears to be two ways to account for these experimental results. One theory based on neutron refraction is taken over directly from the field of X-rays. The other, based on diffraction, has recently been developed by Halpern and Gerjuoy. In the refraction theory the width of the angular distribution is given by

$$\alpha_s = \left[4 \delta^2 n \left(\log \frac{2}{|\delta|} + 1 \right) \right]^{\frac{1}{2}}$$

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for spherical particles and

$$\alpha_e = \left[2 \delta^2 n \left(\log \frac{1}{2|\delta|} + \gamma \right) \right]^{\frac{1}{2}}$$

for particles with random surfaces. α_e is the half-width of the Gaussian distribution at the 1/e ordinates, δ is the index of refraction -1, and n is the average number of particles traversed by the neutrons in going through the sample. The powders used probably fall between these two cases which are amenable to calculation. The diffraction theory, which is certainly on a sounder foundation than the refraction, is unfortunately much harder to calculate, for the spreading is sensitive to the degree of coherence in diffracted beams from adjacent particles and for real particles of complex shapes is virtually impossible to find. An approximation to the value is given by

$$\alpha_e = Na (3 \pi M)^{\frac{1}{2}} \left(\frac{\lambda}{\pi d} \right)^2$$

where N is the number of atoms in the average particle, a is the scattering amplitude per atom, M is the number of particles per square cm. of the sample and d is the average particle diameter. Both theories give the correct dependence of α_e on neutron energy and sample thickness.

A comparison of the three formulas with the experimental results is shown in Table I. The large discrepancies could be accounted for by the uncertainties in particle size determination in the case of the refraction formulas and by an incorrect calculation in the case of the diffraction formula. The results are not really decisive between the two theories but they do indicate that the refraction formulas can probably be used for rough calculations.

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TABLE I

Material	Sample Thickness gms/cm ²	Observed Particle Diam. in Microns	$\alpha_s = \frac{1}{2}$ width of scattered beam in radians			
			Experi- mental	Refrac- tion by Spheres	Refrac. Random Surfaces	Diffrac- tion For- mula
Aluminum	17.3	16.	0.014	0.012	0.010	0.0020
CaCO ₃	4.19	0.2	0.035	0.126	0.104	0.021
Lampblack	.348	0.3	0.027	0.056	0.040	0.008

2. Spiral Velocity Selector for Neutrons (G. R. Ringo)

A velocity selector designed to give higher intensities of low velocity neutrons than the present time-of-flight selector is being built. This selector is a rotating cylinder with spiral grooves cut in its periphery permitting the passage of neutrons moving parallel to the axis if the time they take to travel the length of the cylinder is equal to the time taken by the cylinder to rotate $\theta - \ell/r$, when ℓ is the length of the cylinder, r is the radius and θ is the angle the projection of the groove makes with the cylinder axis. More exactly it is found that

$$\frac{\langle v_n \rangle}{v_c} = \frac{1}{\frac{2\langle v_n \rangle}{\Delta v_n} \left(\frac{w}{\ell} + \alpha \right)}$$

where $\langle v_n \rangle$ is the average velocity of the neutrons passed by the selector, v_c is the velocity of the cylinder, Δv_n is the range in velocity of the neutrons passed by the selector at any one speed of rotation, w is the width of the spiral grooves and α is the angular spread of the neutron beam incident on the selector. In the selector to be built

$\langle v_n \rangle / \Delta v_n$ has been taken as 10, w is 0.1", ℓ is 12" and α is taken as 1/120; this gives $\langle v_n \rangle \approx 3 v_c$. If a peripheral speed of 200 M/sec can be attained the selector will give neutrons of a velocity as high as 600 M/sec.

This type of selector gives neutrons of a velocity within say 5% of that of the average only. This is useful in activation experiments and it permits the use of counters of any length. It has the obvious disadvantage of giving data on only one velocity at a time.

The selector will be constructed by assembling slotted discs on a central shaft which is the method previously used by Wollan at ORNL in constructing a similar device. The discs will probably be made of stainless steel as that gives the best combination of high fast neutron cross section and high ratio of tensile strength to density. They will have an 8 inch radius and the slots will be 4 inches long.

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Group #4 - T. Brill

1. Electronic Development - Jan. 1, 1949 to Feb. 11, 1949
(Terminating in transfer of group to Laboratory Electronics Unit)

Circuits for "Chopper II" (high energy velocity selector) comprise most of the work. The timing and delay circuits were revised slightly. Several power supplies were built. The first of ten chassis containing pulse gating and recording channels was built. Each chassis contains eight channels, each consisting of gate control tube ("string circuit"), gate tube, scale of 8, and register. Thus operation of the system with eight (of the eventual 80) channels will be possible as soon as the shutter and detector units are completed.

Another delayed coincidence circuit was built. Operating from G.-M. tubes, it has variable delays in both channels with range of .5-30 microseconds; and a resolution adjustable from 0.5-20 microseconds. It has not yet been adjusted.

Two small accessory units were built for the "Reac" (analogue computer). One is simply a multiple switch to select step functions; the other is an automatic unit serving the same purpose, but operating at a given value of some variable (represented by a voltage).

Group #5 - C. O. Muehlhause

1. Determination of Neutron Cross Sections by Co and Mn Detection
(C. T. Hibdon)

We continued the measurements of total neutron cross sections by the resonance scattering of Co (115 ev) and Mn (300 ev). Several newly measured elements showed strong resonance overlapping with Co and Mn. The most outstanding of these was Tl for which $\Delta i_{Mn} = 17\%$ and which, according to the Columbia¹ velocity selector data, has a neutron resonance at 300 ev.

Both Re ($\Delta i_{Mn} \approx 32\%$) and Tl were found to have $< .02\%$ Mn impurity by spectrographic analysis and this was further checked by activation (cf section 2). The activation analysis showed the Mn impurity in both Re and Tl to be $< .001\%$. This is less by a factor of 20 than the amount of Mn impurity that could be detected by self indication (i.e. to make $\Delta i_{Mn} = 1\%$).

The minimum impurity requirements for Co and Mn were investigated by measuring the Co-detected transmission curve of a set of Co-Al pellets (.1% Co by weight) and the Mn-detected transmission curve of a set of Mn-Al pellets (.1% Mn by weight). The Co transmission curve gave $\Delta i = 13.6\%$ from which, using $\sigma_p \text{ Al} = 1.46 \text{ b}$, the value $2.31 \times 10^{-5} \text{ Co/b\%}$ was determined. In a similar manner, the Mn transmission curve gave $\Delta i = 6.5\%$ from which the value $5.2 \times 10^{-5} \text{ Mn/b\%}$ was obtained. In both of these expressions the Co and Mn were in units of $10^{24} \text{ atoms/cm}^2$. In order that $\Delta i = 1\%$ (the smallest observable initial component) from a Mn impurity in Re ($\sigma_p = 15.2 \text{ b}$), it was necessary that:

1 Rainwater, et al, Phys. Rev. 71, 65 (1947)

$$\frac{\sigma_{Mn}}{\sigma_{Mn}} = 5.2 \times 10^{-5} \times 15.2 \frac{55}{186} = 2.3 \times 10^{-4} \text{ or } .023\%$$

Table I lists all the elements measured to date giving corrected values (via the C-detected transmission curve - cf ANL-4237) of σ_i , σ_r , σ_p , σ_c and Δ_p for both the Co and Mn data. These terms are redefined below. In a corrected Co or Mn-detected transmission curve:

σ_i = initial transmission cross section

σ_r = difference or resonance overlap cross section

σ_p = asymptotic cross section, i.e. potential scattering, minimum or for B and Cl some additional capture cross section

σ_c = asymptotic C-detected cross section (taken as the most proper potential scattering cross section)

Δ_p = % asymptotic component (formerly termed Δa)

The corrected σ_p are related to the observed σ_p' by coefficients involving the detector resolving powers (4.5 and 9.8 for Co and Mn respectively).

$$\sigma_p = \sigma_p' + .22 (\sigma_p' - \sigma_c) \quad \text{for Co}$$

$$\sigma_p = \sigma_p' + .10 (\sigma_p' - \sigma_c) \quad \text{for Mn}$$

It should be noted (Table I) that in many cases of resonance-overlap $\sigma_c > \sigma_p$ (e.g. Zn). This was taken as an indication of interference between the resonance and potential scattering components. It further implied that the detector energy was less than that of the overlapping resonance. Conversely, when $\sigma_c \leq \sigma_p$, the detector energy was assumed greater than that of the overlapping resonance. This was the basis of the numerous comments in the last column of Table I.

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TABLE I

Element	Co (115 ev)					Mn (300 ev)					Comments
	σ_p	Δ_p	σ_i	σ_n	σ_c	σ_p	Δ_p	σ_i	σ_n		
	b	%	b	b	b	b	%	b	b		
^1H	20.9	100			17.3	19.9	100			H_2O measured, Corrected by C	
^4Be	6.07	100				6.04	100				
^5B	12.1	~100			~4.5	9.7	~100			Large capture	
^{12}C	4.89	100			4.60	4.72	100				
^{16}O	4.08	100				4.15	100			Al_2O_3 measured	
^{19}F	3.57	100				3.67	100			CF_2 measured	
^{23}Na	3.47	100				3.71	100				
^{27}Al	1.45	100				1.47	100				
^{31}P	4.11	100				4.16	100				
^{32}S	1.13	100				1.14	100				
^{35}Cl	~6.1	100				3.32	100			CCl_4 measured, Large capture	
^{40}Ca	4.56	100				4.37	100			CaF_2 measured	
^{48}Ti	5.10	100				5.39	100			Beam attenu- ated only 35%	
^{52}Cr	3.28	96	4.0	22	3.72	4.56	100			Cr & Cr_2O_3 measured 115ev < Res < 300 ev	
^{55}Mn	6.78	100			3.47	3.98	8.7	~2500		Detector	
^{56}Fe	9.14	91				8.50	95			Uncorrected by C	
^{59}Co	9.30	16	~3000		7.35	7.23	91	11	38	Detector	
^{58}Ni	16.6	100				15.6	100				
^{63}Cu	6.68	100				6.88	100				
^{66}Zn	3.91	100			4.23	3.74	87	7.8	35	Res > 300 ev	
^{75}As	6.22	96	9.1	77	6.90	7.20	80	15	44	115ev < Res < 300 ev	
^{78}Se	8.11	100			8.60	11.3	100			Corrected by C	
^{80}Br	9.66	77	29	93	7.89	8.94	89	16	72	Res < 115 ev	

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TABLE I (Cont.)

Element	Co (115 ev)					Mn (300 ev)				Comments
	σ_p b	Δ_p %	σ_i b	σ_n b	σ_c b	σ_p b	Δ_p %	σ_i b	σ_n b	
³⁸ Sr	13.5	100				13.0	100			SrF ₂ measured
⁴¹ Cb	7.24	100				7.16	98-100			Cb ₂ O ₅ measured
⁴² Mo	6.71	92				5.63			93	Uncorrected by C
⁴⁷ Ag	6.21	88	22	135	8.98	6.43	92	10	57	Res ₁ > 115 ev, Res ₂ > 300 ev
⁴⁸ Cd	5.67	95	8.8	69	6.10	5.17	93	11	92	
⁴⁹ In	5.84	95	9.6	81	6.85	6.06	95	10	89	
⁵⁰ Sn	5.07	96	6.7	48	5.02	4.87	96	6.5	45	Small Resonances
⁵¹ Sb	6.37	88	15	79	5.35	5.46	95	7.2	40	Res < 115 ev
⁵² Te	5.17	100			5.48	5.05	95	9.2	87	Res > 300 ev
⁵³ I	4.19	97	10	214	5.15	4.64	94	9.4	99	Res ₁ > 115 ev, Res ₂ > 300 ev
⁵⁶ Ba	5.76	100				6.05	100			BaF ₂ measured
⁵⁸ Ce	5.77	100				4.80	100			CeO ₂ measured
⁷³ Ta	11.3	90	32	217	10.7	9.60	83	28	118	Res ₁ < 115 ev, Res ₂ > 300 ev
⁷⁴ W	8.62	95	16	151	10.2	10.1	84	30	136	115 ev < Res < 300 ev
⁷⁵ Re	17.9	~100			15.0	15.2	68	56	143	Res near 300 ev, Corr. for .1% Co
⁷⁸ Pt	12.7	89				12.0	91			Uncorrected by C
⁷⁹ Au	10.6	100			11.1	10.8	84	21	74	Res > 300 ev
⁸⁰ Hg	13.6	90	27	151	12.4	13.2	89	22	89	Res ₁ < 115 ev, Res ₂ < 300 ev
⁸¹ Tl	9.52	100				11.7	83	18	46	Res near 300 ev
⁸² Pb	11.1	100				10.7	100			
⁸³ Bi	9.28	100				10.6	100			
⁹⁰ Th	13.0	95				12.4	94			Uncorrected by C
⁹² U	11.6	93	14	46	10.1	9.42	76	17	41	

2. 18.9 hr Re-Be Photo Neutrons (C. O. Muehlhause)

In order to evaluate a possible Mn impurity in the Re sample described in section 1, ~ 3 gm Re and ~ 1 gm Mn were bombarded together in the rabbit flux of CP-3 for 30 minutes at 250 K.W. Ten minutes after irradiation the samples were placed one at a time inside an 8" cube of Be surrounded on all sides by 8" of paraffin in which was imbedded a boron lined proportional neutron counter. The relative counting rates above background were recorded as a function of time. No 2.59 hr Mn decay was found in the Re; instead, a weak 18 hr period was observed. This was attributed to 18.9 hr Re¹⁸⁸. A comparison with the $\sim 10^3$ more intense Mn sample indicated that one γ -ray in 750 Re disintegrations had occurred which was capable of disintegrating Be (i.e. $E_\gamma > 1.63$ Mev). The calculation assumed that the Re and Mn γ -rays had the same Be photo neutron cross section. This figure is consistent with A. Wattenberg's results, which showed the fraction of such γ -rays in Re¹⁸⁸ to be $< 1\%$.

The same procedure was carried out for Tl (using ~ 11 gm Tl) and no photo neutrons were observed. It is permissible to conclude that the Mn impurity in each substance was $< .001\%$.

3. Pile Neutron Absorption Cross Sections (S. Harris, S. Rasmussen, H. Schroeder, G. Thomas)

Measurements with the CP-3 pile oscillator continued, and in accordance with our previously stated policy we list in Table II tentative and final values of pile neutron cross sections.

The new FS dow metal system of moving parts reduced the no-sample (i.e. blank) reading from 1300 μ (for an Al system) to 730 μ .

S4

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TABLE II

Element	Tentative b	Final b	Comments
1H		.245	
7N	1.45		
11Na		.509	
12Mg		.07	
13Al		.226	
14Si		.17	
16S		.52	
17Cl		32.1	
19K		2.05	
20Ca		.43	
21Sc		31.1	
22Ti	5.87		
23V.	5.55		
24Cr		3.07	
25Mn		12.5	
26Fe		2.46	
27Co		36.1	
28Ni		4.53	
29Cu		3.63	
30 Zn		1.11	
31Ga		3.09	
32Ge	3.15		
33As		5.46	
34Se		12.5	
35Br		9.12	
38Sr		1.54	
40 Zr		.4	
41Cb	1.48		
42Mo		3.01	
44Ru	6.21		
45Rh		171	

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TABLE II (Cont.)

Element	Tentative b	Final b	Comments
^{46}Pd	8.8		
^{47}Ag	89		
^{48}Cd	3170		
^{50}Sn		.711	
^{51}Sb		8.25	
^{52}Te		5.87	
^{53}I	9.1		
^{56}Ba	1.38		
^{58}Ce	.64		
^{60}Nd		53.5	
^{62}Sm	8100		
^{64}Gd	36700		
^{72}Hf	157		
^{73}Ta		36.3	$\sim 100 \text{ mg/cm}^2$
^{74}W		28.0	$\sim 100 \text{ mg/cm}^2$
^{77}In		472	
^{78}Pt	13.3		
^{79}Au	152		
^{80}Hg	360		
^{81}Tl		3.65	
^{82}Pb		.18	

A 2.25 cm long 2.06 cm diameter (7.5 cc) cylindrical volume centrally located in the 75 cc sample volume of the oscillator was calibrated with boron-aluminum pellets. These ranged in boron density from 2.33 to 10.7 mg B/cc. A 1% deviation from linearity (i.e. boron-ohm effect, cf previous quarterlies) was observed at $\sim 1.1 \text{ mg B/cc}$. An asymptotic limit of 13000 $\sim$

was calculated by correcting the observed ohm-effect for a hollow Cd cylinder of the same dimensions as the pellets. The large amount of boron necessary to observe nonlinearity further justified the use of a linear boron-ohm relationship for the dilute boron calibration of the entire 75 cc volume used for samples in the measurement of σ_{pile} . This value of $1890 \Omega/\text{cm}^2$ is therefore a valid conversion factor to $\sim 6000 \Omega$ effect for the 75 cc volume.

The factor for converting barns of resonance capture integral, Σ_c , into effective pile cross section was re-evaluated by measuring carefully the Cd-ratio for Au in the GP-3 thimble. More fully discussed in section 4, the result only is given here:

$$\sigma_{\text{pile}} = \sigma_{\text{th-c}} + .0542 \Sigma_c'$$

4. Neutron Resonance Activation Integrals (G. Thomas)

To supplement the measurements on σ_{pile} and Σ_c (resonance scattering integral), a series of neutron activation Cd-ratio determinations were begun. The Cd-ratio relates the thermal capture cross section, $\sigma_{\text{th-c}}$, and the total resonance capture integral, Σ_c , when compared with a standard substance whose resonance capture integral and thermal capture cross section are known:

$$\Sigma_c = \sigma_{\text{th-c}} \frac{\Sigma_{\text{c-std}}}{\sigma_{\text{th-c std}}} \cdot \frac{(\text{Cd-ratio-1})_{\text{std}}}{\text{Cd-ratio-1}}$$

To evaluate Σ_c , either $\sigma_{\text{th-c}}$ may be assumed or Σ_c and $\sigma_{\text{th-c}}$ may be solved simultaneously with the aid of $\sigma_{\text{pile}} = \sigma_{\text{th-c}} + .0542 \Sigma_c'$. In the above, Σ_c includes the "1/v" contribution to the resonance integral ($\sim .45 \sigma_{\text{th-c}}$), while Σ_c' includes only the true resonance component.

The rabbit flux was chosen as most convenient for making these measurements, but several investigations of its energy and spatial distributions had to be made before Cd-ratio measurements could be considered valid.

a) Spatial distribution of the flux

In order to avoid more than one bombardment per Cd-ratio determination, it was necessary to know the flux ratio between two chosen points in the rabbit. These two points would be the positions occupied by the out-Cd and in-Cd foils. It was of even greater importance to ascertain if at all energies the resonance flux was spatially distributed identically. To investigate this, a series of principally thermal neutron absorbers were bombarded together (both out-Cd) in the two positions of the lucite holder that fixed the foils 2-5/8" apart in the rabbit.

The results on front to hind foil ratios were as follows:

Thermal - both foils out-Cd

Al - 1.38

Cu - 1.38

Mn - 1.38

Next a series of resonance foils were bombarded in-Cd with the following results:

Resonance - both foils in-Cd

Cu (0.5 - 1.0ev)	- 1.57
In (1.44 ev)	- 1.56
Au (4.8 ev)	- 1.54
Co (115 ev)	- 1.56
Mn (300 ev)	- 1.56

This latter ratio was the only one of concern in the calculation of the Cd-ratio in which the front foil was out-Cd and the hind foil was in-Cd. The hind or in-Cd foil must be multiplied by 1.56. However, it was a matter of interest to determine the thermal flux ratio as well. To complete the description of the flux spatial conditions, two phosphorous foils were also bombarded in-Cd, and the fast neutron (>1 Mev) induced reaction (170 min) was observed. Here the flux ratio between the two points was found to be 1.79.

Foils were always placed edge-on to minimize the effect of mutual shadowing. Preliminary experiments indicate this effect to be $<1\%$, but additional experiments have still to be made to ascertain this accurately. As an extra precaution the Cd box was always placed in the hind position so that it would have no effect on the beam-like component of the flux.

b) Energy distribution of the flux

The validity of the $1/E$ distribution was checked by carefully measuring the Cd-ratios of very thin ($\sim .2$ mg/cm²) Au and In in both the rabbit and the emptied thimble of CP-3. If the rabbit flux is distributed in energy as the thimble flux ($1/E$), then the invariant relation between these figures is the ratio of Cd-ratio-1. The following values illustrate the point:

	Thimble	Rabbit
Au	2.25	2.91
In	2.44	3.26
$\frac{(\text{Cd-ratio}-1) \text{ In}}{(\text{Cd-ratio}-1) \text{ Au}}$	$\frac{1.44}{1.25} = 1.15$	$\frac{2.26}{1.91} = 1.18$
	thimble	rabbit

This agreement (2.5% deviation) was considered sufficient.

Large resonance absorbers such as Au, In, and W were evaporated on 1 cm^2 - 1 mil thick puron (electrolytic Fe) squares and had thicknesses ($\sim .2 \text{ mg/cm}^2$) which transmitted $\sim 98\%$ of peak resonance neutrons. The weights of the small amounts deposited were obtained by weighing the puron squares on a micro-balance before and after deposition. Since only the weight ratio was important, this figure was determined by activation of the two foils in-Cd (out-Cd would involve the Cd-ratio) at the same distance apart that had been employed in the Cd-ratio measurements. These two methods were found to agree to within 1%; therefore, the latter and more simple procedure was used extensively.

The thimble Au Cd-ratio was also used to re-evaluate "k" in the expression for σ_{pile} :

$$\sigma_{\text{pile}} = \sigma_{\text{th-c}} + k \sum_c'$$

where $\sum_c' = \int \sigma_{\text{rc}} \frac{dE}{E}$ (other than $1/v$ component)

For Au:

$\sum_c' = 1300\text{b}$ (obtained from careful Breit-Wigner curve fitting - private communication - University of Illinois)

$\sigma_{\text{th-c}} = 93\text{b}$ (A. Wattenberg's most recent chopper value - Argonne)

The $1/v$ contribution to the total resonance capture integral, $\sum_c$, is

$.45 \sigma_{\text{th-c}}$ or $\sim 40\text{b}$ for Au. Then:

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$$\frac{\sigma_{\text{pile}}}{k \sum_c'} = \frac{\sigma_{\text{th-c}}}{k \sum_c'} + 1$$

$$\frac{1300}{1340} \cdot \frac{\sigma_{\text{pile}}}{k \sum_c'} = \frac{1300}{1340} \left(\frac{\sigma_{\text{th-c}}}{k \sum_c'} + 1 \right) = 2.25$$

$$\frac{93}{1340k} = 2.25 - .97 = 1.28 \quad k = .0542$$

$$\therefore \sigma_{\text{pile}} = \sigma_{\text{th-c}} + .0542 \sum_c'$$

Table III lists tentative values of Cd-ratios, the ratio $\sum_c'/\sigma_{\text{th-c}}$, $\sigma_{\text{th-c}}$, and $\sum_c'$ which in successive quarterlies will be reported with greater accuracy. Final Cd-ratios should be accurate to $\sim 1\%$, but the 1300b value for $\sum_c'_{\text{Au}}$ is probably not better than 5%.

Using the above values for Au, the rabbit equation for converting barns of thermal cross section into barns of resonance integral becomes:

$$\sum_c' = \sigma_{\text{th-c}} \frac{1340}{93} \cdot \frac{1.91}{\text{Cd-ratio}-1} = 27.5 \frac{\sigma_{\text{th-c}}}{\text{Cd-ratio}-1}$$

5. Resonance Scattering Integrals (S. Harris)

We continued measurement of resonance scattering integrals, $\sum_s$, as outlined in the previous quarterly, ANL-4237. An improved expression for the scattering integral as measured by the annular chamber is now being used. The epi-Cd scattering cross section, $\sigma_{\text{epi-Cd}}$, determined by comparison of thin foils with carbon in the epi-Cd beam is related to $\sum_s$ by:

$$\sigma_{\text{epi-Cd}} = \sigma_p + a \sum_s$$

where σ_p is the potential scattering cross section and

$$\sum_s = (E_{\text{Cd}})^n \int_{E_{\text{Cd}}}^{E_f} \sigma_{\text{rs}} \frac{dE}{E^{1+n}} \quad a = 1/(E_{\text{Cd}})^n \int_{E_{\text{Cd}}}^{E_f} \frac{dE}{E^{1+n}}$$

TABLE III

ELEMENT	Isotope	Activity	DETECTOR THICKNESS	Cd-Ratio	Σ_c/σ_{th-c}	σ_{th-c}	Σ_c	COMMENTS
		Half life	mg/cm ²			b	b	
¹³ Al	27	2.3m	13.1	43.2	.651	.224	.146	Let $\sigma_{th-c} = \sigma_{pile}$
²¹ Sc	45	208	2.0	56	.500	31	15	Let $\sigma_{th-c} = \sigma_{pile}$
²⁵ Mn	55	2.59h	19	44	.64	12.5	8.0	Let $\sigma_{th-c} = \sigma_{pile}$
²⁷ Co	59	10.7m	6.0	22.8	1.26	34.5	43.6	$\sigma_{pile} = 36.1$ b
²⁹ Cu	63	12.8h	21	30.5	.932	3.54	3.28	} $\sigma_{pile} = 3.63$ b
	65	5.0m	21	30.8	.924			
³³ As	75	26. h	7.0	4.48	7.90	3.89	30.7	$\sigma_{pile} = 5.46$ b
⁴⁵ Rh	103	4.5m	5.0	6.14	5.35	149	797	
⁴⁹ In	115	54m	.35	3.26	12.2	199	2430	
⁵⁷ La	139	40h		29.3	.972	8	7.8	
⁷² Hf	180	46d	8.0	14.4	2.05	10	21	
⁷³ Ta	181	117d	8.5	2.00	27.5	21	580	
⁷⁴ W	186	24.1h	.33	4.01	9.14	34.2	313	Seren's σ_{th-c} GP2376
⁷⁵ Re	185	90h	5.0	6.42	5.07	85	431	} Seren's σ_{th-c} GP2376 High for $\sigma_{pile} = 472$ b
	187	18.9h	5.0	6.42	5.07			
⁷⁷ Ir	191	1.5m	6.0	9.20	3.35	1010	3380	} Seren's σ_{th-c} GP2376 High for $\sigma_{pile} = 472$ b
	193	19h	6.0	2.87	14.7	128	1880	
⁷⁹ Au	197	2.66d	.16	2.91	1.44	93	1340	Standard
⁸¹ Tl	203	3.5y	29	10.43	2.92	.27	.79	} Seren's σ_{th-c} GP2376 Low for $\sigma_{pile} = 3.65$ b
	205	4.23m	29	7.22	4.42	3.1	13.7	

E_{Cd} ($\sim .5$ ev) is the low energy cut-off value, E_f (~ 1.5 Mev) is the high energy cut-off value, and "n" is a number $< .5$ that determines the manner in which the chamber sensitivity varies with neutron energy.

Then $1/a = N_e$ where N_e is the number of natural logarithmic cycles in the neutron spectrum, and is given by:

$$N_e = \frac{1 + \epsilon}{2} \log \frac{E_f}{E_{Cd}}$$

where ϵ is the fractional reduction in chamber sensitivity from E_{Cd} to E_f . Substituting in these values yields:

$$N_e = \frac{1 + 1/8}{2} \log \frac{1.5 \times 10^6}{.5} = 8.4 \text{ (e - cades)}$$

It can also be shown that:

$$n = \frac{1}{N_e} = \frac{1}{8.4} = .12$$

$$\therefore \Sigma = (.5)^{.12} \int \sigma_{rs} \frac{dE}{E^{1.12}} = 8.4 (\sigma_{epi-Cd} - \sigma_p)$$

$$\therefore \Sigma' = \int \sigma_{rs} \frac{dE}{E^{1.12}} = 9.1 (\sigma_{epi-Cd} - \sigma_p)$$

A similar relationship exists between the initial transmission cross section, σ_i , using a flat detector and the total resonance integral Σ_r :

$$\sigma_i = \sigma_p + a \Sigma_r$$

Therefore, "a" or "n" may be evaluated if the initial cross section for a known resonance absorber and a carbon detector is measured. The material most suited for this is boron since its resonance capture integral may be readily evaluated, and the maximum cross section is only 159 b (at .5 ev). σ_i for boron was measured as 26 b and when substituted in the above gave $n = .13$. This agreement was considered sufficient as a check, but not superior to the original method of determining N_e from the experimental sensitivity function.

Table IV lists Σ' for about 30 resonance elements and, where measured, the total cross section for self indication. This latter value was corrected by multiplying it by the reciprocal of the fraction of resonance neutrons scattered by the foil:

$$\frac{\sigma_{\text{epi-Cd}}}{\sigma_{\text{epi-Cd}} - \sigma_p}$$

In many cases this correction was large and the measurements should be supplemented with activation self-indication experiments.

6. Note on Sections 4 and 5 (C. O. Muehlhause)

When the results of sections 4 and 5 have been accumulated and Σ_c' have been evaluated, it will be possible to state the fractions of resonance scattering and absorption in many elements. This will yield an effective Γ_n/Γ and Γ_γ/Γ which in many cases can be identified with one or two resonances. The measurements on σ_{self} taken with a value for E_0 will yield Γ and $g\Gamma_n/\Gamma$, from which in a few cases it may be possible to evaluate the spin of the compound state.

Table V lists a few elements in which these data are nearly complete, but no attempt is yet made to determine "g".

TABLE IV

Element	Isotope	$\sigma_{\text{ap-2}}$	σ_p	$\sigma_{\text{tr-s}}$	Σ	E_0	$\sigma_{\text{self-ns}}$	$\sigma_{\text{self-core}}$	Comments
		b	b	b	b	ev	b	b	
²¹ Sc	45	16		12.8	29	high	147	735	
²³ V	51	16		7	82	high	115	200	
²⁵ Mn	55	34.2	3.5		279	300	1865	2070	σ_{self} via very thin Mn
²⁷ Co	59	42.5	7.3		320	115	2550	3200	σ_{self} via two 1 mil foils
²⁹ Cu	all	9.1	6.7		22	high	26	100	
³⁰ Zn	all 67	8.0 36	4.2		35	480	69 86	145	
³¹ Ga	all	17	8.1		82	<500	225	430	
³³ As	75	12.2	6.9		48	<300	820	1900	
³⁵ Br	all	8.8	7.9		8.2	<115	54	530	
³⁹ Y	89	5.1		4.0	10				
⁴¹ Cr	93	7.7	6.5		11	high	24	155	
⁴⁵ Rh	103	6.3		3.6	25	1.28	270	630	$\sigma_{\text{th-s}}$ probably too small
⁴⁶ Pd	all	13.1		4.3	80	low	1420	2100	
⁴⁷ Ag	107 109	7.4 12.4	6.8 7.7		5.5 43	low low			
⁴⁹ In	all	7.9	6.8		10	1.44	2100	15000	
⁵¹ Sb	all	8.91	5.35		32	low	25	48	
⁵³ I	127	10	5.15		44	~20			
⁵⁷ La	139	10.1	9.1		9.1	8.5			
⁵⁹ Pr	141	30.6		10.9	179				
⁶⁰ Nd	all	43					80		
⁶² Sm	all	102		23.4	720	~10	4800	6200	$\sigma_{\text{th-s}}$ probably too large
⁶³ Eu	all	34.1		30.1	36	~1	1100	9400	"
⁶⁴ Gd	all	23		24	0				"

TABLE IV (Cont.)

ELEMENT	Isotope	σ_{sp-cs}	σ_p	σ_{th-s}	Σ'	E_c	σ_{sp-cs}	σ_{sp-cs}	Comments
		b	b	b	b	ev	b	b	
⁷² Hf	all	53.8		26.0	253	~1	5200	9900	σ_{th-s} probably too large
⁷³ Ta	181	17.8	10.7		65	4.0	920	2300	
⁷⁴ W	186	149	23		1050	~15	16400	19400	
⁷⁵ Re	all	22.2	15.2		64	low	2400	7600	
⁷⁷ Ir	all	25			~130	low			
⁷⁹ Au	197	29.6	10.8		171	~300			
⁸¹ Tl	all	14.7	11.7		27	300			
⁹⁰ Th	all	17.2	10		65	>0	440	1050	
⁹² U	all	19.6	10.5		83	low	930	2000	

TABLE V

ELEMENT	Σ	Σ'	E_c	Σ	Σ'	Fraction Capture	Fraction Scattering
	b	b	ev	b	b	%	%
²⁵ Mn	8	279	300	446	454	2	98
²⁷ Co	44	320	115	470	514	9	91
²⁹ Cu	3.3	22	~1000	40	43	8	92
³³ As	31	48	~250	76	109	28	72
⁵⁷ La	7.8	9.1	8.5	10.9	18.7	42	58
⁷² Hf	900	253	~1	264	1164	77	23
⁷³ Ta	580	65	4.0	74	654	89	11
⁷⁴ W ¹⁸⁶	313	1050	~15	1310	1623	19	81
⁷⁵ Re	431	64	2.3 ~300	~70	~500	86	14
⁷⁹ Au	1340	171	4.8 ~300	~240	1580	85	15
⁸¹ Tl	~10	27	300	43	53	21	79

1. Photographic Plate Techniques Applied to Gamma Ray Studies (Bernard Hamermesh)

a) The Capture γ -Ray Spectrum of Cadmium.

The capture γ -ray spectrum of cadmium has been studied using the D₂O-soaked plate method described in the Argonne Quarterly Report October - December, 1948, No. ANL-4237. The experimental arrangement is shown in Fig. 13. Fig. 14 shows the details of the plate holders. The 1/8" lead filter prevents the very low energy γ -rays from cadmium from blackening the plates. The boron carbide prevents any neutrons from reaching the plates and giving rise to the (n,p) reaction in the nitrogen contained in the emulsion. The background plate is over 20 times as far away from the cadmium as is the experimental plate. Therefore, the number of tracks on the background plate due to capture γ -rays from cadmium is negligible. On the other hand, both plates are comparatively close to each other and should be subject to the same background of fast neutrons and γ -rays coming from the pile.

A total exposure of about 5×10^9 γ -rays per cm² was used. 56 mm² of each of the plates were examined. 40 tracks were found in the background plate and 301 on the experimental plate. Fig. 15 is a histogram showing the range distribution of the tracks on the two plates corrected for the angle of dip into the emulsion. Fig. 16 shows the spectrum which has been obtained by correcting Fig. 15 for

(a) The probability of a track leaving the emulsion

(b) The variation with energy of the (γ ,n) cross section of the deuteron. This has been obtained by using the calculations of Moskowsky and Myers carried out at this laboratory. These extend to just beyond 5 Mev. For energies above 5 Mev an extrapolation using

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DIAGRAM OF APPARATUS

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FIG. 13

DETAILS OF PLATE HOLDERS

FIG. 14

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FIG. 15

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FIG. 16

the simple equation for the photoelectric cross section given in Bethe and Bacher was used.

The spectrum appears to be continuous. It is difficult to determine whether there is any significance to the initial rise. The location of the cutoff energy is also uncertain. A value of about 7.5 Mev seems reasonable. This value would agree with the result obtained using a semi-empirical binding energy formula.

b) Capture γ -Rays from Other Elements.

Other elements now under study are:

1. Chlorine
2. Aluminum
3. Iron

2. Diffraction of Slow Neutrons by D₂O (S. J. Czyzak and A. Wattenberg)

Experiments reported in ANL-4208, 4129 and 4174 have been completed. The apparatus used in this experiment was that previously described and developed by O. Chamberlain^{1,2}. The container for the D₂O was made from .020" aluminum with internal dimensions 15" x 10" x 3/32" reinforced every 1 3/4" with 3/32" aluminum rods. This was to insure that a uniform thickness be maintained. The transmission of the D₂O was 87-89%. The D₂O was of 99.63% isotopic purity.

The experimental data was measured as indicated below. Measurements were made with and without cadmium:

-
1. ANL-4129, p. 36
 2. ANL-4174, p. 36

- 1) Container full of D₂O
- 2) Container empty
- 3) Plexiglass
- 4) Background

Typical counting rates (counts/min.) obtained were as follows:

$\frac{\sin \varphi}{\lambda}$	Container D ₂ O		Container Empty		Plexiglass		Background	
	No Cd	Cd	No Cd	Cd	No Cd	Cd	No Cd	Cd
.16	800	130	225	130	2080	130	160	30
.20	760	100	270	100	2080	128	140	100
.25	480	80	192	80	1600	100	100	80
.45	830	220	290	192	1800	160	130	90

The $\frac{1}{\sigma} \frac{d\sigma}{d\omega}$ was calculated using the formula previously reported in ANL-4237.

$$(1) \quad \frac{1}{\sigma} \frac{d\sigma}{d\omega} = \frac{1}{F} \frac{(\sec \theta_1 - \sec \theta_2) \cos \theta_1}{AB(D-C)} \left[S-E \left(\frac{AC + BD}{A + B} \right) \right]$$

where S = cadmium difference of the full cell

E = cadmium difference of the empty cell

The method of obtaining F was described in ANL-4237. The multiple scattering effect was estimated to be about 10%; however, no correction was applied since the main interest was in observing the maxima. The values of $\frac{c}{\sigma} \frac{d\sigma}{d\omega}$ are plotted in Fig. 17. The slight bump observed in the experimental curve in the region of $\frac{\sin \varphi}{\lambda} = .65-.75$ may be due to poor statistics.

In order to verify whether correct formulae were being used in converting data to differential scattering cross sections, measurements using vanadium were made. Since vanadium has mainly incoherent scattering

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$\frac{c}{\sigma} \frac{d\sigma}{d\omega}$ should be a constant. This was found to be the case within statistical accuracy.

The curve obtained experimentally for D_2O does not agree with the curve calculated by M. Hamermesh. M. Hamermesh employed a technique similar to that of Menke³. However, since X-ray data on water⁴ was available Hamermesh was able to correlate the neutron intensity for the differential scattering of neutrons by D_2O , Fig. 18.

It will be observed that the experimental data does not increase with increasing $\frac{\sin \psi}{\lambda}$ as predicted in the calculated curve. It was necessary to employ neutrons of energy greater than 0.10 ev to explore the region of $\frac{\sin \psi}{\lambda} > .60$; the question therefore arises as to whether the simple assumption needed to perform a theoretical calculation remain valid for these energies and large changes of momentum.

3. Angular Distribution of Photo-Neutrons from Beryllium (B. Hamermesh, M. Hamermesh and A. Wattenberg).

Measurements of the relative yields of neutrons from beryllium as a function of the angle between the γ -ray and the emitted neutrons have been completed. The apparatus and the measurements involved have been described previously in ANL-4237.

Sb^{124} γ -rays, which have an energy about 30 kev above the beryllium threshold, were found to produce neutrons in a spherically symmetrical manner.

Further measurements were made with Na^{24} γ -rays (2.76 Mev). Table I gives the results obtained from one run in which measurements were

3. Menke, Phys. Z. 33 593 (1932)

4. Morgan & Warren, J. Chem. Phys. 6, 666.(1938)

made at six angles.

TABLE I
Observed Angular Distribution from Na^{24} + Be Source

Angle	Observed Counting Rate Counts/Minute	Least Square Fit of Data
0°	91.6	91.2
20°	97.4	97.6
40°	110.7	113.8
55°	131.9	127.9
75°	141.1	142.2
90°	145.8	145.9

The data plotted in Fig. 19 was fitted by least squares to a curve of the form $A + B \sin^2 \theta$. The least squares values are given in the last column of Table I.

Other runs in which measurements were taken at only 0° and 90° were made in order to determine carefully the ratio A/B. The average value of A/B was found to be 1.58. This value must be corrected for the following:

- (1) The finite size of the target, source, and detector causing a spread around the listed central angle.
- (2) The neutron scattering within the beryllium target.

The latter correction was estimated and is being checked experimentally in connection with the D_2O experiment where it is a more serious correction. Applying these corrections, we obtain that the probability distribution for the emission of neutrons by a beryllium nucleus is $1.22 + 1.00 \sin^2 \theta$ for 2.76 Mev γ -rays.

Guth and Mullins (unpublished) have obtained exact agreement with our experimental value on the assumption that the dominant transition is from a $P_{3/2}$ to a $D_{5/2}$ state.

Group #7 - E. der Mateosian

A. $^{49}_{20}\text{Ca}$ (E. der Mateosian, M. Goldhaber, A. Smith)

The element of lowest Z for which isomers have been reported is Ca. For Ca^{49} two activities (30 m, 2.5 hr) leading to a 57 m Sc^{49} daughter have been reported in the latest Seaborg tables. We have bombarded enriched " Ca^{48} " (62% Ca^{48}) in the rabbit and find a β^- activity of 8.5 m half-life and one of 1 hr half-life whose intensity is in good agreement with that to be expected in a daughter product. For both activities a Cd ratio of ~ 37 was found, which corresponds to $1/\nu$ absorption. The β energies were determined by absorption and were found to be 2.7 Mev and 2.4 Mev respectively. A hard γ -ray was found associated with the 8.5 m period. Photoneutrons from both Be and D are produced by this γ -ray. The intensity of photoneutrons was compared with that from Al^{28} and Be for similar β^- activities and appeared to be 0.4 times as much. In view of the lower photoneutron cross section of Be for harder γ -rays this is compatible with the assumption of 1 γ -ray per β -ray. Confirmatory experiments with " Ca^{46} " and ordinary Ca as well as chemical separation of Ca and Sc were carried out.

B. Rare Earth Program

1) Gadolinium (E. der Mateosian, A. Smith)

Further studies were made this quarter of the radiations from 3.3 m gadolinium. We have already reported the presence of an electron of 66 kev energy and a β of ~ 2.0 Mev. Copper and lead absorptions were performed on the photons emitted by this activity using a Geiger Mueller counter for detection and an ~ 48 kev X-ray and an $\sim .4$ Mev γ -ray were observed. An attempt was made to identify the X-ray by critical absorption

in cerium, praseodymium, neodymium and samarium matched absorbers. Although the 0.4 Mev γ -ray interfered with the tests, an indication of a change in absorption appeared between neodymium and samarium, identifying the X-rays as terbium K-rays and not gadolinium X-rays. Coincidence measurements were made and $\beta - e^-$ coincidences were observed decaying with an approximately 3.3 m half-life. Although neither one of these last two experiments was completely reliable due to inherent difficulties, we believe at the moment that the 3.3 m activity is not due to an isomeric state in gadolinium, but is a ground state decaying by β decay followed by two γ rays.

2) Scandium (E. der Mateosian, M. Goldhaber, A. Smith)

Two activities have been assigned to Sc^{46} , one decaying with a 20s half-life and the other decaying with an 85 d half-life. A third activity has been reported in Sc^{46} with a 24 m half-life¹ which would make this the second known example of triple isomerism produced by neutron bombardment. We bombarded pure Scandium in the rabbit for different lengths of time and searched for a 24 m activity but failed to see it. A one milligram sample bombarded for 5 secs and observed in an ion chamber decayed with a 19.5 s half-life and the initial activity was 7000 times the background of longer activities.

The rare earths used in this program were obtained from Oak Ridge and are material purified by ion exchange.

1 Plutonium Project Report Mon N-432, p.56 (Dec. 1947)

C. Separated Isotope Program

- 1)
- W^{183m}
- (E. der Mateosian, M. Goldhaber, A. Smith)

W¹⁸² was bombarded in Cd through various layers of boron in order to determine the energy of its neutron resonance. The average energy is ~ 7 ev. Using our values of thermal cross section (0.5 b) and Cd ratio (2.8, determined for W¹⁸² with more accuracy than we were previously able to do for normal W), we estimate the partial resonance integral of W¹⁸² ($\rightarrow$ W^{183²} 5.5 s) to be $\sim 7.5 \times 10^{-24}$ cm². W¹⁸³ (n,n) plays a relatively unimportant part in the activation of 5.5 s in the W¹⁸³ enriched isotope fraction. The activity is mainly due to W¹⁸² in the "W¹⁸³".

- 2)
- Se^{77m}
- (E. der Mateosian, M. Goldhaber, A. Smith)

A 17.5 s Se activity was first reported by J. R. Arnold and N. Sugarman and was assigned to Se^{77²}. The Cd ratio for this activity has been found to be 125, indicating this activity to be the result of a negative resonance.

- 3)
- Mo⁹³
- (R. Caldwell, E. der Mateosian, M. Goldhaber)

A search was made for the 17 m and 6.7 hr isomers reported for Mo⁹³ (see Seaborg and Perlman). We bombarded enriched Mo⁹² isotope in the rabbit and thimble and tested for a β^+ activity of lifetime between a few minutes and a few hours, using a magnetic field and a Geiger-Mueller end window counter. No β^+ activity was detected. β^- activities, probably due to impurities, were noted. The other Mo isotopes (except Mo¹⁰⁰) also did not show the 17 m and 6.7 hr activities.

Separated isotopes used in this program were supplied by Dr. Keim's group at Oak Ridge.

D. β -ray Spectrograph Measurements of Internal Conversion Electrons
(R. Caldwell)

The following table contains the results of experiments performed with the fixed magnet β -ray spectrograph fitted with a gate to allow rapid introduction of the sample into the chamber.

I. Internal Conversion Electrons of Isomeric Transitions

Isomer	$T_{1/2}$	Shells From Which Electrons Were Observed	Transition Energy (kev)
Co^{60}	10.7 min	K, L, M	58.9
Co^{94}	6.6 min	K, L, M	41.4

II. Internal Conversion Electrons From Gamma Rays Following Beta Emission

Element Bombarded	$T_{1/2}$	Shells From Which Electrons Were Observed	Transition Energy (kev)
Dy	2.6 hr	K, L _I , L _{III} , M, N - Plus one unexplained line 219 kev.	87.8
W	24 hr	K, L, M, N - In addition three very weak lines were observed which were not assigned. No lines were seen corresponding to the reported ³ 86 kev and 101 kev gamma rays; this confirms the recent work of Beach, Peacock and Wilkinson ⁴ .	133.8
Tm	120 day	K, L _I , L _{III} , M, N	85.6*

³ Valley, Phys. Rev. 59, 686 (1941)

⁴ L. A. Beach, C. L. Peacock & R. C. Wilkinson, Phys. Rev. 75, 211 (1949)

* Saxon's value

E. Hafnium (S. B. Burson)

Pure hafnium, supplied by J. J. Katz (New Chemistry), was activated in the rabbit and showed the presence of the previously reported 6 hr and 46 d periods, but not the 66 m period, indicating that this period was due to impurities in the earlier samples. Absorptions in lead of the photon radiations of the 6 hr period confirmed the presence of two γ -rays, $\sim .6$ Mev and $\sim .3$ Mev. Coincidence measurements show that these two γ -rays occur in coincidence.