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PHYSICS DIVISION
QUARTERLY PROGRESS REPORT FOR PERIOD ENDING MARCH 15, 1950

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PHYSICS DIVISION

A. H. Snell, Director
E. O. Wollan, Associate Director

QUARTERLY PROGRESS REPORT

for Period Ending March 15, 1950

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INTRODUCTION AND SUMMARY

This is the unclassified section of the ORNL Physics Division Quarterly Report, covering December 15, 1949, to March 15, 1950.

Scintillation Spectrometry. Following publication of results on K^{40}, attention is now being turned to Rb^{87}. An improvement in the resolution of the instrument has been made. Monoenergetic electrons have been used to test the linearity of the pulse height vs. electron energy response; excellent linearity has been found in the range 0.12 to 3.2 Mev.

The 2.5 sec erbium isomer is found to have a gamma ray of 185 Kev, which is partially internally converted.

Short-Lived Isomers. An interesting observation is made relative to the occurrence of the short- and long-lived isomers in the heavy group (N or Z = 63 to 81). In this group, isomers in which the odd particle is a neutron are found almost entirely to have long decay periods (seconds to days), whereas if the odd particle is a proton, the decay periods are short (microseconds or less).

Physical Electronics. A single channel differential pulse height selector has been designed, using an anticoincidence circuit to prevent registration of pulses larger than those in the desired interval. A ten-channel differential pulse height analyzer also has been designed, which employs twelve 6BN6 discriminator tubes. The first grids of these tubes are biased five volts apart, so that arrival of a pulse of given size will prepare some of the tubes to conduct. A sweep generator then applies rising voltage to the third grids of the tubes, likewise biased five volts apart, until the first tube is reached which has already been prepared to pass plate current. When this tube conducts, the process is stopped, a count is registered on the appropriate scaler, and the circuit is reset.

Neutron Cross Section of Holmium. Preliminary results with the crystal spectrometer indicate that holmium may have an unusually large scattering cross section at .03 ev.

Neutron Diffraction. Angular distribution studies of the neutron scattering by unmagnetized Co have succeeded in separating the magnetic scattering from the nuclear scattering. The magnetic scattering amplitude is found to

be slightly greater than the nuclear scattering amplitude; this suggests that a very high degree of neutron polarization might be achieved by Bragg reflection from magnetized cobalt.

New results have been obtained on the coherent scattering cross sections of the nickel and calcium isotopes. Ni^{62} scatters with "negative" phase; all others are "positive."

Neutron Decay. A set of coincidence data is presented which seems to demonstrate beyond reasonable experimental doubt that neutrons do indeed undergo radioactive decay.

Low Temperatures. The following elements were found to become superconducting at the indicated temperatures: Zr, 0.603°K; Ga, 1.11°K; Cd, 0.542°K. Results on Th (1.71°K) and Y (no superconductivity above 0.15°K) are not considered final because of possible impurities.

Irradiation of Semiconductors. Examination of the values of the minimum conductivity of germanium samples exposed to pile radiation indicates that about three acceptor states are produced per incident fast neutron. This is in reasonable agreement with the number (six per incident neutron) of atomic displacements to be expected to be produced as the result of scattering of fast neutrons in the Ge sample.

Irradiation of Ge changes it from an *N*- to a *P*-type semiconductor. Two mechanisms are involved: (1) formation of lattice displacements; (2) formation of impurity centers by transmutation following slow neutron capture. The former effect can be annealed out. The effect which remains is now shown to be quantitatively accounted for from the flux data, provided one uses the latest Ge capture cross section values, and therefore it can be completely understood as a result of transmutations.

Radiation Damage. Electron bombardment of water-cooled Be-Cu in the Van de Graaff machine has produced a 3% increase in electrical resistance. This effect is being examined closely to see if it is a true "radiation damage" effect.

High Voltage Program. A radiofrequency ion source has been constructed which gives a H_1^+/H_2^+ ratio of two, and delivers 30 μa of protons with the rather low gas consumption of 8 cc (atmospheric pressure) per hour.

PUBLICATIONS

Physics Division publications which have appeared in scientific journals since the appearance of the last Quarterly Report are as follows:

1. "Temperature Dependence of Scintillation Pulses in Anthracene," G. G. Kelley and M. Goodrich, *Phys. Rev.* 77, 138 (1950).

2. "A High Speed Synchroscope," G. G. Kelley, *Rev. Sci. Instr.*, 21, 264 (1950).

3. "Response of Anthracene Scintillation Counter to Monoenergetic Electrons," J. I. Hopkins, *Phys. Rev.* 77, 406 (1950).

4. "7×10^{-9} sec. Isomeric State in $_{79}Au^{197}$," F. K. McGowan, *Phys. Rev.* 77, 138 (1950).

5. "Beta Spectrum of Be^{10}," P. R. Bell and J. M. Cassidy, *Phys. Rev.* 77, 301 (1950).

6. "Gamma Rays from K^{40}," P. R. Bell and J. M. Cassidy, *Phys. Rev.* 77, 409 (1950).

7. "The Beta Rays of K^{40}," P. R. Bell, Boyd Weaver and J. M. Cassidy, *Phys. Rev.* 77, 399 (1950).

The Physics Division congratulates one of its members, E. C. Campbell, and an ex-member, H. Soodak, on the publication of their book, *Elementary Pile Theory* (Wiley, 1950).

SCINTILLATION SPECTROMETRY

SCINTILLATION SPECTROMETER

P. R. Bell, J. M. Cassidy and R. C. Davis

Beta Spectrum of K^{40}. The measurement of the β spectrum of K^{40} was completed, using a potassium sample enriched to 8.1% K^{40} by electromagnetic separation at Y-12. The results have appeared in the *Physical Review*, along with the K^{40} gamma-ray measurement.

Rb^{87}. Preliminary studies have been made of the radiation from naturally active Rb^{87}. Results thus far indicate the possibility of a hard gamma ray in addition to a β-ray with an endpoint energy of approximately 270 Kev.

Resolving Power of the Scintillation Spectrometer. The availability of better 5819 photomultiplier tubes has made possible a considerable improvement in the resolving power of the spectrometer. Figure 1 shows the lower energy β-ray of 33-year Cs^{137} and the γ-ray and conversion electrons from the Ba^{137} daughter. The full width at half maximum of monokinetic electrons of 630 Kev energy is 15%.

ELECTRON ENERGY STUDIES WITH THE ANTHRACENE SCINTILLATION SPECTROMETER

J. I. Hopkins

Some results concerning the response of the anthracene scintillation counter to monoenergetic electrons have been reported for the energy range 50 Kev to 665 Kev.[1] Further studies have been made in the low energy range and in the energy range 665 Kev to 3200 Kev. The experimental arrangement was the same as described before except for a few necessary alterations.

An aluminum foil having a thickness of 0.2 mg/cm^2 was used to cover the crystal for the low energy measurements instead of a previously used 1.4 mg/cm^2

(1) Hopkins, J. I., "The Response of the Anthracene Scintillation Counter to Monoenergetic Electrons," *Phys. Rev.* 77, 406 (1950).

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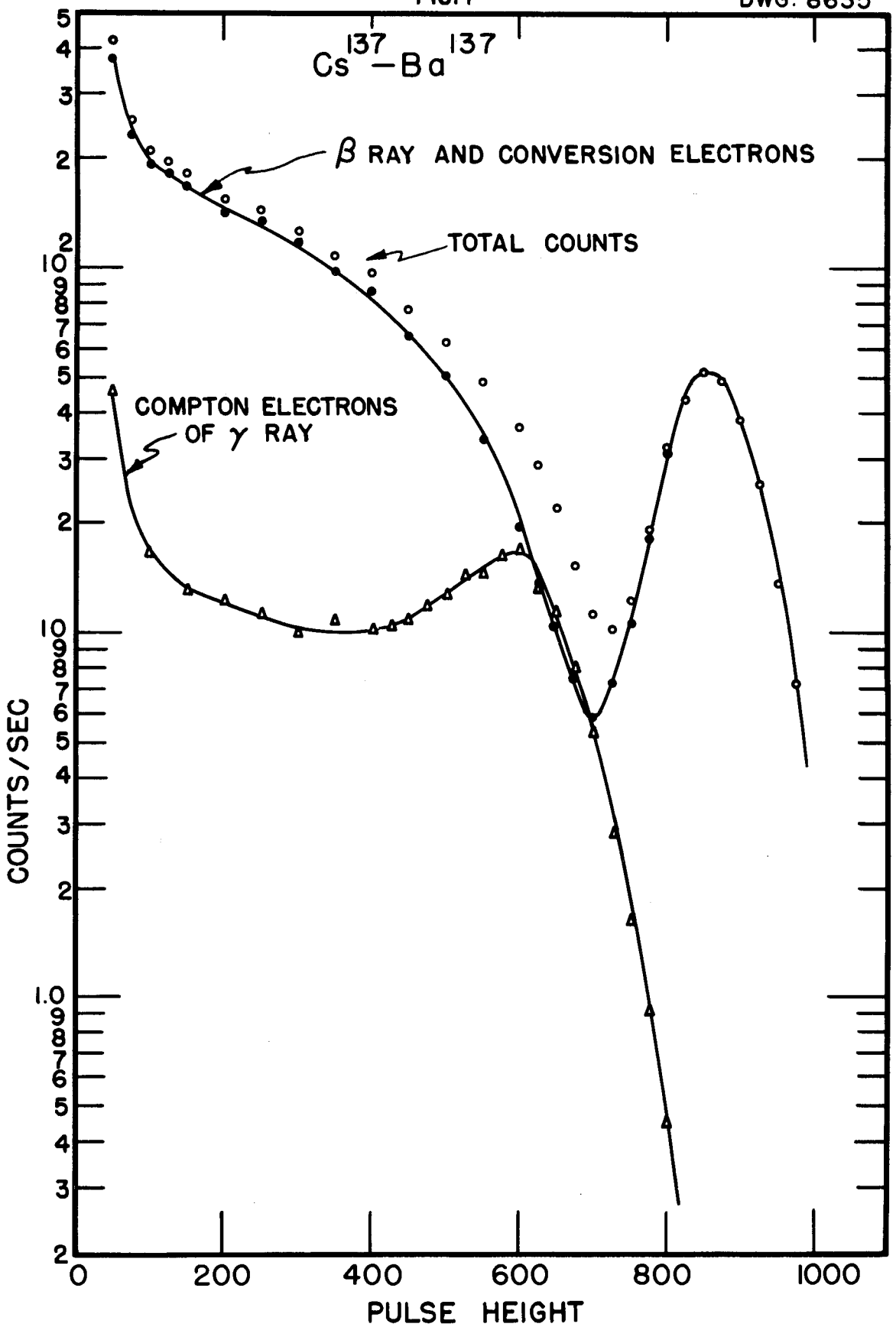
FIG. 1



thickness. Approximately 40 microcuries of Ru^{106} on a thin film of formvar served as a source of electrons for the energy range above 665 Kev. A mumetal shield, in addition to the previously described magnetic shielding, was fitted closely over the photomultiplier tube to prevent variations in the magnetic field in the region of the tube.

It was found necessary to use magnetic compensating coils around the multiplier for energy studies above 1900 Kev. Above this energy the magnetic field due to the lens spectrometer was sufficient to cause an appreciable distortion in the differential count distribution with a consequent lowering of the pulse height value. A test for no distortion was made by using a Cs^{137} source before the crystal but with no source in the lens spectrometer. Counting rate pulse height data were taken on the Cs^{137} conversion line for various currents through the lens spectrometer coil. With the arrangement described above no pulse height shifts greater than 0.5% were observed.

Counts per second versus pulse height data were recorded for each chosen energy from 30 Kev to 3200 Kev and the differential curves plotted to determine the pulse height giving the maximum number of counts per second. Some typical data are shown in Fig. 2 where the counts per second have been normalized and plotted against the energy of the electrons in Kev. These curves are Gaussian distribution curves fitted to the experimental data.

If one writes the distribution equation in the form

$$n(E) = A\ e^{-(\Delta E/a)^2} \quad ,$$

then $n(E)$ represents the number of counts per second for an energy different from the mean energy (the energy corresponding to the maximum of the differential curve) by an amount ΔE. The constant A has been chosen such that when $\Delta E = 0$, $n(E)$ is equal to ten counts per sec. The constant a then represents the line half-width at $1/e$th the maximum counting rate. If one plots a^2 against electron energy, the points follow a linear curve as closely as could be expected. This graph is shown in Fig. 3. Tabulated data giving the results of these line width-energy studies are shown in Table I.

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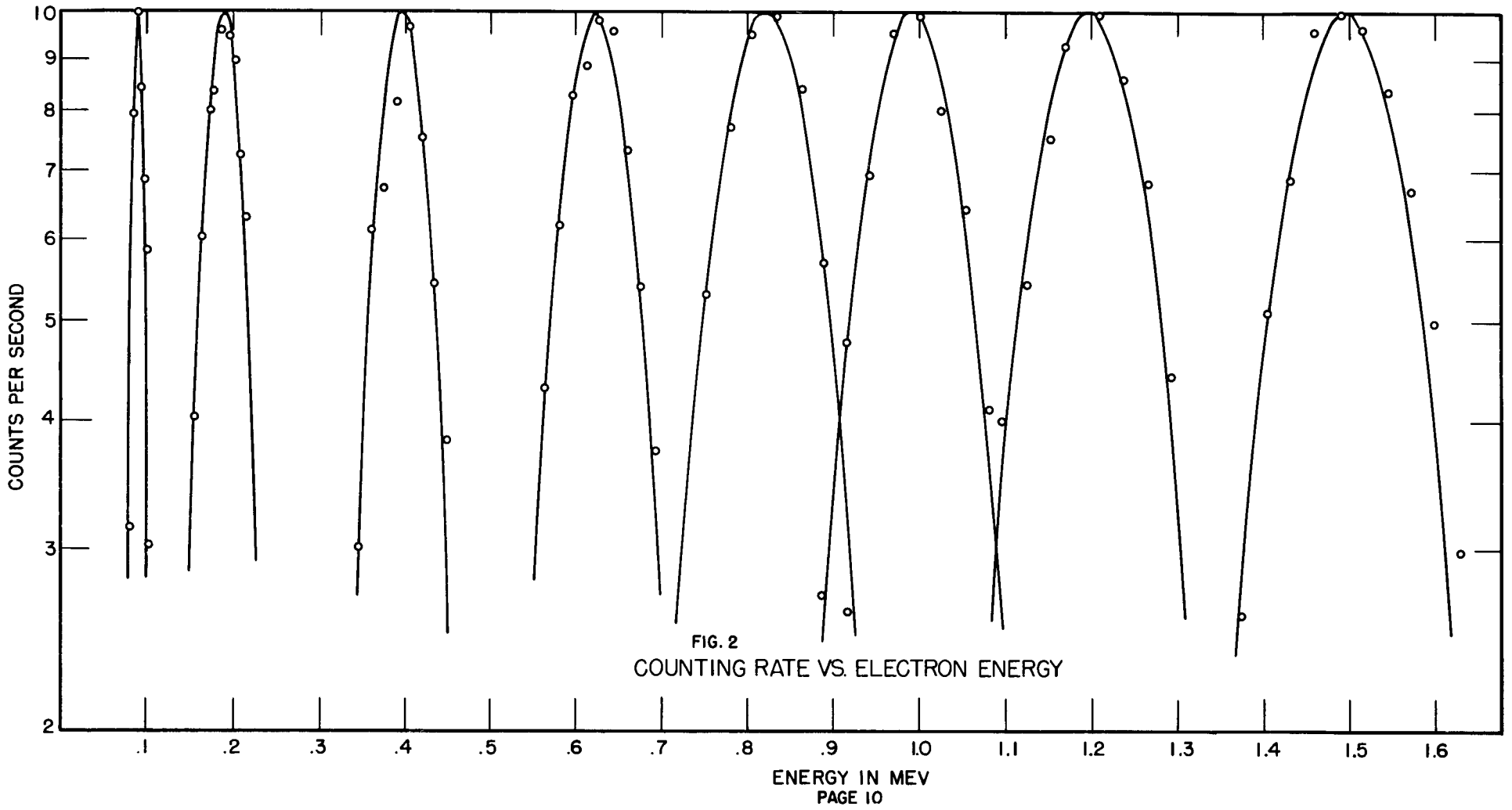

FIG. 2
COUNTING RATE VS. ELECTRON ENERGY

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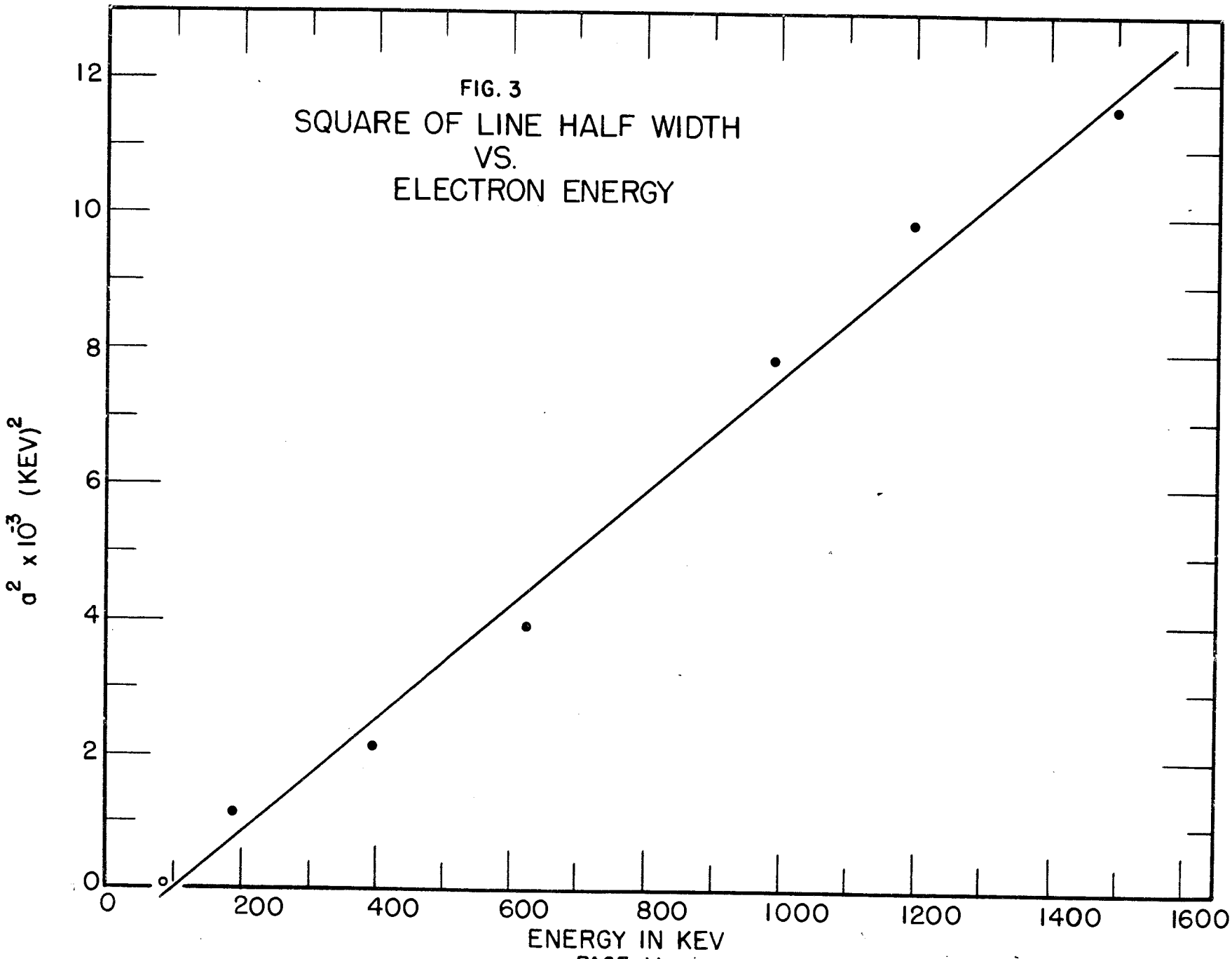

TABLE I

ENERGY (Kev)	a (Kev)	a^2 $(Kev)^2$	$a/E \times 100$
88.9	9.3	$.086 \times 10^3$	10.
189.	34.	1.1×10^3	18.
397.	46.	2.2×10^3	12.
624.	63.	4.0×10^3	10.
991.	89.	7.9×10^3	9.0
1200.	100.	9.9×10^3	8.3
1500.	108.	$12. \times 10^3$	7.2

In making pulse height-energy studies two crystals were used. A crystal of 1.29 ± .02 cm thickness was used to study the energy range 30 Kev to 1900 Kev and a second crystal of 2.50 ± .02 cm thickness was used to study the energy range 800 Kev to 3200 Kev. This was done in order to be sure that some of the electrons were not passing completely through the crystal. The results of these studies are shown in Figs. 4 and 5. A definite linear relation is observed to exist between pulse height and energy from 125 Kev to 1900 Kev and from 800 Kev to 3200 Kev. Both of these curves, when extended in a straight line, intersect the energy axis at approximately 25 Kev. Experimental data below 125 Kev show a decreasing slope with the curve directed toward the origin.

In order to investigate the response of a thin crystal to electrons which have sufficient energy to pass through the crystal completely, a crystal thickness of 0.38 ± .02 cm or 471 mg/cm^2 was used. According to absorption data, electron energies up to 1100 Kev should be absorbed in anthracene of this thickness. The pulse height-energy curve for this crystal was found to be quite linear up to 1500 Kev. At 1800 Kev the differential count distribution curve became so broad that the pulse height value was not defined sharply but could still be located very near the same straight line. The distortion in the differential curves above 1100 Kev gives effectively a decreased counting rate with increase of energy as a result of the scintillation spectrometer

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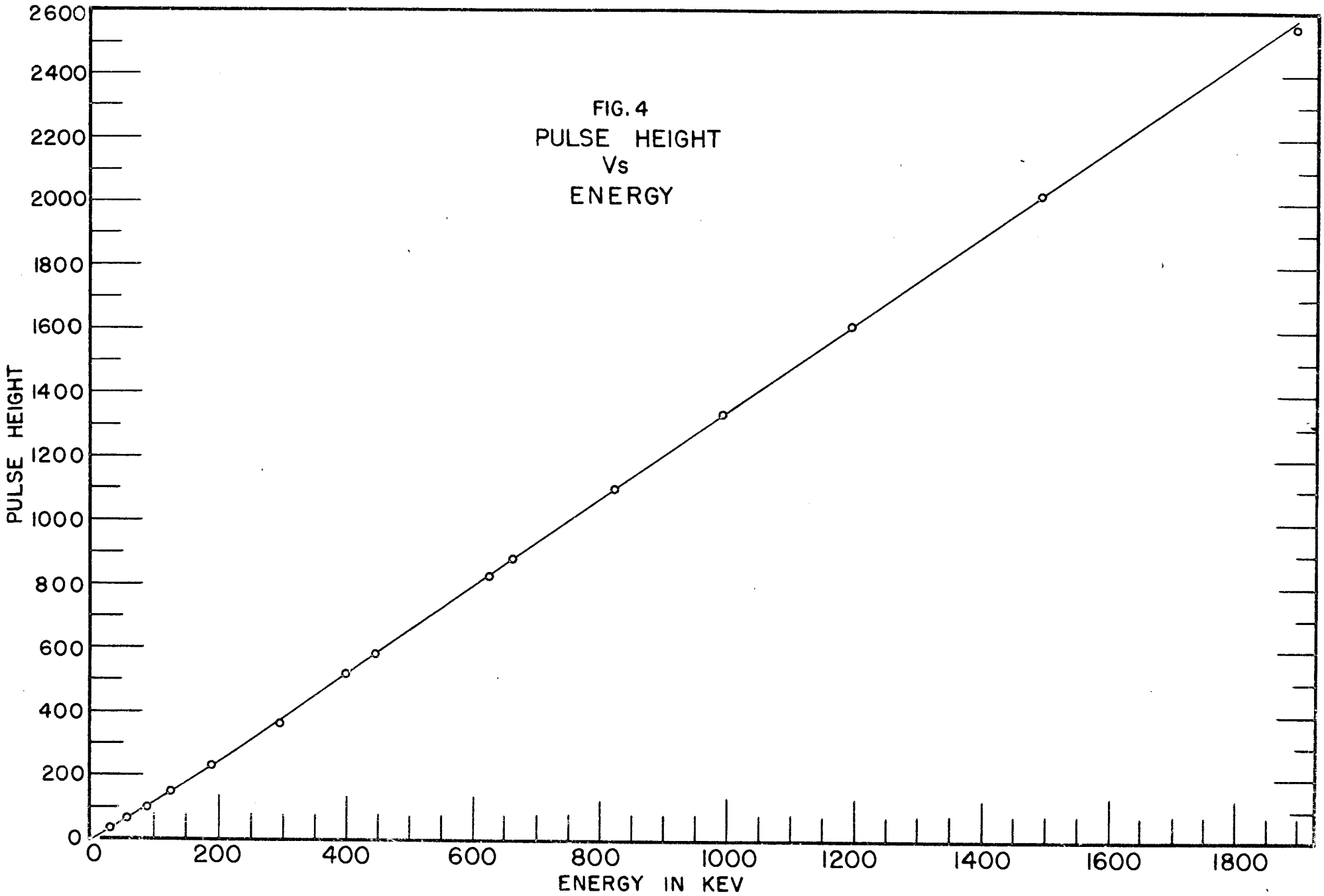

FIG. 4
PULSE HEIGHT
Vs
ENERGY

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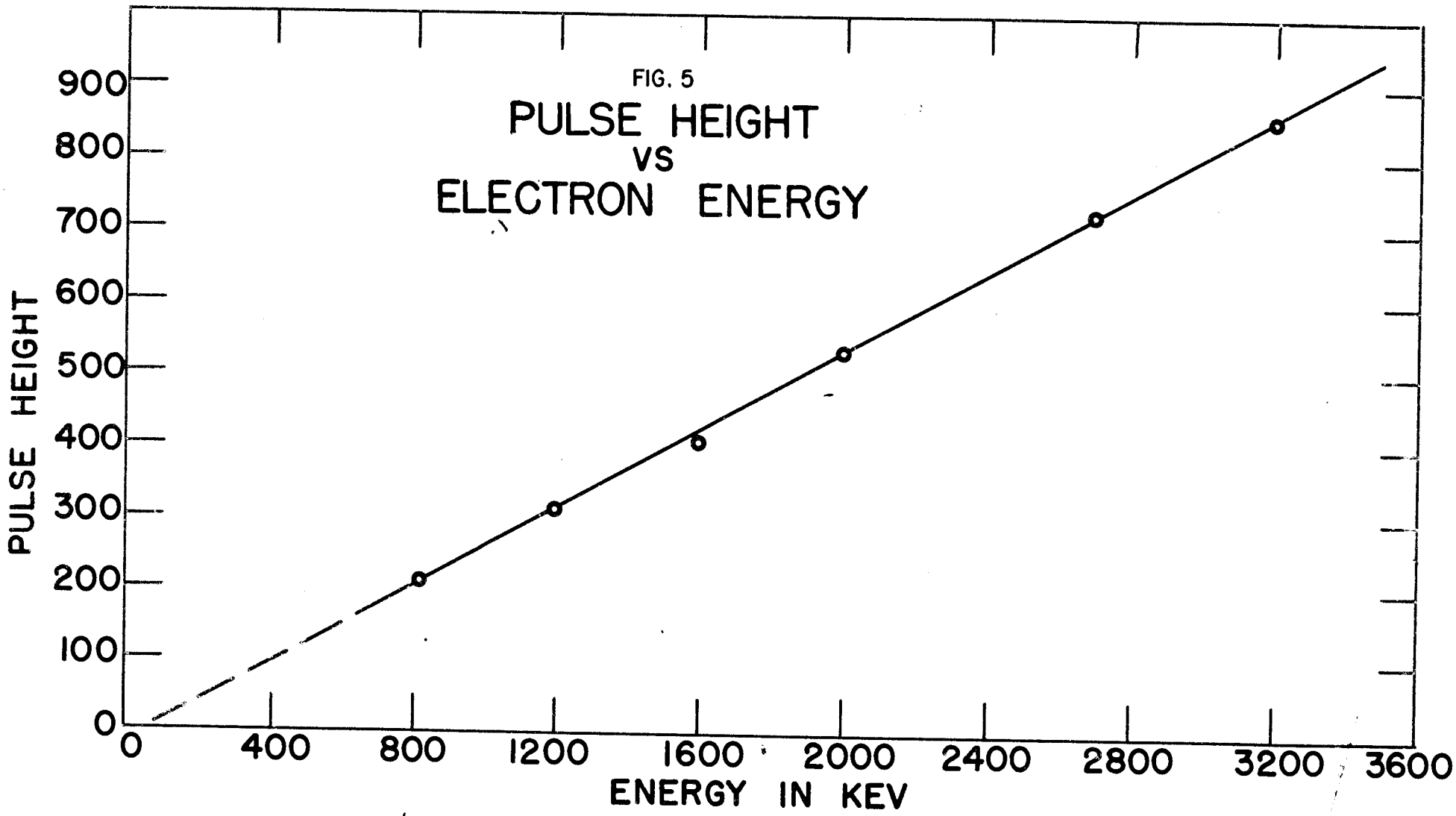

FIG. 5

being able to see fewer and fewer light pulses with amplitudes proportional to energy. Pulse height-energy curves for the three crystal thicknesses used are shown in Fig. 6 for a limited energy range.

It is observed that thin crystals give larger pulse heights for a given energy than the thicker crystals. This is probably due to the fact that thin crystals are clearer and of better quality in addition to making for the production of photons nearer the photosensitive surface. Larger counting rates are obtained with the two thicker crystals but this can be partially accounted for in that they have larger cross-sectional areas. The counting rates may be more nearly equalized if a lucite light "piper" 1-5/8 inches in diameter and 3/4 inch long is used between the crystal and the photomultiplier tube to distribute the light over a larger photosensitive area. The use of a light "piper" however gives a 10 to 15 percent decrease in pulse height depending upon the efficiency of the optical system.

It is estimated that the error in determining the energy of electrons by the pulse height differentiating method is not greater than 1% for the energy range studied. Possible unaccountable errors in these experiments may be due to (1) background variations, since the spectrometer is located in the pile building, (2) temperature changes in the region of the photomultiplier and crystal, (3) generator hash in the magnet current at times, and (4) temporary magnetic variations near photomultiplier tube.

SPECTRUM OF 2.5 SEC ERBIUM ISOMER

E. C. Campbell and J. H. Kahn

An energy spectrum of the 2.5 sec isomer of erbium[2] has been obtained using the scintillation spectrometer previously described[3] which is installed at the fast pneumatic tube. A minute sample of very pure erbium (obtained from Bruce Ketelle of the Chemistry Division) is then placed in front of a scintillation counter whose output if fed through a linear amplifier and then into a cathode ray oscilloscope. An approximately rectangular pulse whose

(2) Caldwell, R. L, Mateosian, E. der, and Goldhaber, M., "Transition Energies of Some Nuclear Isomers," *Phys. Rev.* 76, 187, Paper W8 (1949).

(3) Campbell, E. C. *et. al.*, "Activation Studies with Fast Pneumatic Tube," *Physics Division Quarterly Progress Report for Period Ending December 15, 1949*, ORNL 577, p. 20 (Feb. 8, 1950).

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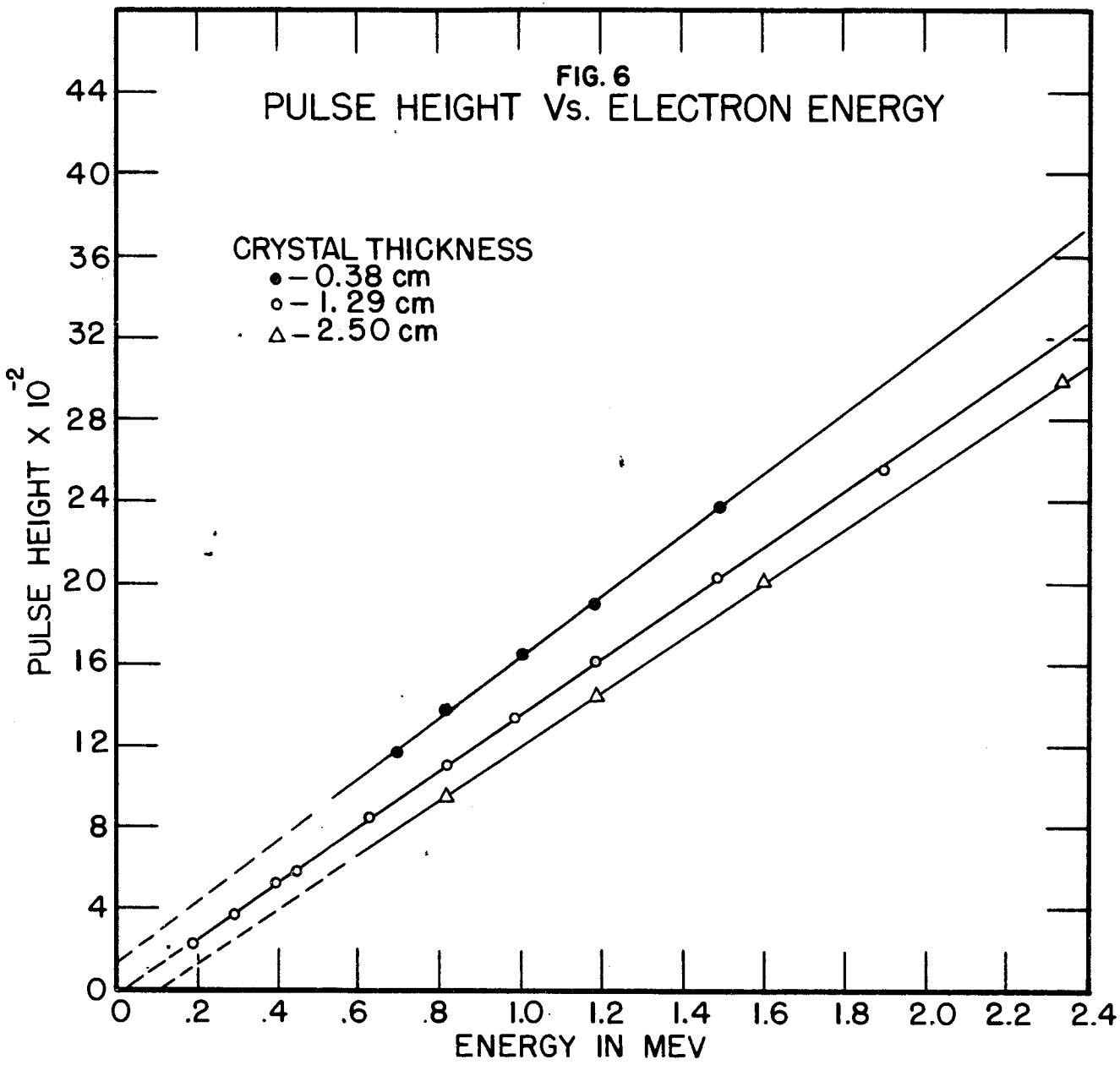

height is proportional to the energy of the radiation being counted is produced on the screen of the cathode ray tube. A time exposure photograph is made while the irradiated sample decays. This photograph is then scanned with a microphotometer whose output is recorded by a Brown potentiometer. Figure 7 shows two tracings made from the recordings produced by the Brown potentiometer in response to the scanning of two "erbium pictures" by the microphotometer. The curve obtained with a 1/8 in. lucite absorber is due only to gamma rays since the lucite stops all the conversion electrons. The gamma rays are detected chiefly by the recoil Compton electrons that they produce in the anthracene crystal of the counter. Therefore all electron energies from a certain maximum down to zero depending on the angle of recoil of the incident gamma ray are present. The curve obtained when no absorber (except for approximately 4 mg/cm^2 air path and 0.5 mg/cm^2 aluminum light shield plus about 1 mg/cm^2 of erbium sample) was used shows a double peak due to the K and L conversion electrons from erbium. The two peaks, which occur at approximately 110 and 160 Kev, respectively, are probably shifted to lower energies by 10 to 15 Kev due to the small amount of absorber still present. From these conversion electron energies it appears that the original gamma ray has an energy of 185 ± 10 Kev.

The spectrum with absorber includes pulses due to the erbium K X-rays as well as to the Compton recoils of the 185 Kev photon and is therefore difficult to analyse. Isotopic identification of this activity can be made very easily when separated erbium isotopes becomes available.

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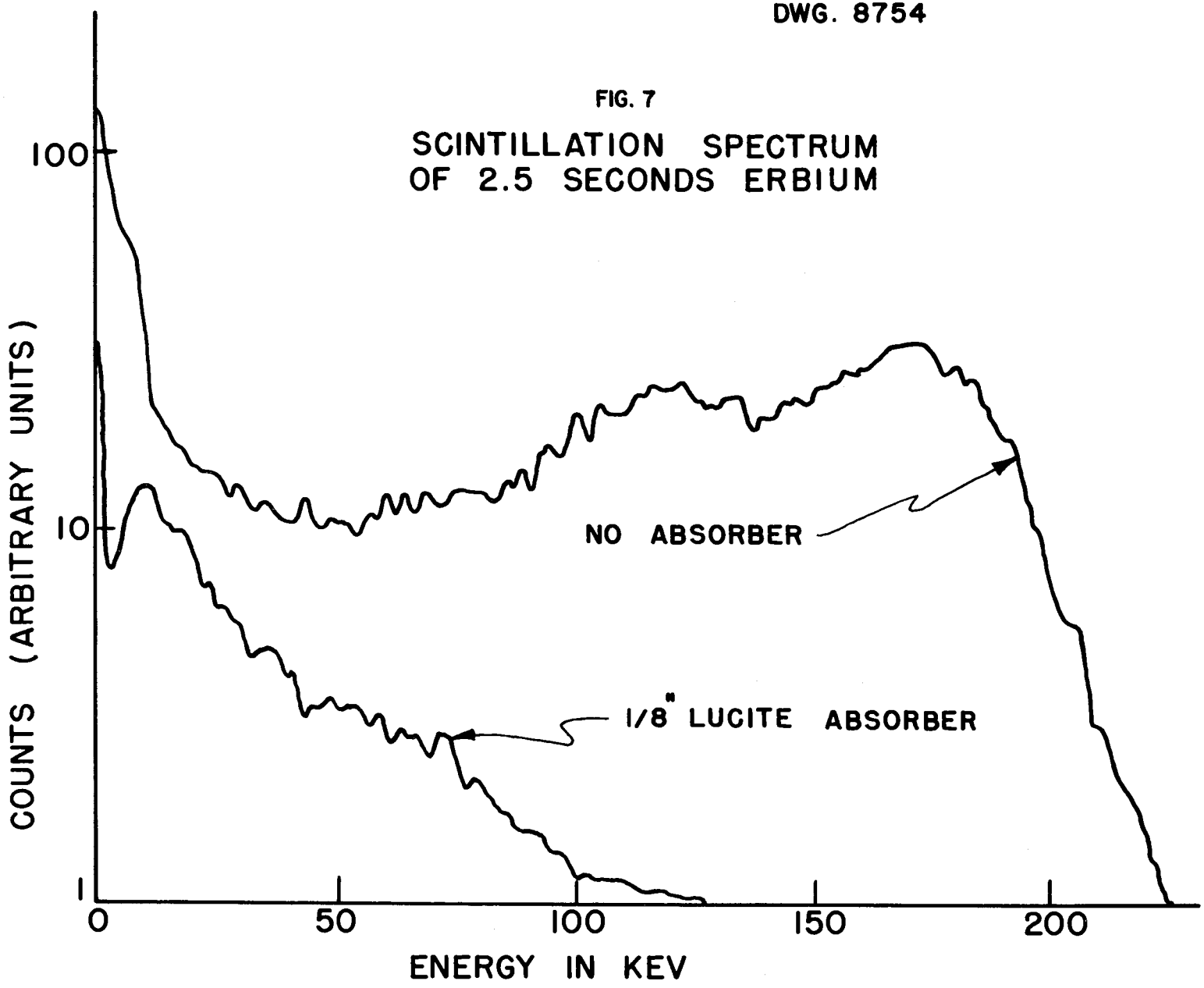
FIG. 7

SCINTILLATION SPECTRUM
OF 2.5 SECONDS ERBIUM



SHORT-LIVED ISOMERS

F. K. McGowan

Practically the only information available about the short-lived isomers so far observed is their half-life together with a rough estimate of the energy of the radiation emitted in their decay (except possibly for cases in which magnetic spectrometer data of γ-ray energies were already available). In order to obtain additional information on the nature of these transitions the delayed coincidence scintillation spectrometer is being used to measure the energy of the radiation resulting from the decay of the isomeric state, the ratio N_K/N_L, and to determine decay schemes. Four of the short-lived isomers have been studied and the results are summarized in Table I.

TABLE I

ISOMER	$(T_{1/2})$ exp. (sec)	E_γ Kev	(N_K/N_L) exp.
$_{71}Lu^{177}$	1.3×10^{-7}	150	3 ± 1
$_{73}Ta^{181}$	2.2×10^{-5}	132	$1.2 \pm .3$
$_{75}Re^{187}$	5.5×10^{-7}	133	5 ± 1
$_{79}Au^{197}$	7×10^{-9}	135	$\lesssim 1$

It is interesting to note that Ta, Re, and Au have essentially the same energy but widely different half-life and (N_K/N_L). Until the relativistic L shell internal conversion coefficients become available, no definite conclusions can be made regarding the multipole order and electric or magnetic character of the radiation. However, one is tempted to speculate by comparing the experimental data with the theoretical estimates for the same data. These speculative conclusions are Au^{197} $el(2)^2$-pole, Ta^{181} $el(2)^3$-pole, and Re^{187} combination $el(2)^3$-pole and $mag(2)^2$-pole.

Feenberg, Nordheim, and Mayer in their development of nuclear shell structure have pointed out that for nuclei with odd mass number isomerism appears to occur in well defined "lakes" extending from $(Z \text{ or } N)_{odd} = 39$ to 49 and $(N \text{ or } Z)_{odd} = 63$ to 81. The isomeric transitions for $63 \leq (N \text{ or } Z)_{odd} \leq 81$ are listed in Table II.

TABLE II

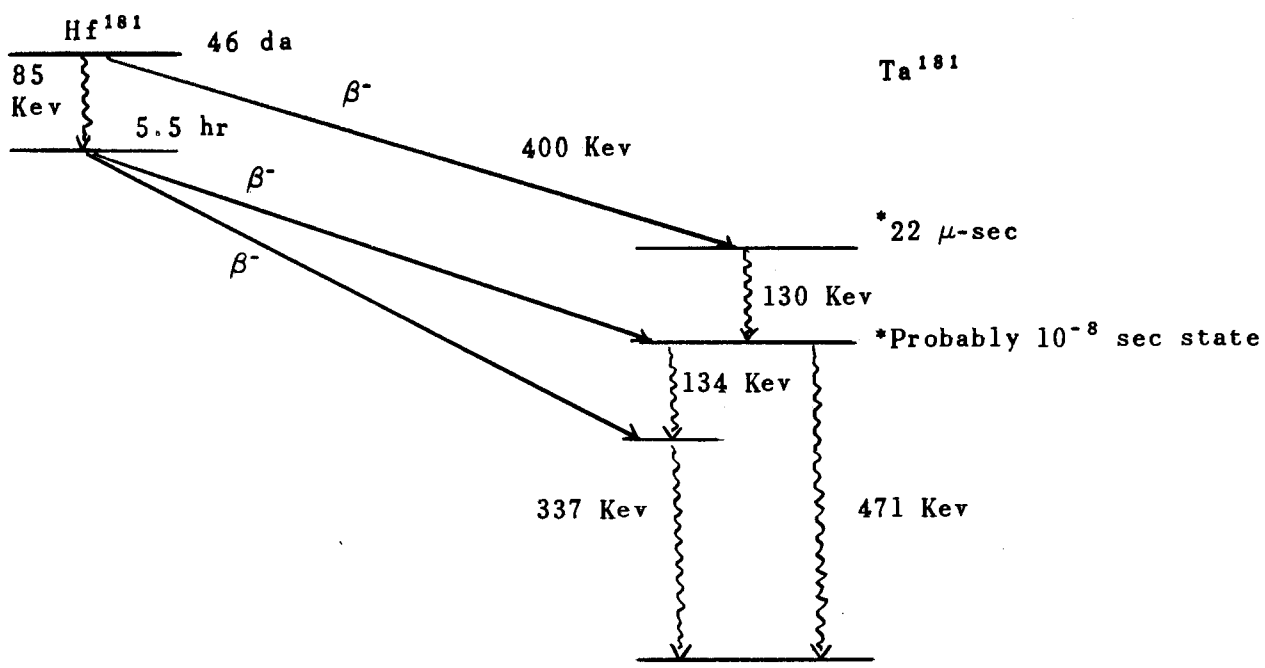
Isomers for $(N \text{ or } Z)_{odd} = 63$ to 81

N or Z	ODD PARTICLE	ISOMER	$T_{1/2}$
63	N	Cd^{111}	48 min
	N	Cd^{111}	8×10^{-8} sec
65	N	Cd^{113}	2.3 min
67	N	Cd^{115}	43 da
69	N	Sn^{119}	> 100 da
	N	Te^{121}	140 da
	Z	Tm^{169}	7.5×10^{-7} sec
	Z	Tm^{171}	2.5×10^{-6} sec
71	N	Te^{123}	90 da
	Z	Lu^{177}	1.3×10^{-7} sec
73	N	Te^{125}	58 da
	N	Xe^{127}	75 sec
	Z	Ta^{181}	2.2×10^{-5} sec
	Z	Ta^{181}	1.1×10^{-8} sec
75	N	Te^{127}	90 da
	Z	Re^{187}	5.5×10^{-7} sec
77	N	Te^{129}	30 da
	N	Ba^{133}	40 hr
	N	Xe^{131}	12 da
79	N	Te^{131}	1.2 da
	N	Ba^{135}	28 hr
	Z	Au^{197}	7.5 sec
	Z	Au^{197}	7×10^{-9} sec
81	N	Ba^{137}	2.5 min
	N	Xe^{135}	10 min

The short-lived isomers in this "lake" are eight, out of a total of nine observed thus far in nuclei with odd mass number. Seven of these occur in nuclei for Z odd. In the case of the long-lived isomers sixteen occur in nuclei for N odd and only one occurs for Z odd. It is immediately apparent that the long-lived isomers are found for N odd and the short-lived ones for Z odd. This coincidence could be a mere accident but probably the experts on shell structure might find some significance. Perhaps there is a difference in the order of the neutron levels $69 \leq N \leq 79$ and proton levels $69 \leq Z \leq 79$. Such difference in level order is not noticeable in the "magic numbers" and thus far has been disregarded in free particle computations.

A second isomeric state in Ta^{181} with a half-life 1.1×10^{-8} sec, first observed by W. C. Barber at Stanford University, has been confirmed. Measurements with the delayed coincidence scintillation spectrometer indicate that the 10^{-8} sec state follows the 22 μ-sec state. Measurements of the preceding and delayed radiation for the shorter isomeric states are being made.

The following decay scheme has been proposed by Burson[1] for Hf^{181}.



(1) Burson, S. B. and Blair, K. W., ANL 4397, p. 58 (Jan. 15, 1950).

Preliminary measurements of radiation from the decay of the 10^{-8} sec state is consistent with the interpretation that the 471 Kev γ-ray follows this isomeric state. If the above decay scheme were correct, the 10^{-8} sec state should be observed following the β^- decay of the 5.5 hr Hf activity. Using sources of Hf with a 5.5 hr period present, no delayed coincidences were observed above the random rate to follow this 5.5 hr activity. This result does not conclusively rule out that the 46 day level is an isomeric state in Hf^{181} but does rule out the softer β^- component which would leave Ta^{181} in the 10^{-8} sec level.

Nuclei investigated for short-lived isomers are shown in Table III.

TABLE III

NUCLEUS	$T_{1/2}$ sec	RADIOACTIVE SOURCE
$_{67}Ho^{166}$	$< 0.3 \times 10^{-8}$	Dy^{166}
$_{52}Te^{123}$	$< 0.3 \times 10^{-8}$	Te^{123*}
$_{63}Eu^{153}$	$< 0.4 \times 10^{-8}$	Gd^{153}
$_{63}Eu^{151}$	$< 0.2 \times 10^{-8}$	Sm^{151}
$_{74}W^{182}$	$< 0.4 \times 10^{-8}$	Ta^{182}
$_{63}Eu^{153}$	$< 0.2 \times 10^{-8}$	Sm^{153}
$_{67}Ho^{165}$	$< 0.3 \times 10^{-8}$	Dy^{165}
$_{80}Hg^{199}$	$< 0.5 \times 10^{-8}$	Au^{199}
$_{65}Tb^{159}$	$< 0.3 \times 10^{-8}$	Gd^{159}
$_{79}Au^{197}$	--	Pt^{197}
$_{76}Os^{186}$	$< 0.4 \times 10^{-8}$	Re^{186}
$_{71}Lu^{175}$	$< 0.4 \times 10^{-8}$	Yb^{175}

The upper limit set for $T_{1/2}$ assumes that the β decay leads to the excited states in a large percentage of the transitions. If it should be a branch of low intensity, the life-time limit should be increased by a factor of three or four.

PHYSICAL ELECTRONICS

SINGLE CHANNEL DIFFERENTIAL PULSE HEIGHT SELECTOR

J. E. Francis, P. R. Bell, and J. C. Gundlach

A single channel analyser has been built for measuring the energy spectrum obtained from scintillation counters and proportional counters.

The analyser contains a pulse height selecting, non-overload, feedback amplifier, followed by two pulse height selectors, a memory circuit, and an anti-coincidence circuit.

Figure 8 is a circuit diagram of the analyser. The feedback amplifier amplifies a segment of the pulse distribution as shown in Fig. 9.

The first tube of the amplifier (V-1) is a cathode follower whose grid bias can be varied over a range of one hundred volts. This allows the d-c level of an input pulse to be varied over a range of one hundred volts. The cathode is coupled to the grid of V-2 through a current limiting resistor. An input pulse must be larger than a certain amount (determined by the bias on V-1) before V-2 gives an output pulse. The grid of V-2 is prevented from going too far positive by a 6AL5 diode which starts to conduct after the grid has reached a certain value. The two 1N34's on the plate of V-2 are biased ten volts apart. The upper one prevents an output signal until V-2 is on the linear portion of its characteristic. The lower one limits the size of the output pulse so that none of the following tubes are overloaded. V-2 together with V-4 and V-5 comprise a conventional feedback loop with a gain of ten. This completes the non-overload amplifier.

The signal from the amplifier is fed into two pulse height selectors.

The lower pulse height selector (V-7, V-8, V-12 and V-13) consists of a long tailed pair followed by a multivibrator. It is biased so that it fires on very small pulses. A pulse is taken from each plate of the multivibrator. The pulse taken from the plate of V-13 is used to turn on the memory circuit by cutting off V-18. The pulse taken from the plate of V-12 is differentiated by a shorted delay line to obtain two pulses, one which marks the beginning

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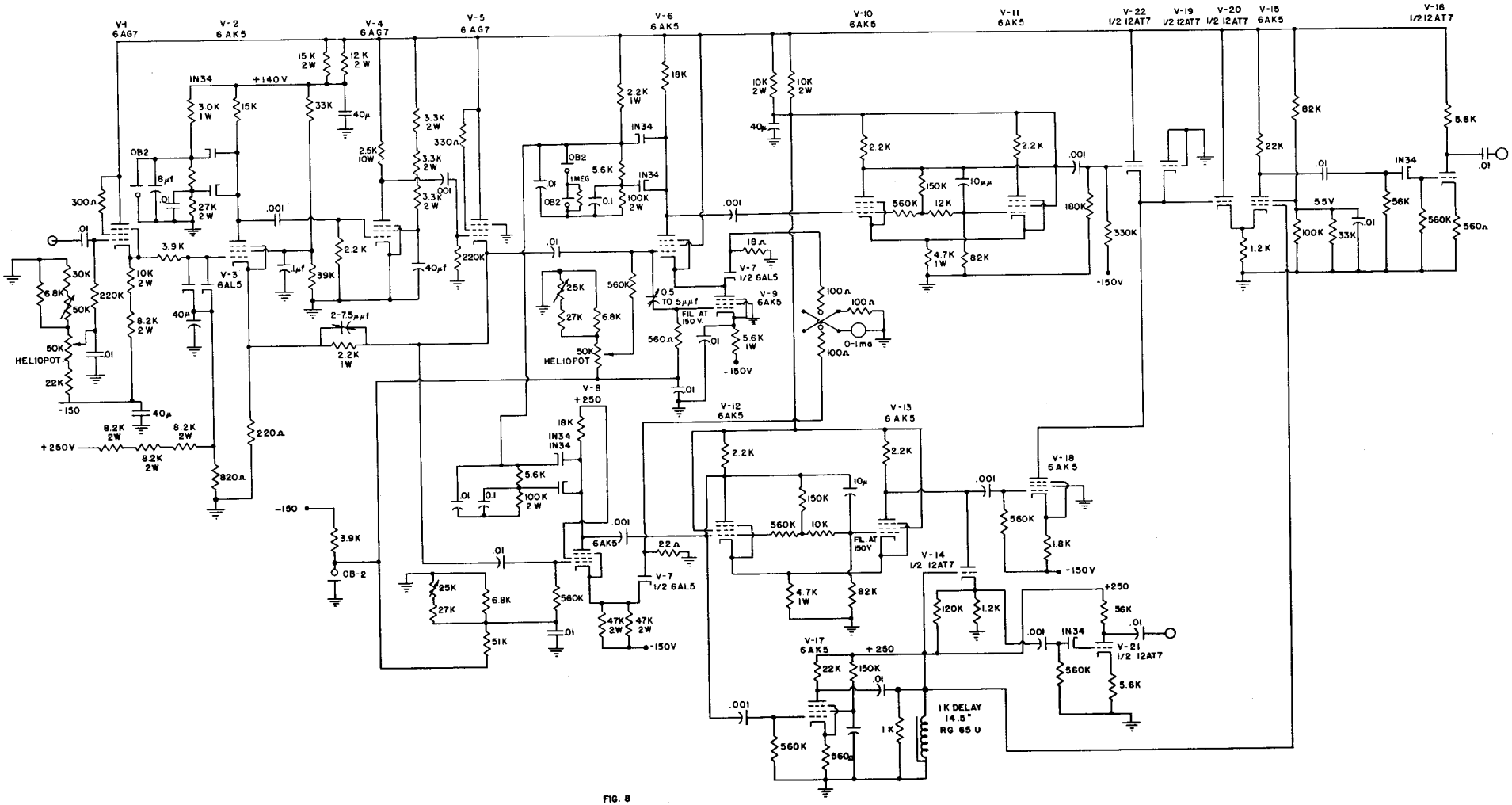

FIG. 8

DIFFERENTIAL PULSE HEIGHT ANALYSER

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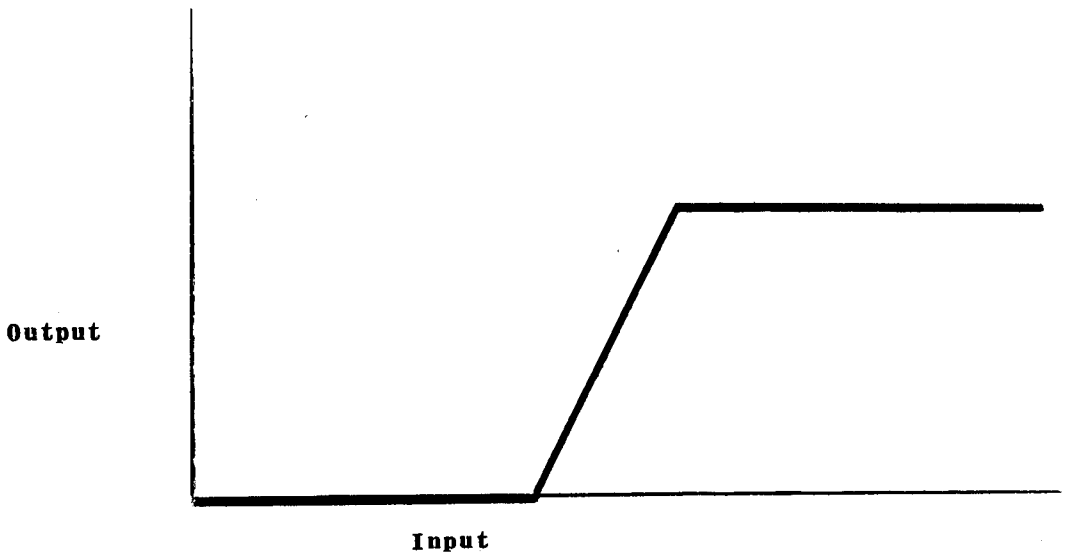

Fig. 9

and one which marks the end of the input pulse. The pulse marking the end of the input pulse is used to hold the memory circuit on, and is also fed to one input of the anti-coincidence circuit.

The upper pulse height selector (V-6, V-7, V-8, V-9 and V-11) is similar to the lower pulse height selector. V-9 is a constant current tube, and is used to compensate for the grid to cathode capacity of V-6. The upper pulse height selector fires only if the pulse is above a certain value determined by the bias on the grid of V-6. This determines the ΔE or "window width." The output pulse from V-10 is fed into the memory circuit.

The memory circuit (V-18, V-19 and V-22) controls one input of the anti-coincidence circuit, which is the grid of V-20. Normally when there is no input pulse to the circuit the grid of V-20 is held down by current flowing from the plate of V-18 through V-19 to ground. When a pulse from the lower pulse height selector turns off V-18, the grid of V-20 is left floating and stays at approximately the same value. If, however, the upper pulse height selector also fires, a pulse is put on the grid of V-22 which pulls the grid of V-20 up. The grid of V-20 will stay up preventing any output from the anti-coincidence circuit. It will not come down until after the differentiated pulse from the lower pulse height selector has disappeared from the grid of V-18. When the grid of V-18 no longer has a pulse on it the tube starts to conduct and resets the memory circuit.

Therefore, if the upper pulse height selector fires, the memory circuit provides one input to the anti-coincidence circuit until after the differentiated pulse from the lower pulse height selector has entered the anti-coincidence circuit. When only the lower pulse height selector fires there is no coincidence; therefore, there is an output pulse from V-18 which is lengthened and amplified by V-16 to get a larger and longer pulse to drive a scaler.

The memory circuit is necessary because the pulse which the upper pulse height selector sees is of shorter duration and occurs after the pulse has entered the lower pulse height selector. Without the memory circuit it is possible to get an anti-coincidence when actually there is a coincidence.

The pulse which marks the end of the pulse from the lower pulse height selector is also taken from the cathode of V-19, lengthened, and amplified by V-21 to get the total number of pulses above a certain value.

A MULTI-CHANNEL PULSE SORTER

G. G. Kelley

The scintillation spectrometer and other devices may be used to produce voltage pulses whose amplitudes are proportional to the energy of an incident radiation. In order to determine the energy spectrum of a source of radiation, some means of sorting voltage pulses according to size must be employed. The most direct method, and the least satisfactory one, is to determine the number of pulses in a fixed time interval whose amplitudes are greater than a certain value, by means of a pulse height discrimination. When this has been done for two values of amplitude, the difference is a statistical measure of the number of pulses expected per time interval with amplitude lying between these values. The basic difficulty with this method lies in the fact that the statistical accuracy of the individual counts at two amplitudes varies as the square root of the number of counts. If N_1 counts are observed greater than A_1 and N_2 counts are observed greater than A_2, then the computed value for the counts between A_1 and A_2 will have a standard deviation of approximately $\sqrt{N_1 + N_2}$ if N_1 and N_2 are large. But a count of the number of pulses actually falling in the interval between A_1 and A_2 will have a standard deviation of the order of $\sqrt{N_1 - N_2}$. Also, a given degree of precision in amplitude discrimination must be multiplied by the increment of amplitude to determine the precision of the spectrum. Thus if a discriminator can be set to a given value within 0.1% of full scale, an error of 20% may be made in the determination of the number of pulses lying in a 1% increment. It may be seen, therefore, that for greater accuracy two discriminators should be used with a means of controlling the difference between their levels to within, say, 1% or 2%. With the total pulse voltages available from pulse amplifiers, this precision requires further amplification of the portion of the spectrum under observation by a factor of between five and ten. This amplification may take place in the circuit, either before or after the desired increment (called the "window") has been set. Requirements of this amplifier are rather severe. Its gain must be constant for a wide range of pulse shapes and speeds, since it may be called upon to amplify either the whole of a small pulse or only the top few percent of a large pulse, and its gain stability with time must be as great as the overall stability required. Discriminators too must be designed with care because their voltage stability divided by the gain of the increment amplifier preceding them must be 0.005% for a 1% window stability. This stability must be

with respect to signal speed as well as time unless some means of standardizing the pulse shapes applied to the discriminators is used. For convenience, circuits may be added following the discriminators to provide no output except when a pulse trips only the lower discriminator. P. R. Bell, J. Gundlach, and J. E. Francis of this division, and E. Fairstein, of the Chemistry Division, have developed independently two single channel analyzers according to the principles outlined above.

A logical improvement in the interest of rapid accumulation of data is the operation of many single channel analyzers in parallel. The difficulty is primarily one of complexity. About 20 tubes are required in the analyzer itself for the operation of a single channel unit. Multiplying the space equipment and power required for one unit by, say, ten is hardly practical. Considerable simplification may be achieved, however, by combining functions. The only necessary duplication is in the discriminators.

A ten channel analyzer containing ten adjoining channels, each of which may be as narrow as 1% of the signal amplitude, is in the process of completion. It operates in such a way that all unnecessary duplication is eliminated, and by means of a time sequencing arrangement also eliminates the need for anticoincidence circuitry.

Figure 10 is a block diagram of this unit. A maximum of about 100 volts of signal, available from an A-1 amplifier, is applied at the input. The d-c Level Adjust," a Helipot, selects a ten volt portion of the input spectrum by changing the d-c level of the signal with respect to the input cathode of the amplifier. This amplifier is similar to one of the feedback groups in an A-1 amplifier except that it has been modified for overloading signals. The possibility of using this type of amplifier with modifications was suggested by P. R. Bell. A similar one is used in the single channel unit described elsewhere in this report. Following the amplifier is a pulse lengthening circuit consisting of two 1N38 diodes normally held conducting by current tubes making the system linear. These current tubes are cut off by operation of the multivibrator which occurs for pulses greater than about three volts. The first diode responds very rapidly to the rising input signal but holds at maximum value for a relatively short time. The second diode maintains a nearly constant level proportional to the maximum value of the signal for the necessary time. The discriminators are type 6BN6 tubes followed by a Schmidt trigger

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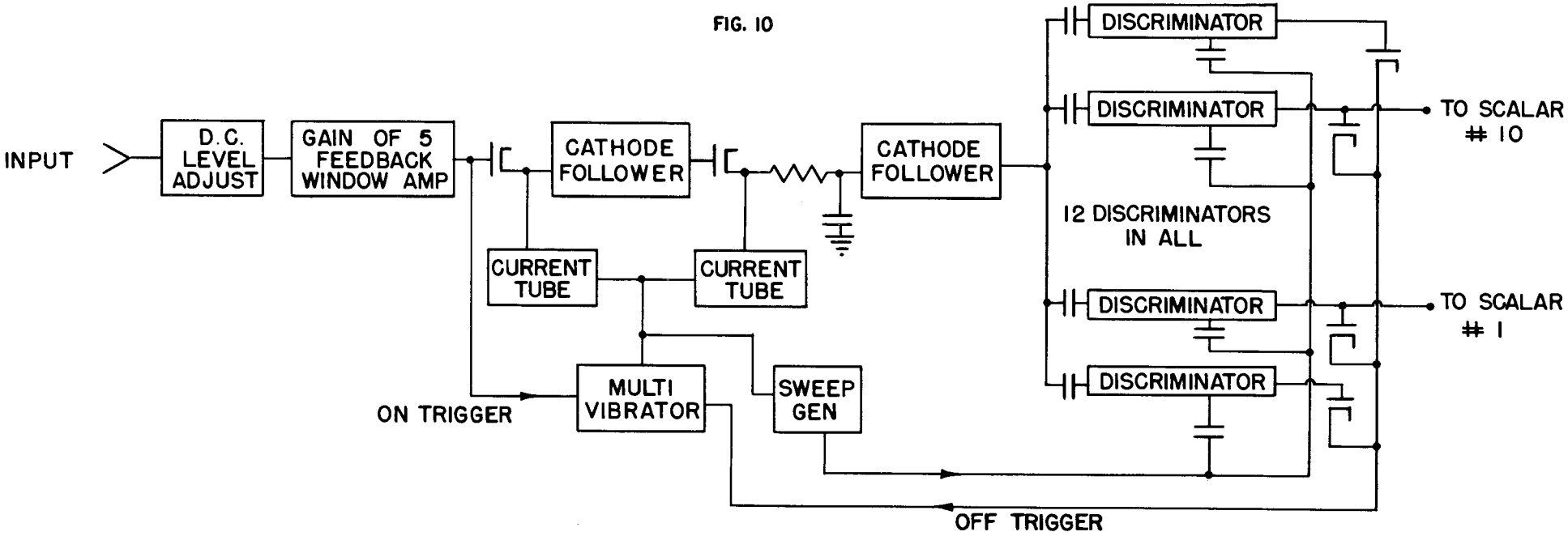
FIG. 10



circuit similar to that used in the pulse height discriminator in the A-1 amplifier. These 6BN6 tubes have rather unusual properties. They have two high mutual inductance, sharp cut-off grids, neither of which draws appreciable current when less than 50 volts positive. Their grid voltage-plate current stability seems unusually good. The lengthened pulse is applied to the number 1 grids of 12 of these tubes in parallel. The d-c level of the pulse is made progressively five volts less negative from tube to tube by a biasing arrangement. A given size pulse will cause the number 1 grids of some of the tubes to rise high enough to allow these tubes to conduct. Plate current will not flow, however, because the number 3 grid of all of the tubes are all biased beyond cut-off. They are returned to a biasing arrangement which causes the d-c level to be five volts more negative from tube to tube. These grids are raised in potential together, at their respective d-c levels, by the sweep generator which is started by the triggering of the multivibrator. Thus the tubes are allowed to operate in time sequence until the first tube whose number 1 grid is above cut-off is reached. Operation of this discriminator provides an input pulse to its respective scaler and at the same time returns the multivibrator to its no-signal condition and resets the pulse lengthener and sweep generator. By this means none of the other discriminators are permitted to operate. About five microseconds are required to search all channels and reset the unit.

THE TOTAL CROSS SECTION OF HOLMIUM

T. E. Stephenson and T. Arnette

The total cross section of holmium as a function of neutron energy is being investigated using the bent crystal neutron spectrometer.

The sample being used weighs 66.8 milligrams and is in the chemical form Ho_2O_3. It was obtained from Dr. G. E. Boyd of the Chemistry Division.

The measurements are not yet complete but the results to date are shown in Fig. 11. The curve shows the cross section per holmium atom as a function of energy. It is not corrected for water; however, the sample is believed to be essentially dry since it was baked at 700°C and transferred, while in a drybox, to the cross-section measurement tube by Mr. Lavalle of the Chemistry Division. The sample will be analyzed upon completion of the cross-section measurements.

If there is indeed no contaminating materials present in the sample, then the substance seems particularly interesting in that the scattering cross section at .03 ev is unusually large. If one assumes that the absorption cross section follows the $1/v$ law in this energy region, and using Mr. Pomerance's value of 64 barns for absorption at .025 electron volts, one would expect an absorption cross section of about 18 barns at 0.3 electron volts. Since the present measurements give about 29 barns for the total cross section at this energy, there are about 11 barns left for the scattering cross section. At 0.03 electrons volts, however, there are about 30 barns left for scattering. Holmium has a large magnetic moment and Dr. Shull has suggested the possibility of magnetic scattering as an explanation for the "excess" scattering cross section. The paramagnetic cross section increases with the form factor. Since the form factor decreases as the energy increases the decrease of the scattering cross section with energy is accounted for.

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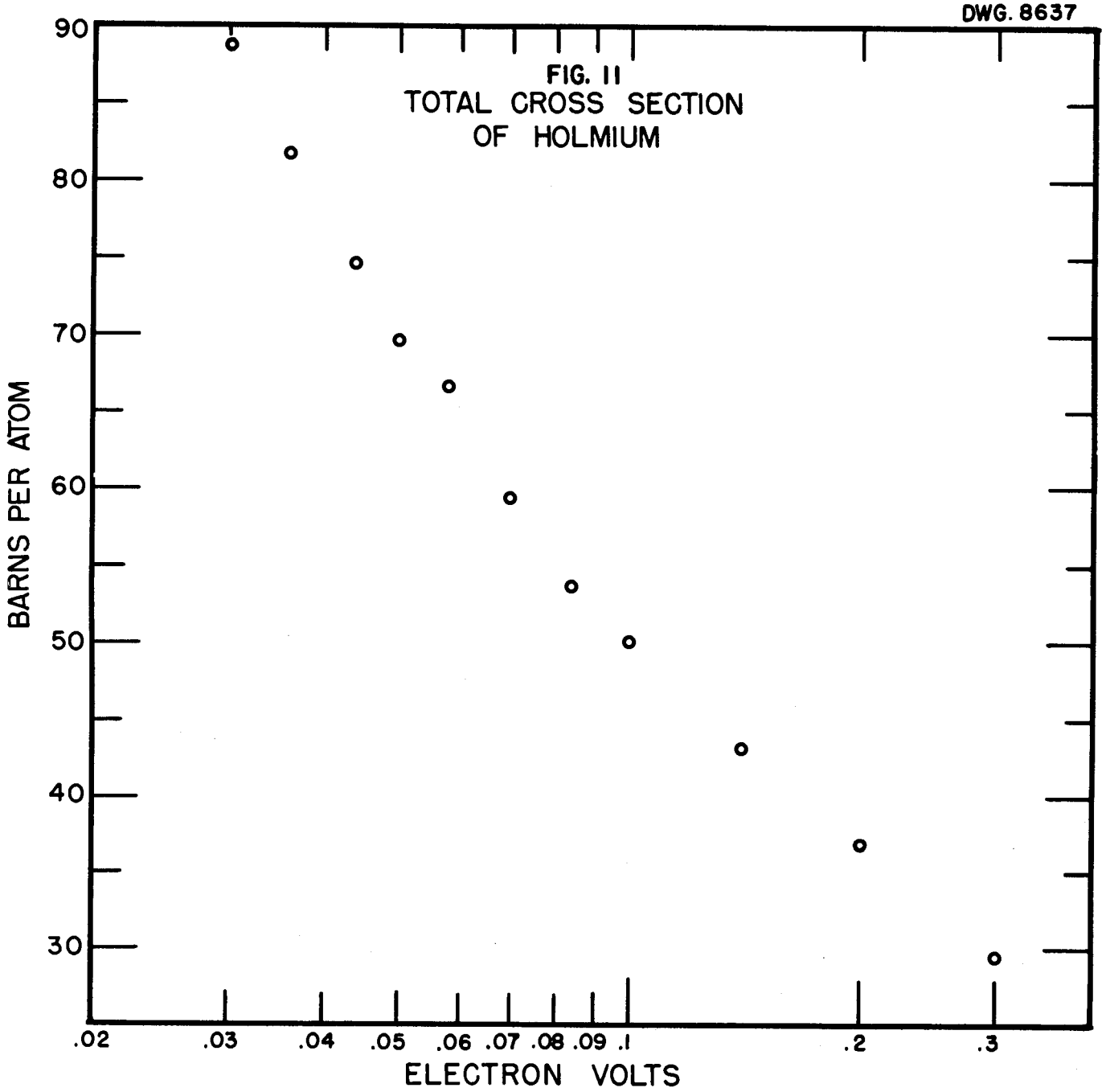

FIG. 11
TOTAL CROSS SECTION
OF HOLMIUM

NEUTRON DIFFRACTION

C. G. Shull, E. O. Wollan, W. C. Koehler and W. A. Strauser

FERROMAGNETIC SCATTERING BY COBALT

Halpern and Johnson have shown on theoretical grounds that the scattering of unpolarized neutrons by an unmagnetized ferromagnetic substance should be characterized by

$$F^2 = C^2 + 2/3\ D^2 f^2 \quad ,$$

where F is the effective scattering amplitude of the magnetic ion, C is the nuclear scattering amplitude, D the magnetic scattering amplitude and f is the magnetic form factor. Since the magnetic form factor is angularly dependent, we should expect a variation of effective scattering amplitude among the different peaks of the neutron diffraction pattern for an unmagnetized ferromagnetic substance. The degree of variation will depend upon relative values of the coherent nuclear scattering amplitude (angularly independent) and the magnetic scattering amplitude.

For this study a sample of cubic-form cobalt filings was used and careful intensity measurements were made for the (111), (200), (220) and (311) - (222) reflections in the neutron diffraction pattern. From these intensities, the F^2_{hkl} values (on an absolute scale) were calculated and these are shown graphed in Fig. 12 as a function of scattering angle 2θ. An appreciable angular dependence is to be noted. Using H-J formulae, the value of D is calculated to be 0.461×10^{-12} cm and along with magnetic form factor data of Wick calculated for the case of Fe, the expected magnetic contribution to the observed F^2_{hkl} values is shown in the graph. Co and Fe are so similar in electronic structure that the Fe form factor should represent to a close approximation that of Co. It is seen that the observed data follow in angular contour closely that of the magnetic part and that the difference is essentially isotropic. The difference should represent the coherent nuclear scattering cross section for Co and this turns out to be 1.0 ± 0.1 barn.

A similar type of study has been carried out with several different iron samples and at present the results are anomalous. It does not seem possible

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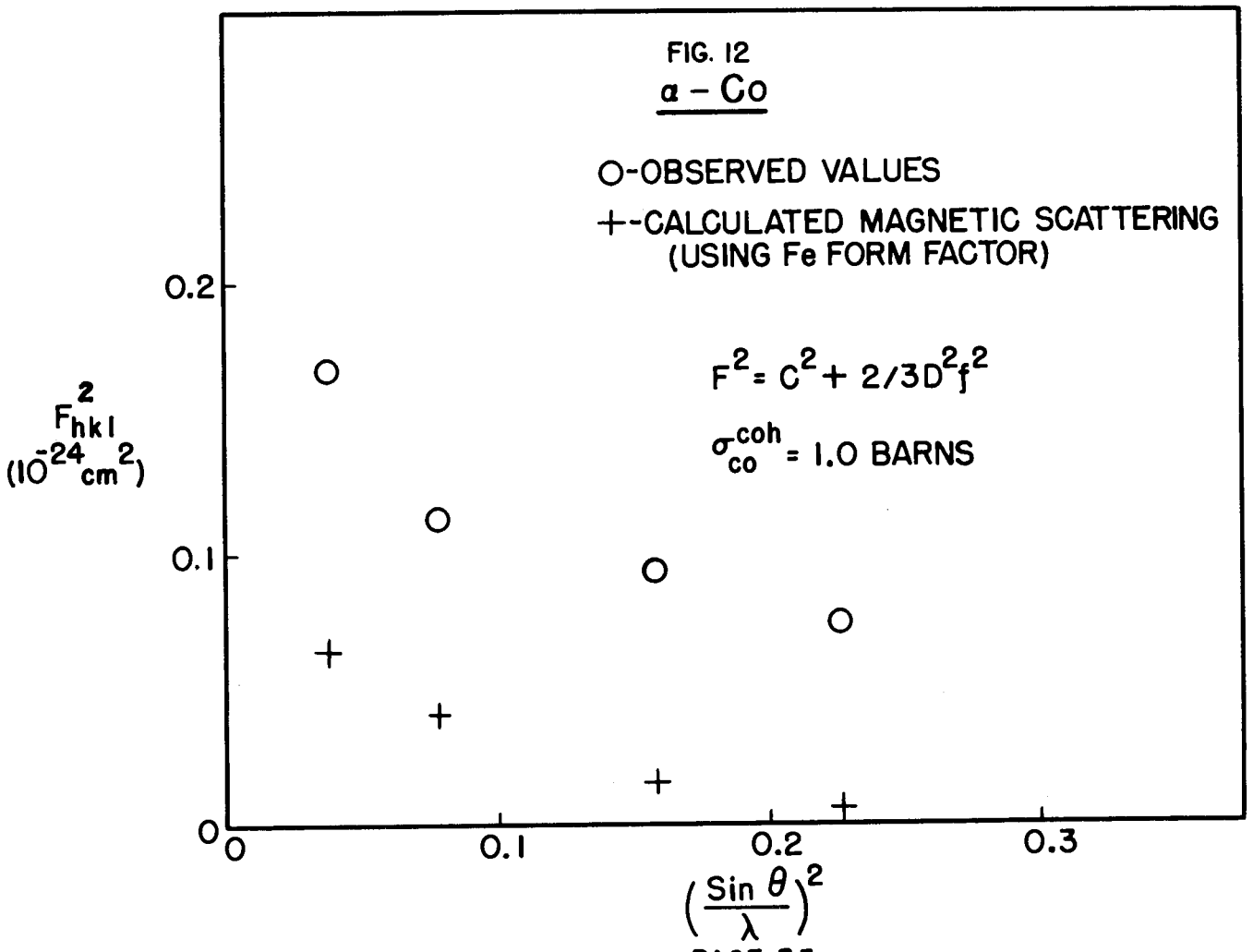

to resolve the observed intensities into the isotropic nuclear intensity and the form factor magnetic intensity as in the case of cobalt above. Further work is being done on this material and results will be reported later.

The above evaluation of the magnetic and coherent nuclear scattering amplitudes for cobalt is interesting in that it suggests the usefulness of Bragg scattering by magnetized cobalt as a source of very highly polarized neutrons. Since the nuclear amplitude is 0.28×10^{-12} cm and the magnetic amplitude for the (111) reflection is 0.31×10^{-12} cm, calculation using H-J formulae shows the polarization in the (111) Bragg reflected beam from magnetized cobalt to be better than 99%. Experiments to establish this nearly complete polarization are underway. Aside from intensity considerations about which very little is known as yet, it may be that the Bragg scattering method of polarized beam production may compete favorably with the magnetized mirror method since the former would permit arbitrary wavelength selection.

COHERENT SCATTERING CROSS SECTIONS

The Isotopes of Nickel. The scattering amplitudes of Ni^{58} and of Ni^{60} have been previously determined in this laboratory, but under less favorable conditions than exist for the present set of measurements. We have also been able to obtain a measureable quantity of Ni^{62}.

In Table I are listed the isotopic compositions of the samples together with the experimentally determined scattering amplitudes for nickel of the indicated isotopic constitution.

TABLE I

SUBSTANCE	Ni^{58}	Ni^{60}	Ni^{62}	f' (in 10^{-12} cm)
Ni^{58}	92.7%	6.9%	0.1%	1.39
Ni^{60}	4.5%	95.0%	0.1%	0.33
Ni^{62}	3.4%	3.1%	92.7%	-0.73
Ni	67.4%	26.7%	3.8%	1.03

The amplitudes for the individual isotopes were calculated from these data. The results are shown in Table II.

TABLE II

The Scattering Cross Sections of the Nickel Isotopes

ISOTOPE	f(in 10^{-12} cm)	(barns)	CONTRIBUTION TO NORMAL NICKEL AMPLITUDE
Ni^{58}	1.48	27.6	1.00
Ni^{60}	0.28	0.97	0.073
Ni^{62}	-0.85	9.1	-0.032
Ni (measured)	1.03		Sum 1.04

It is interesting to note that Ni^{62} scatters negatively and with a fairly large amplitude. Figure 13 shows portions of the diffraction patterns for the several samples of NiO examined. A comparison of the relative intensities of the (111) and (200) reflections is in this case sufficient to establish the phase of scattering for the nickel isotopes. In the Ni^{62} sample the (200) reflection is very weak or absent. This implies that oxygen and Ni^{62} must be scattering with opposite phase; hence if oxygen scatters with positive phase, as we assume, Ni^{62} scatters negatively, Ni, Ni^{58} and Ni^{60} scatter with positive phase.

The Isotopes of Calcium. The following results have been obtained for coherent scattering cross sections of the isotopes of calcium.

ISOTOPE	f	σ	PHASE
Ca	0.49	3.0	(+)
Ca^{40}	0.49	3.0	(+)
Ca^{44}	0.18	0.4	(+)

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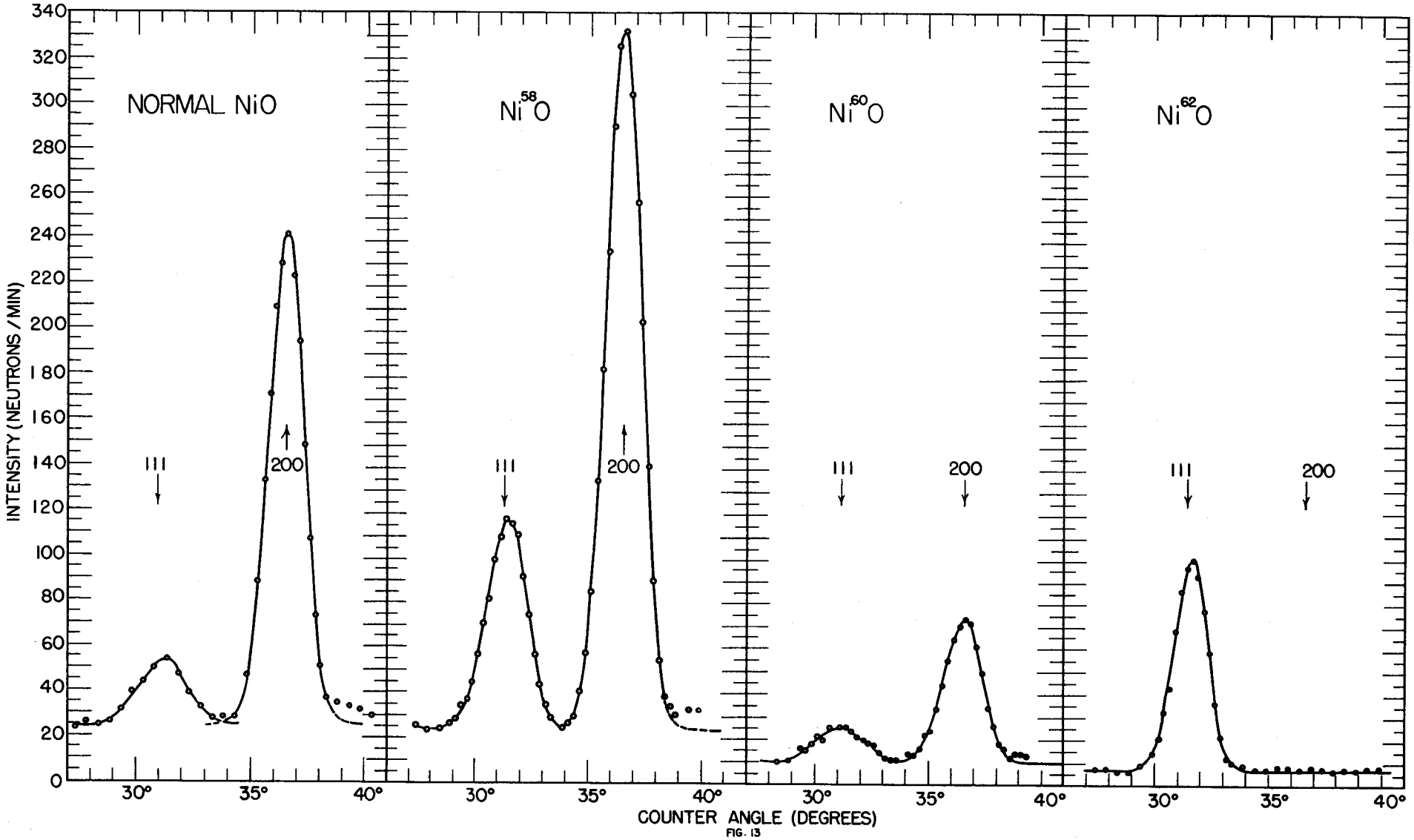

FIG. 13
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NEUTRON DECAY EXPERIMENT

R. V. McCord, F. Pleasonton and A. H. Snell

A Letter to the Editor of the *Physical Review* has been submitted for publication, and should appear shortly. The text of the letter is reproduced below. Meanwhile, apparatus changes are in progress in an effort to make possible a more accurate evaluation of the collection geometry, so that the half-life can be determined more accurately. The main change is the installation of a multiplier with plates six inches long in the direction parallel with the beam, and arranged so that various parts of the entrance aperture can be separately closed off. It is hoped that this will permit evaluation of end-effects on the collection volume of the neutron beam. The beta counters have also been revised and improved. The single two-celled AB counters have been replaced by four smaller two-celled counters of faster response. After considerable effort, these have now been made to function well in parallel.

RADIOACTIVE DECAY OF THE NEUTRON*

(Submitted to the *Physical Review*)

Experimental evidence concerning the instability of the neutron(1) has been obtained with the apparatus shown in Fig. 14. A beam of neutrons from the Oak Ridge uranium-graphite reactor passed longitudinally (perpendicular to paper) through an evacuated tank shown in section. An electric field was applied between an open-sided cylindrical electrode (+) and a plane electrode (-) such that positive particles appearing in this region of the beam would be accelerated upward through 8 kv and would be focused upon the enlarged first plate of a secondary electron multiplier situated behind an aperture in the negative electrode. The aperture and the multiplier plates were 7.3 cm long in the direction parallel with the beam. The two-celled beta proportional counter placed below the beam had an effective length of about 11 cm.

Triple coincidences were sought, namely coincidences between discharges of counter *A* and counter *B* resulting from beta particles emitted from neutrons

* This document is based on work performed under Contract No. W-7405, eng. 26 for the Atomic Energy Project at Oak Ridge.

(1) Chadwick, J. and Goldhaber, M. "The Nuclear Photoelectric Effect," *Roy. Soc. Proc.* A 151, 479 (1935).

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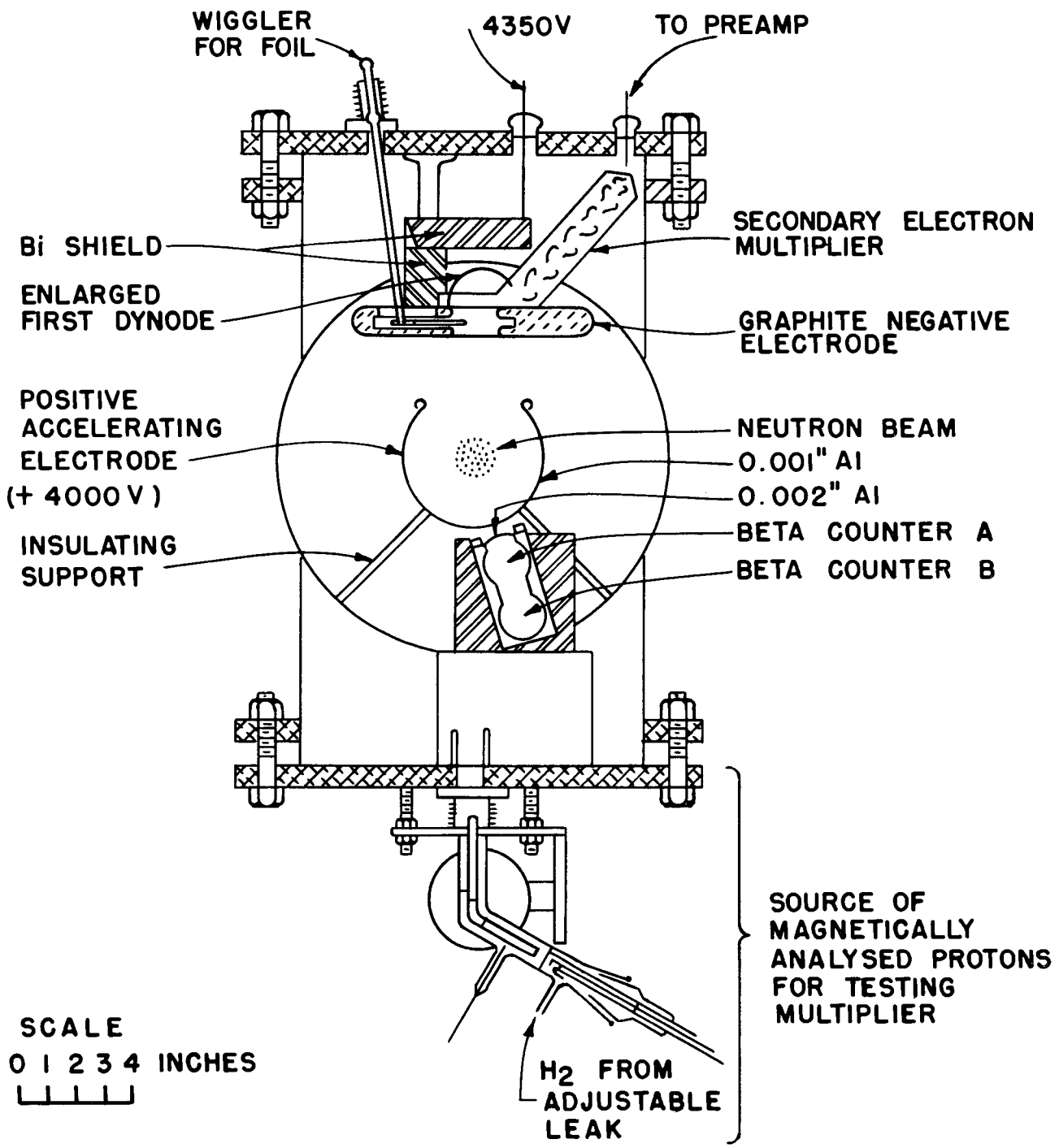

FIG. 14

Apparatus used for seeking beta-proton coincidences arising from neutron decay. The neutron beam is indicated in section at the center. A vertical electric field accelerates the protons upward and focuses them upon the secondary electron multiplier; the beta particles register in the double beta proportional counter below.

in the beam, and pulses in the multiplier caused by the focused product protons.

Because of stray radiation the single counting rates were high(~ 75,000 per minute in *A* and *B*, and 1500 per minute in the multiplier). With an effective resolution time of 1.3 μ-sec, the random coincidence rate was almost equal to the expected genuine rate. Genuine coincidences were nevertheless observed. They could be divided into two classes.

(1) Coincidences which appeared when no special delays were introduced in the circuits. These coincidences did not depend upon the presence of the electric field. They were probably caused by fast secondary electrons in the background radiation, which traversed the three detectors. They do not concern us further.

(2) Coincidences which appeared when 0.25 μ-sec delay was inserted in the *AB* counter channel. These coincidences depended upon the presence of the electric field across the beam. A field plot had shown that 0.25 μ-sec was approximately the minimum time required for a coiling proton to be collected upon the multiplier.

Table I gives some observations made with the 0.25 μ-sec delay in the *AB* channels. Random coincidence rates which have been subtracted were about 0.9 counts per minute throughout. A field-sensitive effect was present (column 5) which was the same under conditions 1, 4, 6 and 8, but which essentially vanished under conditions 2, 3, 5 and 7. Tests were also made with the reactor off, using a pure gamma source (Co^{60}) to actuate the detectors to approximately the same individual rates as prevailed when the reactor was on; no significant field-sensitive effects appeared either in the coincidences or in the single counting rate of the multiplier alone.

Taken together, these observations indicate the existence of coincident events involving on the one hand the appearance of positive particles with low energy and of roughly protonic mass, and on the other hand the discharge of counters by something which could penetrate 0.003 inches of aluminum but failed to penetrate 0.054 inches of aluminum. In addition, the events depended upon the presence of slow neutrons in a manner unconnected with their capture gamma rays, and they did not involve ionization processes in the residual gas.

The observations would be explained completely and with internal contradiction if neutrons in free flight transform spontaneously into protons with the emmission of beta particles having a maximum energy of less than about 0.9 Mev.

We are not yet in a position to give an accurate value for the half-life of the neutron because of difficulties in evaluating the collecting geometry, in which beta-proton directional correlations are involved. A half-life in the range 10-30 minutes would, however, be consistent with all of our observations.

E. F. Shrader, D. Saxon and L. C. Miller have collaborated actively in the experiment in the past. Appreciation is expressed to W. H. Jordan for generous help in the electronics.

TABLE I

	CONDITIONS	TRANSVERSE ELECTRIC FIELD	GENUINE COINCIDENCE RATE (cpm)	FIELD-SENSITIVE GENUINE COINCIDENCE RATE (cpm)	REMARKS
1	Normal	on off	0.74 ± .05 0.08 ± .04	0.66 ± .07	Conditions would allow neutron decay coincidences to appear.
2	Boron interrupting slow neutron beam	on off	0.13 ± .03 0.03 ± .03	0.10 ± .04	B^{10} shutter known to be about 10% transparent to slow neutrons.
3	Cadmium in beam, eliminating slow neutrons and substituting strong source of capture gammas	on off	0.18 ± .08 0.17 ± .10	0.01 ± .13	Pile power reduced until individual counting rates about equal to those in other tests (Factor 1/7).
4	3 sq ft Cd wrapped around vacuum tank	on off	0.73 ± .08 0.19 ± .07	0.54 ± .11	Neutrons again present in beam. Local captures increased many fold.
5	0.0002 in. Al foil covering multiplier aperture	on off	0.05 ± .04 0.05 ± .04	0.00 ± .06	Reassuring check; contributes little new.
6	H_2 gas in vacuum tank to 5 times base pressure	on off	0.73 ± .05 0.06 ± .04	0.67 ± .07	No more field-sensitive coincidences than in 1, 4 or 8.
7	0.051 in. Al over *AB* counter window	on off	0.11 ± .04 0.12 ± .03	-0.01 ± .05	Sufficient Al to stop betas of expected energy (0.8 Mev).
8	Repeat 1	on off	0.75 ± .04 0.08 ± .03	0.67 ± .05	

LOW TEMPERATURES

ALIGNMENT OF NUCLEI

S. Bernstein, L. D. Roberts, J. W. T. Dabbs

C. P. Stanford and J. B. Capehart

Due to the recent reconstruction work in the pile building, as mentioned in the last Quarterly Report, the equipment for adiabatic demagnetization was transferred from the pile face to the liquefier laboratory. The purpose of this transfer was to develop, in connection with the equipment, a way of obtaining a very small heat input to the demagnetized, very cold, chrom alum sample. The approach which was followed was to produce as high a vacuum as possible in the region containing the demagnetized salt. This was accomplished by the usual method of using a quite fast oil diffusion pump, and as large pumping lines as possible. In addition, considerable attention was given to the design and construction of the sample suspension to minimize the heat leak through the sample support. The effort was quite successful and the heat leak to the cold sample has been reduced to between 10 and 20 ergs per minute. This corresponds to a rate of temperature rise of .003°K per hour for the sample. Upon the completion of the above work, this equipment was turned over to Dr. J. G. Daunt for superconductivity experiments.

The reconstruction of the balconies at the south face of the pile is now essentially complete and we have installed sufficient equipment to begin work there, although some of this equipment is still of a temporary nature. The installation includes a 5 hp Kinney pump which backs a Distillation Products KV-150 ejector type diffusion pump. This diffusion pump is connected by a suitably large vacuum line to the Dewar flask containing the liquid helium. Calculation based on previous experience indicates that this equipment should give a temperature at least as low as 0.9°. The large, oil cooled, electromagnet has been reinstalled with a 200 kw oil-water heat exchanger in the cooling circuit. The magnet is connected at present to a 30 kw generator. As mentioned in the last Quarterly Report, however, a 300 kw mg set is being installed to supply increased power for the magnet, and this installation should be completed in the next quarter. The construction of especially designed Dewar flasks and associated equipment, which will be especially convenient in

adiabatic demagnetization and nuclear alignment work, is proceeding well.

Actual work with polarized neutrons was suspended during the period of balcony construction. During this period we have had designed and built a 1 kw magnet. This magnet gives 8600 gauss over a 2 inch pole gap. This field, plus the mechanical features of the magnet, should make it especially convenient for neutron polarization work. A second magnet of 5 kw power is about 50% complete. This magnet is designed to be used either for double transmission neutron polarization work, or for low temperature work. Equipment was designed and is being fabricated for procuring 100% polarized neutron beams by means of total reflection from magnetized cobalt. This equipment involves two ½ kw magnets and suitable optically flat reflecting cobalt surfaces.

The low temperature group has very much enjoyed having Dr. J. G. Daunt as one of its members during the past three months and wishes to record its appreciation of numerous discussions of possible nuclear alignment experiments and other problems of low temperature physics.

INVESTIGATION OF NUCLEAR EFFECTS IN PARAMAGNETIC SALTS

S. F. Malaker

Studies of the specific heat of copper sulfate at low temperatures[1] show two anomalies, one at a temperature near 1°K and another near .1°K. The anomaly at 1°K has been explained on the basis of electronic interaction, but that at .1°K is not explainable on this basis alone. Below 1°K there are three main types of interaction: (1) dipole-dipole coupling, (2) exchange, and (3) coupling between nuclei and electrons (below 0.5°K lattice specific heat is negligible). The first two are functions of the concentration of paramagnetic ions but the third is not. It should be possible to measure the specific heat as a function of concentration of paramagnetic ions, extrapolate to zero concentration and obtain a value for the nuclear specific heat.[2] Quantitative proof can be obtained from the hyperfine structure of the paramagnetic ion.

(1) H. A. Ashmead and A. H. Cooke.

(2) This type of experiment has been carried out recently for a number of salts by A. H. Cooke.

The first salts we plan to investigate are cobalt ammonium sulfate, cobalt rubidium sulfate, cobalt caesium sulfate, cobalt fluosilicate and cobalt potassium sulfate.[3] An a-c bridge will be used to measure susceptibilities. A mutual inductance astatically wound and having decade dials of 100, 10, 1, .1 and .01 turn has been designed and is being fabricated. A magnet is in the process of construction. Vacuum equipment has been completed. A new type of cryostat, permitting rapid change of samples, even during a run, has been designed and used, giving satisfactory results. Preliminary measurements will be made in a few weeks.

Appreciation is expressed to Dr. J. G. Daunt for his suggestion of this problem and for helpful discussions, and also to Dr. S. Bernstein and Dr. L. D. Roberts for discussions of the work.

EXPERIMENTS BELOW 1°K—MEASUREMENTS ON SOME SUPERCONDUCTORS

J. G. Daunt

Experiments have been carried out in the temperature region below 1°K on the following elements: (a) Yttrium, (b) Zirconium, (c) Gallium, (d) Cadmium and (e) Thorium. The results are briefly given below:

(a) Yttrium. The experiments were carried out on January 30, February 8 and February 14, using equipment previously set up for magnetic cooling work. Tests were made to note possible superconductivity of yttrium and these showed that our yttrium sample did *not* become superconductive at any temperature above 0.15°K. A specific heat anomaly, however, was observed to occur in the temperature range 0.15°K to 1°K. Owing to the impurity of the yttrium sample, however, it is considered that the results are not conclusive and render interpretation of the observed specific anomaly difficult. It is recommended that these experiments be continued in detail using purer yttrium.

(b) Zirconium. For the experiments on the zirconium and on the other elements subsequently reported herewith, a new cryostat was constructed of novel design which rendered the process of changing from one specimen under investigation to another only a matter of minutes. This new equipment would

(3) Using the method developed by Garrett.

enable specimens to be changed even during a "run", *i.e.*, during the time liquid helium temperatures are maintained.

The magnetic threshold values, H_c, for zirconium were observed and are given in Table I, below. The magnetic threshold values were observed using a technique previously employed and described in detail by Kurti and Simon[4] and by Daunt and Heer.[5] The results gave a superconducting transition temperature in zero magnetic field of 0.603°K, a value somewhat lower than that previously observed by Kurti and Simon (0.68°K). The slope of the threshold curve at the transition temperature was 375 gauss/degree, indicating that zirconium falls into the group of "hard" superconductors.

TABLE I

Zirconium

T°K	H_c (gauss)
.603	0
.513	34.5
.49	42.5
.415	67
.350	92
.310	111
.224	140

From the observed threshold values, the calculated specific heat of the "normal" electrons in zirconium is 22×10^{-4} T cals/mole/degree.

(c) Gallium. As with zirconium the threshold values were observed and are as given below in Table II.

The calculated specific heat of the "normal" electrons in gallium from these data is 0.84×10^{-4} T cal/mole/degree.

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(4) Kurti, N. and Simon, F., "Experiments at Very Low Temperatures Obtained by the Magnetic Method. II. New Supraconductors," *Roy. Soc. Proc.* A 151, 610 (1935).

(5) Daunt, J. G. and Heer, C. V., "Some Properties of Superconductors below 1°K. I. Titanium," *Phys. Rev.* 76, 715 (1949); "II. Aluminum and Zinc," p. 1324.

TABLE II

Gallium

$T°K$	H_c (gauss)
1.13	0
1.11	0
.84	23.8
.703	31.7
.642	36.1
.504	44.7
.392	49.4
.303	54.0
.163	58.2
.160	59.0

(d) Cadmium. The observed threshold values are given below in Table III. The results are in good agreement with those previously observed by Kurti and Simon.[6]

TABLE III

Cadmium

$T°K$	H_c (gauss)
.542	0
.440	7.6
.413	9.9
.412	9.6
.402	10.35
.279	20.5
.244	22.4
.243	22.6
.134	30.4

The calculated specific heat of the "normal" electrons in cadmium from these data is 0.77×10^{-4} T cal/mole/degree.

(e) Thorium. The sample of thorium became superconducting at 1.71°K, a value much higher than that previously observed by Shoenberg (1.39°K). The observed magnetic threshold was very high (> 350 gauss/degree), which together

(6) Kurti, N. and Simon, F., *op. cit.*

with the observed irreversibility of the magnetic transition indicates that the sample was physically very impure. It is recommended that a repeat of the observations be made after the thorium sample is well annealed. In view of the unsatisfactory results no data of magnetic thresholds are given.

Appreciation is expressed to the low temperature group, in particular to Dr. L. D. Roberts, Dr. S. Bernstein, Mr. Dabbs, Mr. Stanford and Mr. Stevenson for their help, particularly in setting up the original equipment used and also to Mr. Malaker, Mr. Erickson and Mr. Capehart for their assistance during experiments.

Recommendations for Future Work. It is recommended that this work be carried through to a satisfactory conclusion. In particular it is recommended that experiments of the same kind as those reported above be made (1) on yttrium metal of higher purity than used to date, (2) on thorium, after complete annealing of the specimen, (3) on pure hafnium metal, and, if available, scandium metal, since no magnetic measurements have yet been made on these elements.

Finally it is recommended that experiments of the same kind, *i.e.*, magnetic observations on the superconducting state, be made in order to survey the effects of radiation damage to those metals which show superconductivity, since such metals are numerous. From previous work, and from the work reported above on thorium, it is known that cold working of metals has a profound influence on the magnetic properties in the superconducting state and moreover observation of such properties provides what is possibly the most sensitive measure of metallic dislocations and cold working. It is suggested therefore that this method would also provide a sensitive measure of radiation damage, and it is believed that investigations of these effects may prove of value.

IRRADIATION OF SEMICONDUCTORS

FAST NEUTRON BOMBARDMENT EFFECTS IN GERMANIUM

J. H. Crawford, Jr. and K. Lark-Horovitz

The total effect of neutron bombardment on the electrical properties of germanium[1,2] in a nuclear reactor includes both the contribution of impurities produced by transmutation induced by thermal neutron capture[3] and that due to lattice damage caused by high energy neutrons. The contribution of transmutation-introduced impurities is in general negligibly small compared to the effect of damage and may be neglected in the first approximation in calculations of the effect of fast neutrons on carrier concentration in Ge.

The initial change in conductivity during neutron bombardment of N-type Ge is

$$\frac{d\sigma}{d(nvt)_{fast}} = e\,\mu_e \frac{dn_e}{d(nvt)_{fast}} + e\,n_e \frac{d\,\mu_e}{d(nvt)_{fast}}, \qquad (1)$$

where e is the electronic charge, n_e is the electron concentration, μ_e is the electronic mobility and $(nvt)_{fast}$ is the integrated fast neutron flux. If we assume that the lattice defects scatter carriers as effectively as ionized impurities, though possibly through a different mechanism, the contribution of the added scattering centers will be a negligible portion of the mobility until their concentration becomes comparable to the original impurity concentration. Although a finite rate of annealing of neutron produced damage has been observed at room temperature, this is not expected to enter into Eq. (1) since only the initial linear portion of the conductivity vs. bombardment curve was used. This assumption is borne out by the fact that the number of acceptor states produced per incident neutron is the same for bombardment at both dry ice and room temperature.

(1) Davis, R. E., Johnson, W. E., Lark-Horovitz, K., and Siegel, S., "Neutron-Bombarded Germanium Semiconductors," *Phys. Rev.* 74, 1255, Paper A3 (1948).

(2) Johnson, W. E. and Lark-Horovitz, K., "Neutron Irradiated Semiconductors," *Phys. Rev.* 76, 442 (1949).

(3) Cleland, J. W., Lark-Horovitz, K., and Pigg, J. C., "Transmutation-Produced Germanium Semiconductors," p. 56, this report.

Using these assumptions Eq. (1) becomes

$$\frac{d\sigma}{d(nvt)_{fast}} = e\,\mu_e \frac{dn_e}{d(nvt)_{fast}} \quad . \tag{2}$$

If it is assumed that every acceptor state produced lies below the impurity level, initially virtually every acceptor level introduced removes one electron from the conduction band. Thus initially,

$$\frac{d\sigma}{d(nvt)_{fast}} = -\,e\,\mu_e\,K \quad , \tag{3}$$

where K is the average net number of acceptors produced per incident neutron. It should be pointed out that K is a weighted average and will depend markedly on the energy spectrum of the neutron flux in the high energy range. The value of K then may be evaluated from the initial slope of the conductivity vs. bombardment curve if the initial mobility is known.

The conductivity minimum was examined in order to ascertain the magnitude of any photo-electric effects due to the high intensity of β and γ radiations present in the pile. The condition of thermal equilibrium between electrons and holes in the temperature range where classical statistics are valid may be represented by the equation,

$$n_e\,n_h = A\,T^3\,e^{\Delta\epsilon g/kT} = K\,(T) \quad , \tag{4}$$

where for Ge,[4] $A = 5.3 \times 10^{32}$ and $\Delta\epsilon g = .75$ ev. The complete equation for the conductivity must contain both the contribution of electrons and holes:

$$\sigma = e\,n_e\,\mu_e + e\,n_h\,\mu_h \quad . \tag{5}$$

The ratio of electron to hole mobility c is independent of bombardment until the scattering due to lattice damage contributes appreciably to the mobility.

(4) Johnson, V. A., *Progress Report*, Contract No. W-36-C39-32020 (Signal Corps), February to April, 1948.

Thus using Eq. (4),

$$\sigma = e\ \mu_h \left[n_e c + \frac{K\ (T)}{n_e} \right] . \tag{6}$$

The electron concentration for minimum conductivity is then

$$n_e = \left[\frac{K\ (T)}{c} \right]^{1/2} , \tag{7}$$

and the minimum conductivity is

$$\sigma_{min} = 2\ e\ c\ \mu_e\ (K\ c)^{1/2}. \tag{8}$$

From this relation and the experimental value of σ_{min} the electron mobility can be calculated. This should be a sensitive check on the magnitude of any β and γ radiation induced photo-electric effects since these would cause the calculated value of μ_e to be apparently larger than the expected value which should be slightly smaller than the original value of the mobility because additional scattering centers are introduced during bombardment.

The data which were examined were taken over a two year period by several investigators, mainly by J. W. Cleland, J. H. Crawford, Jr., W. E. Johnson, K. Lark-Horovitz and J. C. Pigg. Not all the data utilized were ideally suited to the present analysis. However, it is believed that the results are consistent within the experimental error which was necessarily quite large (~ 50%) due to the limiting accuracy of the various measurements involved.

Figure 15 shows the form of the conductivity vs. bombardment curve for ambient temperature. The curves taken at dry ice temperature are quite similar. The initial portion is linear for a sufficient number of points to make a slope determination accurate. Table I summarizes the results of the analysis.

The mean value of K is 3.1 acceptors per incident neutron. This is in good agreement with the theoretical value for the number of displaced atoms in

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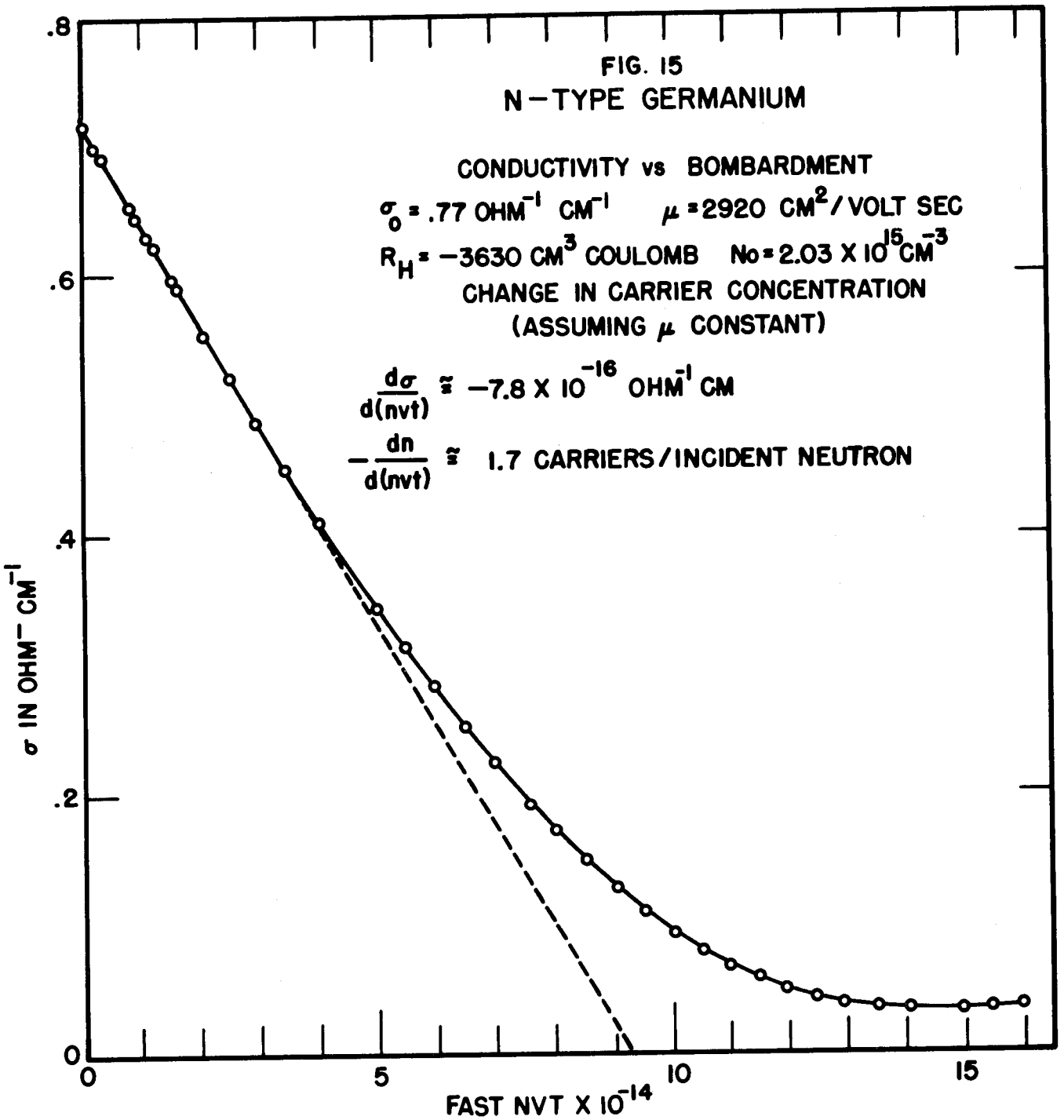

TABLE I

SAMPLE	TEMPERATURE OF EXPOSURE (°C)	INITIAL NUMBER OF CARRIERS (cm^{-3})	INITIAL MOBILITY (cm^2/volt sec)	MOBILITY AT MINIMUM (cm^2/volt sec)	NUMBER OF ACCEPTORS PER INCIDENT NEUTRON (cm^{-3})
17L3	~ 32	2.0×10^5	2,920	2,200	1.7
42V4	30	4.3×10^{14}	2,010	2,020	1.5
44C3	20	8.9×10^{14}	2,600	2,190	3.5
16N3	~ 32	2.8×10^{16}	2,180	1,440	2.6
16N4	~ 32	5.5×10^{16}	800	13,700	5.2
15A2	-79	--	10,000	--	4.3
15A3	-79	--	6,070	--	3.1
44R3	-79	--	4,530	--	3.2

Ge obtained by G. E. Evans[5] on the basis of radiation damage theory. He obtains about 135 atomic displacements per scattered neutron for the energy spectrum used in these bombardments which, if one assumes a scattering cross section of about one barn, gives six displacements per incident neutron.

The slope of the bombardment curve after conversion to *P*-type, *i.e.*, after the minimum is reached, is much smaller than the initial slope of the original *N*-type material, the ratio of the slope after conversion to the intial value being less than 0.1. Two of the possible factors causing this difference in slope are: (a) after a certain concentration is reached recombination of lattice defects becomes appreciable, and (b) only those acceptors which can be thermally ionized are effective in increasing the hole concentration. One set of bombardment data for initially *P*-type material which was available for analysis gives 0.77 for the number of conducting holes produced per incident neutron. This is smaller than the mean value of K given above by a factor of four. Consequently, one might suspect both of these factors to be important.

In every case but one the calculated mobilities bear out the assumed thermal equilibrium between electrons and holes reasonably well. The exception, sample 16N4, has an abnormally low initial mobility which indicates an inhomogeneous distribution of impurity centers. If the impurity gradient were perpendicular to the direction of current one would never observe the correct minimum conductivity since this is analogous to a system of parallel resistors in which the highest resistance of any element never exceeds that corresponding to the minimum conductivity. Also the presence of a *P-N* barrier (the gradient parallel to current) would cause a conductivity minimum much higher than the expected value since K. Lark-Horovitz[6] and co-workers have shown that such a boundary is photosensitive to high energy radiations. In either case the calculated value of the mobility at the minimum conductivity would be spurious and high. Thus one is led to the conclusion that photo-electric effects due β and γ radiation are in general negligible in uniform samples.

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(5) Evans, G. E., ORNL 576, p. 15 (Feb. 7, 1950).

(6) Orman, C., Fan, H. Y., Goldsmith, G. J., and Lark-Horovitz, K., "Germanium *P-N* Barriers as Counters," *Am. Phys. Soc. Bull.* 25, 15, Abst. I8 (1950).

TRANSMUTATION-PRODUCED GERMANIUM SEMICONDUCTORS

J. W. Cleland, K. Lark-Horovitz and J. C. Pigg

Germanium exposed in a nuclear reactor becomes a *P*-type semiconductor ("hole" or defect conduction).[7] It has been shown that this change is due to (a) lattice displacements produced by fast neutrons, and (b) impurity centers produced by the transmutations due to slow neutrons. That this latter effect must exist became apparent when heat treatment at 450°C failed to restore the original conductivity in samples which were exposed for a long period ($nvt < 10^{18}$). The cross sections for activation given in the literature[8] lead to an *N*-type semiconductor and therefore K. Lark-Horovitz suggested a redetermination of capture cross section on separated germanium isotopes. Such a determination was carried out by H. L. Pomerance[9] as in shown in Table I.

The capture cross sections obtained by Pomerance predict an excess of *P*-type impurities (Ga) over *N*-type impurities (As).

$$N_e = nvt \times \sigma_e \times N_{Ge} \times P_i \quad , \tag{1}$$

where N_e is the number of events observed, nvt is the integrated neutron flux, σ_e is the cross section for the event, N_{Ge} is the number of atoms per cc in the material and P_i is the isotopic percentage of the atomic species. Therefore

$$N_{Ga} - N_{As} = nvt \times 4.4 \times 10^{22} \ (3.25 \times 21.2 - 0.6 \times 37.6)10^{-26}$$

$$= 2.05 \times 10^{-2} \ nvt. \tag{2}$$

The impurity centers are formed at the lattice sites themselves. The semiconductor thus obtained, if one starts with "pure" single crystals of germanium, is therefore a substitutional alloy.

(7) Lark-Horovitz, K., "Conductivity in Semiconductors," *Elec. Eng.* 68, 1047 (Dec., 1949).

(8) Seren, L., Friedlander, H. N., Turkel, S. H., "Thermal Neutron Activation Cross Sections," *Phys. Rev.* 72, 888 (1947).

(9) Pomerance, H., "Capture Cross Section of the Elements as Determined with Pile Oscillator," *Physics Quarterly Progress Report for Perid Ending December 15, 1949*, ORNL 577, p. 25 (Feb. 8, 1950).

TABLE I

Absolute Cross Section of Separated Germanium Isotopes

After L. Seren, Argonne

ISOTOPE	ABUNDANCE	CAPTURE CROSS SECTION (in barns)		END PRODUCT
		ISOTOPIC	ATOMIC	
Ge^{70}	21.2	0.073	0.0155	Ga
Ge^{70}	21.2	0.45	0.095	Ga
Ge^{74}	37.1	0.38	0.14	As
Ge^{76}	6.5	0.085	0.0055	Se

After H. L. Pomerance, ORNL

ISOTOPE	ABUNDANCE	CAPTURE CROSS SECTION (in barns)		END PRODUCT
		ISOTOPIC	ATOMIC	
Ge^{70}	21.2	3.25	0.69	Ga
Ge^{72}	27.3	0.94	0.26	Ge
Ge^{73}	7.9	13.69	1.08	Ge
Ge^{74}	37.6	0.60	0.22	As
Ge^{76}	6.1	0.35	0.02	Se

Germanium samples with known type and number of impurity centers (as determined by the Hall effect and the dissociation equation)[10] are exposed for various lengths of time in the reactor, in a region of determined flux. After exposure, Hall effect and resistivity are determined giving *P*-type centers due to (a) displacements, (b) transmutations. The sample is then heat treated for various lengths of time at 450°C until further heat treatment does not produce any more changes. Provided the rate of cooling from 450°C does not freeze in any lattice defects and that all displacements produced by knock-on collisons are completely annealed out at this low temperature, the resulting conductivity is now due to the originally introduced chemical impurities and the newly produced impurities from transmutations.

Fig. 16. Hall Coefficient vs. Temperature

Fig. 17. Resistivity vs. Temperature

The Hall curve obtained in a sample containing lattice defects cannot be interpreted by an ordinary dissociation equation, since it shows a curvature which is usually not observed in chemically prepared samples. Quantitatively, Table II shows good agreement between the final number of carriers calculated and determined experimentally within the limits of experimental error (20% for flux measurements, 20% for cross sections, and heat treatment).

Activation cross sections for deuterons measured by E. Bleuler and D. Tendam at Purdue lead to the conclusion that deuteron bombardment should lead to *N*-type germanium. Similarly α-activation should also lead to *N*-type germanium. Activation by fast neutrons (Cd shielded samples) should lead to a larger preponderance of *P*-type centers (Ga) but with a much smaller cross section than slow neutron activation. Preliminary experiments are in agreement with this expectation.

We find, therefore, (a) that there is a balance between donators and acceptors, and that the Hall effect and conductivity are determined by the excess type present, (b) that there is one current carrier released per impurity center produced, (c) agreement between the activation energies of impurity centers produced chemically and by transmutations, indicating that chemical doping is a substitution process.

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(10) Johnson, V. A. and Lark-Horovitz, K., *Final Report*, NDRC, Purdue (1945).

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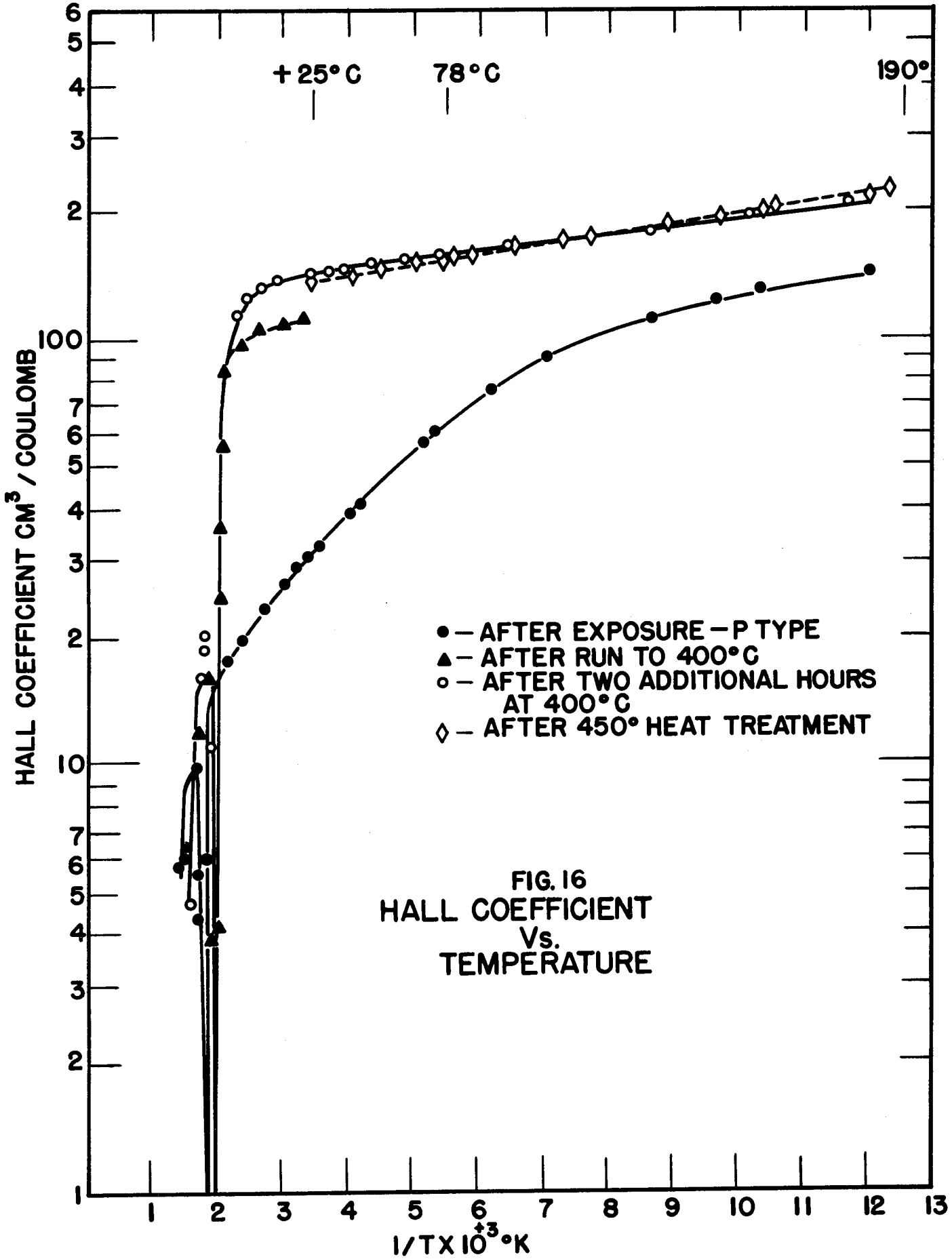

FIG. 16
HALL COEFFICIENT
Vs.
TEMPERATURE

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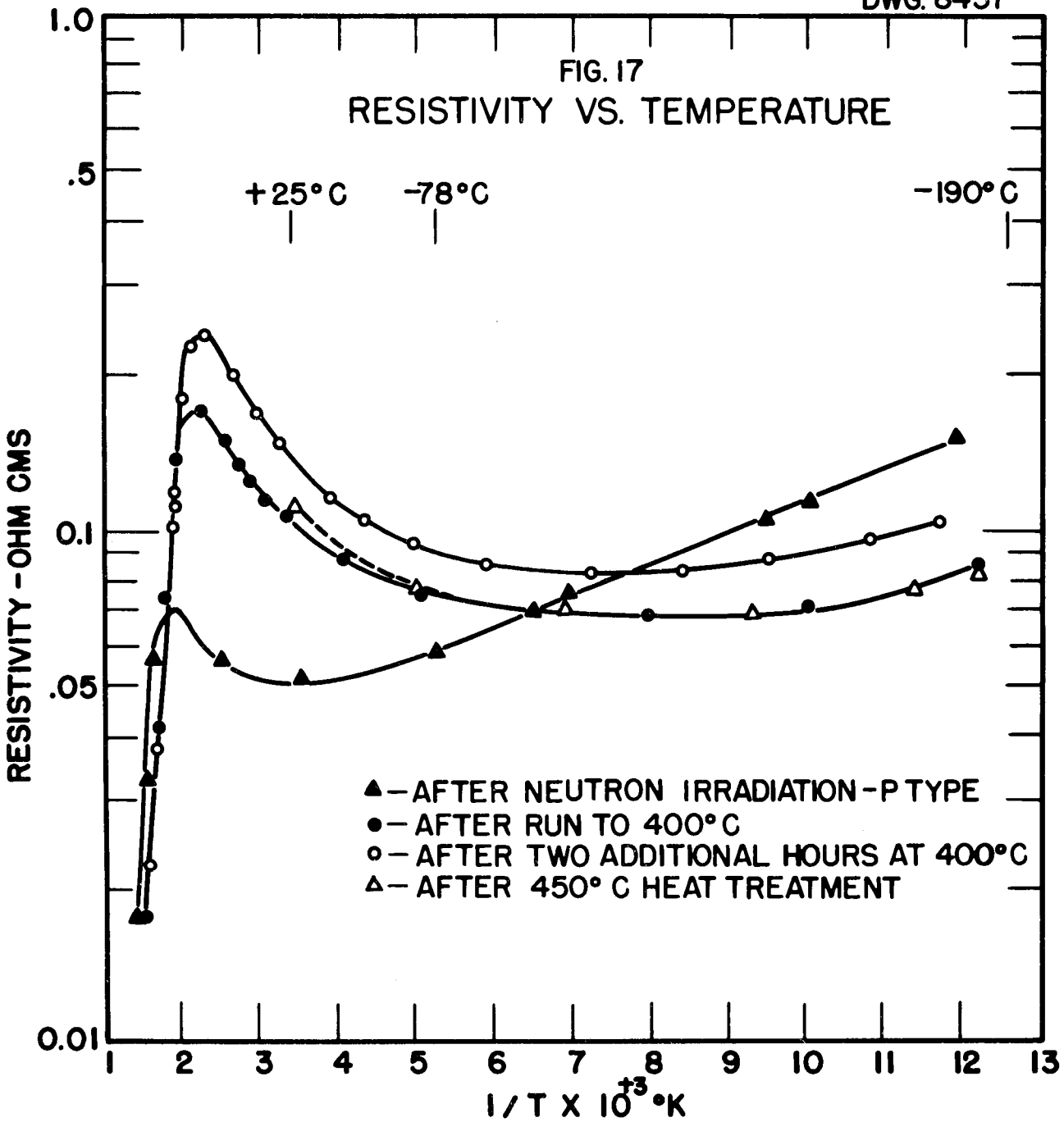

TABLE II

Density of Impurity Atoms in Germanium

SAMPLE NUMBER	ORIGINAL NUMBER OF CARRIERS/cm^3 n_o	TOTAL FLUX (nvt)	FINAL NUMBER OF CARRIERS/cm^3 n_f		PERCENT DIFFERENCE
			CALCULATED FROM CROSS SECTIONS	MEASURED BY HALL EFFECT	
1 - N-type	-5.25×10^{14}	4.56×10^{17}	$+8.82 \times 10^{15}$	$+6.16 \times 10^{15}$	-27%
2 - N-type	-2.28×10^{16}	2.54×10^{18}	$+2.92 \times 10^{16}$	$+3.21 \times 10^{16}$	+ 9%
3 - N-type	-5.47×10^{16}	4.37×10^{18}	$+3.48 \times 10^{16}$	$+5.25 \times 10^{16}$	+33%
4 - N-type	-1.17×10^{16}	2.54×10^{18}	$+4.03 \times 10^{16}$	$+5.20 \times 10^{16}$	+22%
5 - N-type	-1.48×10^{14}	2.54×10^{18}	$+5.05 \times 10^{16}$	$+4.45 \times 10^{16}$	-13%
6 - P-type	$+5.02 \times 10^{14}$	2.54×10^{18}	$+5.15 \times 10^{16}$	$+4.95 \times 10^{16}$	- 4%
7 - P-type	$+4.60 \times 10^{14}$	8.04×10^{17}	$+6.25 \times 10^{16}$	$+5.22 \times 10^{16}$	-20%
8 - N-type	-4.04×10^{14}	1.06×10^{19}	$+2.15 \times 10^{17}$	$+1.90 \times 10^{16}$	-13%

PREPARATION OF INTRINSIC SEMI-CONDUCTORS

J. W. Cleland, J. H. Crawford, K. Lark-Horovitz, J. C. Pigg

Some time ago it was pointed out that irradiation of germanium with neutrons produces an increase in resistivity due to removal of electrons to acceptor levels and a decrease again after a certain maximum resistance is reached when holes are conducting the current. One would expect that in this case the maximum resistance corresponds to intrinsic resistivity, and as a matter of fact, it should even be larger because of the scattering of the intrinsic electrons and holes by the ionized donators and acceptors.

Experiments, therefore, have been carried out now using single crystals of germanium, apparently homogeneous as to impurity content measured at room temperature, exposing them until they reached maximum resistance and then pulling them out of the pile and measuring first the resistance as a function of time and then the resistance and Hall coefficient as a function of temperature.

If the intrinsic resistivity is reached, then it is obvious that the slope of the log $RT^{-3/2}$ vs. $1/T$ curve should give the activation energy for intrinsic electron excitation across the forbidden band.

Since a finite rate of healing of radiation-produced lattice defects has been observed at room temperature, the first experiments were carried out at dry ice temperature to minimize any healing of lattice damage during the long period required for the decay of activity. Figure 18 shows the plot of the log of the Hall coefficient vs. the reciprocal of the absolute temperature after bombardment to the resistance maximum. It is obvious that the intrinsic slope (slope at high temperature) is not maintained during the whole temperature range. However, the low temperature slope indicates a much higher activation energy for the production of current carriers than is usually observed in chemically doped samples.

By heat treatment it was possible to remove all traces of this irradiation completely, and a second experiment has been carried out, up to the present observing only the changes in current at dry ice temperature as a function of time. Certain effects of decay of current, as have been observed in the case of deuteron bombarded samples, have been found. Also production of an emf was observed which can only occur if there is a barrier, so that one comes

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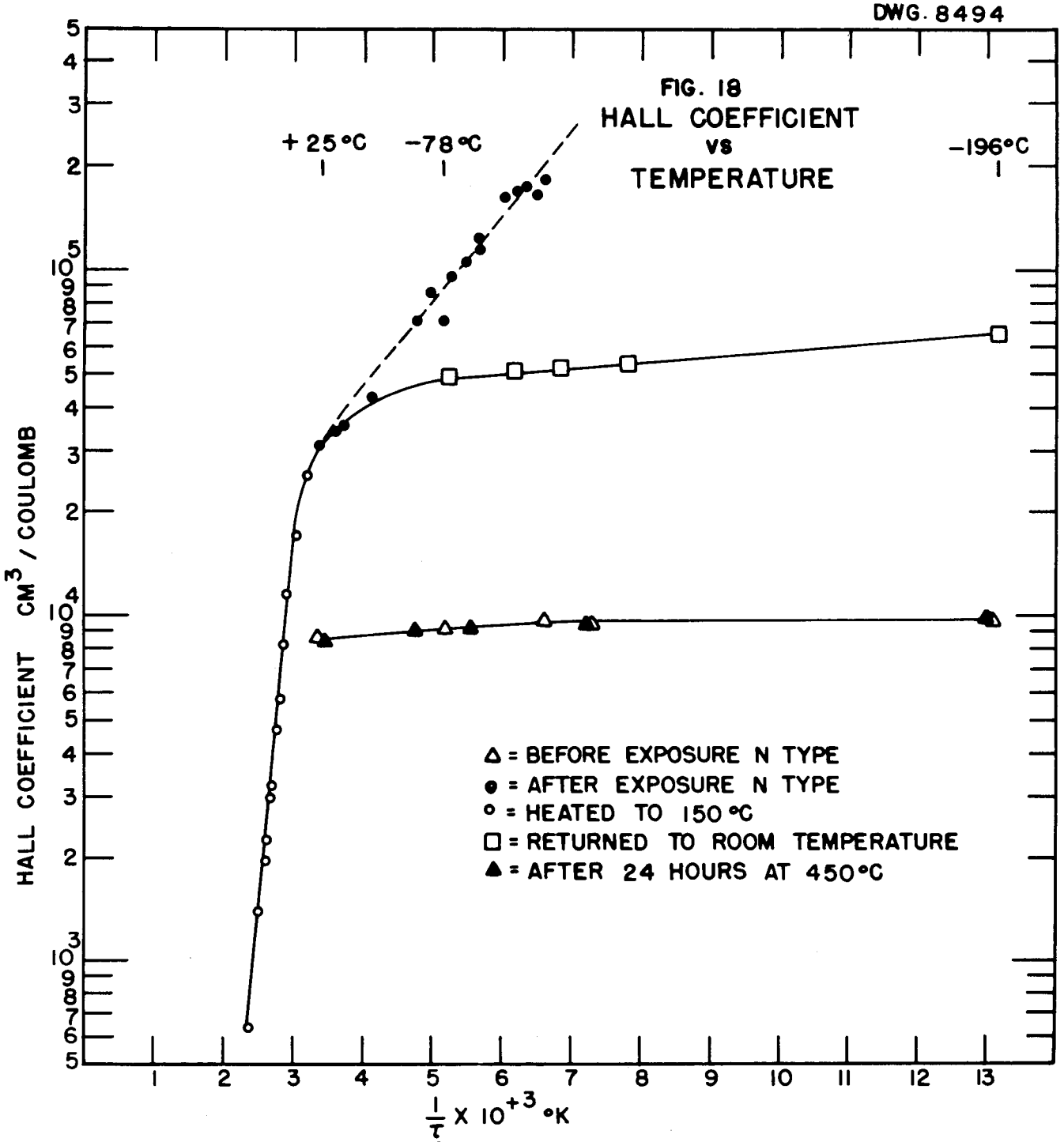

to the conclusion that this sample, even if it is a single crystal and apparently homogeneous at room temperature, has a concentration gradient and therefore such inhomogeneties, that a barrier is developed.

In the case of a resistance inhomogeneity due to a concentration gradient, one would expect either an *N-N* barrier or a *P-N* barrier to develop, and as a consequence the bulk resistivity seems to be increased. Since it has been shown recently at Purdue that a *P-N* barrier can act as a counter both for beta and gamma rays, ionization of the barrier in the pile will produce very low resistivity, and as a consequence one is dealing with a material which is bounded on both sides by low resistance *P* and *N*, and due to the breakdown of the *P-N* barrier, this also offers a comparative small resistance. As a consequence, it is not possible in such a case to reach intrinsic value. The experiments are now being continued with material which has been tested at low temperature for homogeneity so as to eliminate the possibility of a hidden concentration gradient, and in this way we hope that intrinsic material can be prepared.

RECTIFIER EXPERIMENTS

J. H. Crawford, K. Lark-Horovitz, and J. C. Pigg

It was pointed out some time ago by Lark-Horovitz that the irradiation of rectifiers should give different results depending on the bias on which these rectifiers are observed. In the back direction the resistance of the rectifier is primarily barrier resistance, and it is also barrier resistance in a forward bias range up to about .2 of a volt. This was established some time ago by exposing several 1N38 germanium rectifiers and observing the characteristic of each one as a function of irradiation time at a fixed voltage. Even with the now available commercial uniformity of such rectifiers, one cannot be certain about the uniformity of the material used. New experiments have now been carried out using a vibrating reed electrometer as a measuring device. Both wax filled Sylvania 1N38 and vaccuum sealed Raytheon CK-708 rectifiers have been studied. These have been exposed in a section of the reactor where the flux is so small that changes for every single bias in one and the same rectifier can be observed in a time short as compared to the time necessary to produce some changes in the bulk material.

A series of such measurements has been carried out, and in this way it is possible to show that with biases up to .1 volt in the forward direction the resistance decreases with bombardment, whereas at voltage above .25 volt first a decrease and then an increase is observed as function of irradiation.

The results of a typical run on a CK-708 rectifier and a 1N38 rectifier are shown in Figs. 19 and 20 respectively. Both rectifiers behave quite similarly when irradiated except that the CK-708 (vacuum sealed) becomes ohmic much sooner than the 1N38 (wax filled) after the minimum conductance has been reached.

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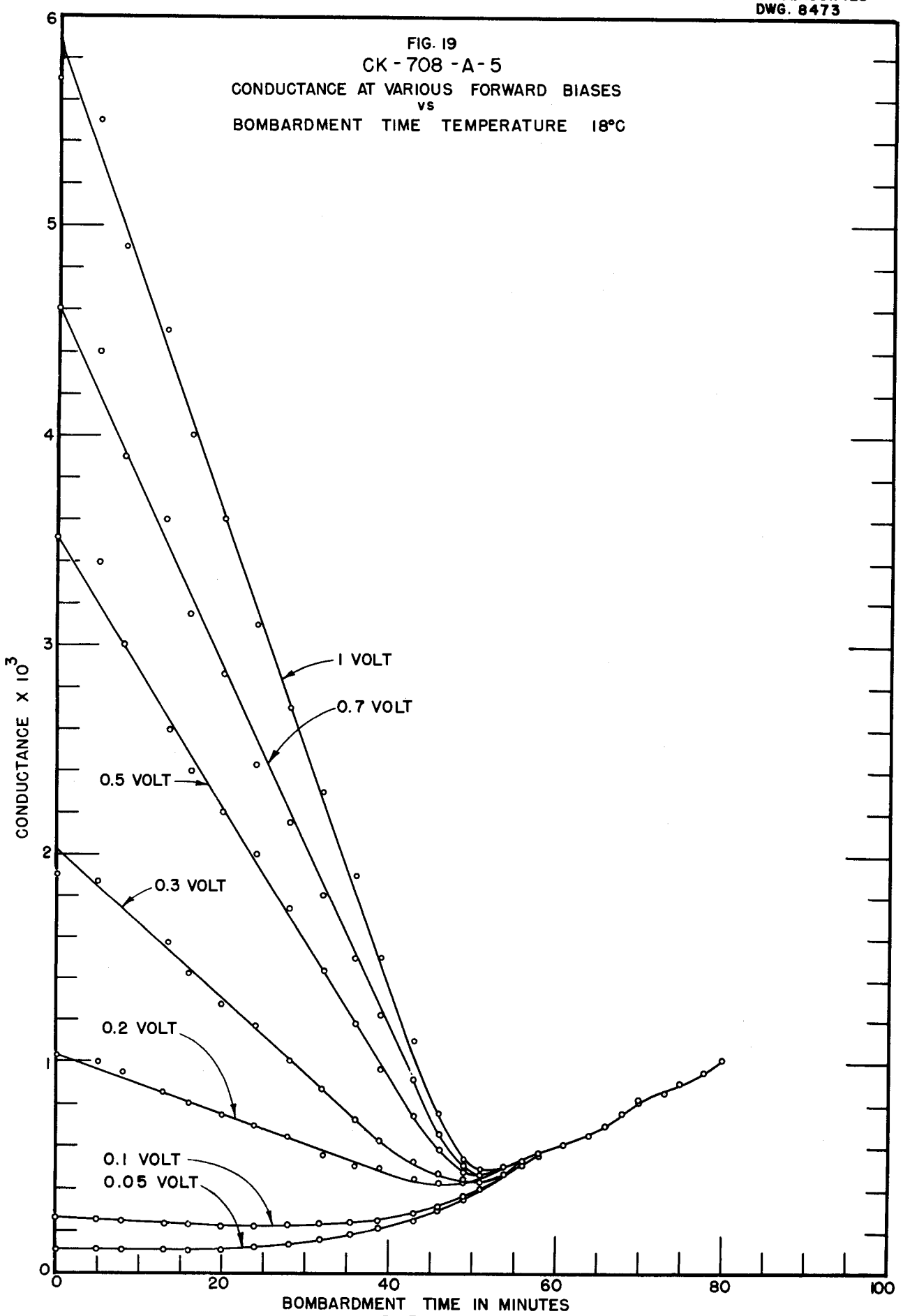

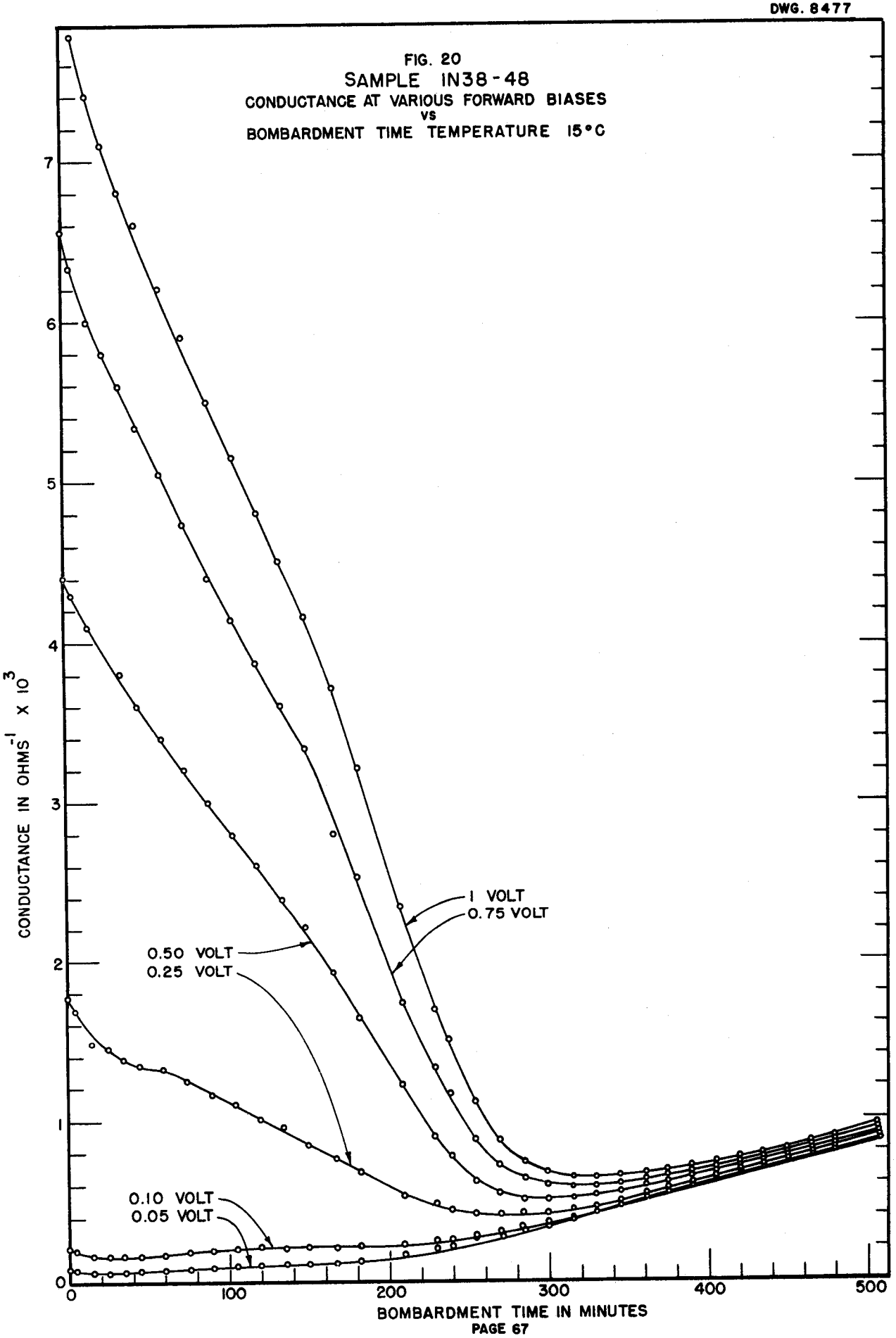
FIG. 20
SAMPLE IN38-48
CONDUCTANCE AT VARIOUS FORWARD BIASES
VS
BOMBARDMENT TIME TEMPERATURE 15°C
CONDUCTANCE IN OHMS^{-1} X 10^{3}
BOMBARDMENT TIME IN MINUTES
0
1
2
3
4
5
6
7
0
100
200
300
400
500
1 VOLT
0.75 VOLT
0.50 VOLT
0.25 VOLT
0.10 VOLT
0.05 VOLT

RADIATION DAMAGE

NEW PHYSICS OF SOLIDS "HOT" LABORATORY

S. E. Dismuke, D. S. Billington*

Building. Construction of the building for the new Physics of Solids "Hot" Laboratory has begun with completion state of October 1, 1950.

The original plan for the building has been modified and expanded with NEPA participation. The original design of three hot cells, five laboratories and seven offices has been expanded to three hot cells, plus space for two more, 11 laboratories including a so-called toxic laboratory, and 12 offices.

The space for the two additional hot cells will be built up to the main floor level by the J. A. Jones Company. ORNL will design and build these cells in such a way that use will be made of the Argonne master slave manipulator.

Remote Control Equipment. The spot lights, chip removal apparatus, transfer through barrier, profile recorder, electrical resistivity, analytical balance, electromagnet and the manipulator are in the shops in various stages of completion.

The engineering design of the apparatus for measuring dimensions, of the wall transfer unit, lead carrier, and impact tester has been completed.

The engineering design of the milling machine, lathe, and Tukon tester has not been completely finished.

CRYOSTAT FOR PILE IRRADIATIONS

R. P. Metcalf

Testing of the cryostat has been delayed by the discovery and repair of a leak in the refrigerating apparatus, supplied last November by the Arthur D.

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* Metallurgy Division.

Little Company and by the necessity for dismantling the equipment during alterations to the 105 building. Reassembling of the apparatus is now nearly complete.

ELECTRON BOMBARDMENT OF Be-Cu

G. E. Evans and B. Robertson*

A target holder has been designed and constructed which permits water cooling of one surface of a metallic foil while the other surface is bombarded with electrons from the ORNL Van de Graaf accelerator. The sample accommodated is a 1½ in. circular foil. Thermocouple connections have been included for monitoring the temperature of the sample. The target holder is attached to the exit flange of the Van de Graaf by insulating bolts to permit measurement of target current. The space between the foil target and the accelerator can be evacuated to minimize any possible surface oxidation effects.

A device for measuring electrical resistance of thin metallic strips has also been designed and constructed. The thin strip sample approximately 1½ in. long × 1/8 in. wide is sandwiched between lucite blocks. At the extreme ends of the lower lucite block are recessed silver bars acting as current leads to the sample. Six spring-loaded silver point contacts in the upper lucite block serve as potential probes along the length of the sample. In a preliminary experiment using non-irradiated Be-Cu foil four mils thick and of various widths, the observed resistance values agreed within 0.5%.

A study of the cooling provided by the target assembly has shown that the temperature of the irradiated portion of the foil rises rapidly with target current despite the use of maximum water flow rate available from the laboratory supply. At 80 μah one 10 mil foil was drawn out into a cup nearly a centimeter deep by water pressure and vacuum. A ten mil foil reaches an equilibrium temperature of 100°C with a 32 μah electron beam, and for all further experiments the target current has been kept at 20 μah or less.

A sample of Be-Cu four mil foil, annealed at 800°C in a cracked gas atmosphere and quenched, was irradiated with 1.4 Mev electrons for a total exposure of 52 μah at a target current of 10-20 μa. The resistance of the sample

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*Nepa

increased by 3.35%; the scatter of individual resistance readings being less than 0.5%.

It is not possible at this time to state whether this resistance increase is a "radiation damage" effect or is caused by surface effects—corrosion, oxidation, etc. In the experiments now under way all three dimensions of each sample are being accurately measured by the NEPA shops and crystallographic section before and after irradiation to permit calculations of absolute resistivity rather than resistance. X-ray and metallographic examination showed no trace of precipitation. Two additional samples have been irradiated and are now being examined. One which was irradiated at 80 μa overheated and shows X-ray diffraction evidence of precipitation. The resistance values of this sample in the region of irradiation are quite erratic, indicating possible competition between effects of radiation and temperature.

There appears to be no major weight change in the samples due to corrosion by the cooling water during irradiation; one sample showed a weight loss of 2 mg in 5 gms (0.04%).

X-RAY DIFFRACTION

M. A. Bredig, B. S. Borie,* F. A. Sherrill, R. M. Steele

X-Ray Diffraction Spectrometer for Highly Radioactive Specimens (M. A. Bredig, B. S. Borie*). The design of this apparatus is being worked out in cooperation with the Instrument Department. The use of a special, pulsed, X-ray tube, of a monochromator crystal, and of a proportional counter detector with discriminator circuit has been decided on. Tests are being conducted on the advisability of the use of Sollar slit collimation in preference to focussing. Advantages of simplicity in both mechanical and X-ray tube design are envisaged.

Low-Temperature X-ray Diffraction (F. A. Sherrill). With a view toward studying crystal structure at low temperature, and in immediate connection with the work on anti-ferromagnetism of the neutron diffraction group, an apparatus has been built for the observation of X-ray diffraction by a specimen held within a few degrees of minus 195°C.

A stainless steel tube 2 in. in diameter, 1/32 in. wall thickness and approximately 12 in. in length is inserted coaxially within a 4 in. diameter brass tubing, 1/8 in. thick and approximately 18 in. in length. The brass tubing may be evacuated and liquid nitrogen filled into the stainless steel tube. The latter is attached to the brass by a still thicker stainless steel neck at the top. At the bottom of the stainless steel tubing a copper block is welded into the steel tube. Specimen holders of various shapes may be attached to the copper block. Since they are not in contact with any other parts, any possible heat gain will be by radiation only.

The apparatus has a suitable base so that it may be mounted onto the standard Norelco Geiger Counter Spectrometer. Beryllium windows 1 in. high have been soft soldered into the brass tubing in such a way that Bragg angles 0-45° may be observed.

A slight change in this base makes this apparatus adaptable to the Norelco Diffraction Unit, and in this way the higher Bragg angles may be observed.

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*Metallurgy Division

This last arrangement was required, e.g., to observe, with cobalt K_α radiation, on photographic film, the splitting of the 420 (Miller Indices) line of nickel oxide, NiO, which H. P. Rooksby (*Acta Crystallographica*, 1948) has found to invert at temperatures below 275°C from a cubic to a pseudocubic, rhombohedral structure. This technique will be applied next to an analogous investigation of MnO and MnS, as suggested by C. G. Shull.

Growing Single Crystals of Iron-Silicon Alloy (F. A. Sherrill). The alloy intended for use by the neutron diffraction group, was melted in a zirconia crucible at 1470°C, as recorded by an optical pyrometer, in a molybdenum-wound resistance vacuum furnace. The alloy contained only enough silicon to suppress the formation of the face-centered cubic phase and thus allow growing single crystals of iron by the Bridgeman method. The ingot thus obtained is now under examination.

THEORETICAL PHYSICS

M. E. Rose

A project for computing the Fermi function in β-decay has been instituted in cooperation with the computing panel. The Fermi function will be tabulated for every atomic number and for a wide range of energy values with a rather fine spacing to within an accuracy of 0.1 per cent. Although this is considerably better than the present needs in view of experimental accuracy now attainable, it was the concensus of all concerned that this tabulation should be carried out with the above-mentioned accuracy. In view of this fact, it was decided to include two additional sets of tables:

(1) The effect of screening,[1]

(2) The effect of finite nuclear size.

The latter effect had been investigated several months ago by the writer and had been referred to in a previous quarterly report. A more careful investigation has now been undertaken with the collaboration of D. K. Holmes. While complete numerical results are yet to be obtained, our present conclusion is in accord with the previous one that for β-decay the nuclear size effect is small but worth including in view of the 0.1 percent accuracy referred to above. Present indications are that much larger effects may be obtained for forbidden transitions when the spin change is equal to the order of forbiddenness.

The effect of nuclear size on K-capture has also been studied and pending receipt of results from the computers one can say the following: it appears from preliminary results that the effect on the branching ratio K-capture to position emission may be significant from the point of view of presently attainable experimental accuracy.

In the course of this work several interesting results on wave function methodology were obtained. These involve the following:

(a) An iterative method whereby the Dirac central field problem can be solved for any scalar field.

(1) Rose, M. E., "A Note on the Possible Effect of Screening in the Theory of Beta-Disintegration," *Phys. Rev.* 49, 727 (1936).

(b) A method of obtaining normalization integrals with a very small fraction of the labor acquired by straightforward substitution methods. This method will give results for the case of finite nuclear size in a very simple way where the usual methods would fail entirely.

HIGH VOLTAGE PROGRAM

W. M. Good, C. D. Moak, B. D. Kern, R. Lamphere,* F. Rink*

The 2 Mev machine continues to be used for radiation chemistry. The new a-c generators for power at the terminal, the new tank section, the reversible polarity 50 Kev supply for spray current, are all on hand. The electrodes and glass sections for the new accelerator tube are completed and test sections made from them are termed satisfactory. Assembly of the first tube is awaiting the results of some design considerations now in the hands of the Mathematics Panel.

Experiments under way by members of the Physics Division will be described at a future time. A preliminary report can be given on a radio frequency ion source of the type described by Rutherglen.(1) With this source the efficiency of the source and mass composition of the beam have been studied as they depend upon gas composition and the settings of various voltages and currents. It has been found that pure water vapor gives H_1^+ to H_2^+ ratios as high as eight but rather small efficiencies. With pure hydrogen, a H_1^+ to H_2^+ ratio of two obtainable with separated H_1^+ up to 100 μa. In this latter case with 30 μa separated H_1^+ beam, the gas consumption was about 8 cc/hr. Materials are on hand and designs are in the shop for the 90° bender and electrostatic analyzer.

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* Instruments Division

(1) Rutherglen, J. G. and Cole, J. F. I., "A Radio-Frequency Ion Source with High Percentage Yield of Protons," *Nature* 160, 545 (1947).