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ORNL-481
PROGRESS REPORT
7A

PHYSICS DIVISION

QUARTERLY PROGRESS REPORT

FOR PERIOD ENDING SEPTEMBER 25, 1949

OAK RIDGE NATIONAL LABORATORY · U.S. ATOMIC ENERGY COMMISSION

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
CARBIDE AND CARBON CHEMICALS CORPORATION
FOR THE
ATOMIC ENERGY COMMISSION

OAK RIDGE, TENNESSEE

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ORNL 481
Progress Report
This document consists of 59 pages. Copy 7 of 149.

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PHYSICS DIVISION
QUARTERLY PROGRESS REPORT
for Period Ending September 25, 1949

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

Date Issued: DEC 21 1949

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INTRODUCTION AND SUMMARY

The unclassified section of the Physics Division Progress Report for July-September 1949, is presented herewith. The classified work is described under separate cover (ORNL 480).

The past quarter was marked by pleasant and profitable association with a number of summer visitors. These included D. O. Caldwell (UCLA), L. W. Cochran (University of Kentucky), S. M. Dancoff (University of Illinois), E. Feenberg (Washington University), A. B. Lewis (University of Mississippi), H. W. Newson (Duke University), Rose Mooney (Sophie Newcomb College, Tulane University), G. C. Phillips, J. R. Risser and C. F. Squire (Rice Institute), Eric Rodgers (University of Alabama), N. Tralli and J. Jackson (New York University), Milton Marney (Wake Forest), T. Welton (AEC) and G. Young (NDA).

Scintillation Spectrometry. Decay times of the light from phosphors have been measured as a function of temperature. For anthracene, the decay time extrapolates to zero at absolute zero. The possible influence of temperature upon the light transmission of the glass envelopes of the multiplier tubes is being investigated.

The 5819 photomultiplier tubes are found to have photosurfaces which are not uniformly sensitive from region to region. A television-like scanning device has been developed by which these irregularities are quickly displayed on an oscilloscope screen.

The resolution of the scintillation spectrometers has been improved so that the width of a conversion line at half maximum now is 13 percent of the energy of the line.

The beta and gamma spectra of K^{40} and Er^{169} have been examined.

"Hot Lab" Manipulator. A small, inexpensive electric motor has been adapted so as to yield a drive that can be standardized and adapted to many varied tasks in remote manipulation.

Short-Lived Isomers. A new isomer has been found in Lu^{177}; the half-life is 13×10^{-8} sec. Observations made elsewhere of an isomeric level in Hg^{198} have not been confirmed. Application of scintillation spectrometry to the delayed coincidence work is beginning to yield information on the energy of the radiations from short-lived isomers.

Neutron Diffraction. The magnetic scattering observations have made it possible to derive the radial distribution of the five electrons in the 3d shell of Mn^{++}. Agreement is satisfactory with the distribution as calculated for the self-consistent field analysis.

Antiferromagnetic structure has been observed in MnO and MnSe at 80° K and in Fe_2O_3 at temperatures below its curie point at 675° C.

Coherent scattering from several zero-spin nuclei has been studied for the purpose of improving the accuracy of the measurement of coherent scattering cross sections.

Neutron Polarization. A 5/8 in. diameter beam yielding 10,000 counts per minute of 70 percent polarized neutrons has been produced. This will be used in the nuclear alignment experiments.

Cross Section of Gold. This has been remeasured with the neutron crystal spectrometer. For $E_n = 0.025$ ev, it is found that $\sigma_T = 103.5$ barns and $\sigma_S = 7.6$ barns.

Low Temperatures. It has been found possible to conduct heat at 0.30 K reasonably quickly from an object on one end of a silver bar to a magnetically-cooled lump of chrome alum on the other end of the bar. The observation is very encouraging, because it is this arrangement that is planned for use in part of the nuclear-alignment program.

Short-Period Activities. The fast pneumatic tube has been equipped with scintillation spectrometer detecting equipment, so that the energies of the short-lived activities can be measured.

Neutron Decay. Because of "improvements" in the apparatus, the data have lost some of their internal consistency.

Semi-Conductors. The resistance of germanium shows interesting variations as a function of temperature during and subsequent to pile irradiation. The germanium is so sensitive to impurities that even the transmuted atoms in the lattice produce major effects upon the resistance.

Van de Graaff. The electron accelerator has produced beams of 200 μa at 1.8 Mev, and smaller beams at higher voltage. Photodisintegration of beryllium is easily accomplished.

Theoretical Physics. Much work has been done on the preparation of the L-shell internal conversion coefficient calculation for feeding it to the Mark III computer. Calculations have also been carried out upon the effect of the finite size of the nucleus on beta-decay, and its effect upon internal conversion.

PHYSICAL ELECTRONICS

Scintillation Phosphors (G. G. Kelley). Shortly after the last report was written, more careful measurement was made of the decay constant of anthracene. The synchroscope sweep was calibrated by means of a signal generator which had previously been checked against a frequency standard. Many photographs were taken of individual scintillation pulses and a value obtained for the decay constant by an averaging method since determination of the decay constant is complicated by the statistical fluctuations of the individual pulses. Two averaging methods were tried. In the first, the best exponential was drawn through each pulse by eye and results averaged for 20 pulses. In the second, the ordinates of 20 pulses were added point by point. Both methods gave essentially the same value for the time constant.

The speed of decay of the light from anthracene was found to be a function of temperature so the time constant was measured at various temperatures down to that of liquid nitrogen. Temperature was measured by means of a small thermocouple in contact with the crystal and changes were made very slowly to assure equilibrium. The results are plotted in Fig. 1. The brackets indicate the 95% confidence interval based on the spread of the data, the first averaging method having been used.

Naphthalene was investigated in the same manner in hopes that it too would indicate an intercept with the temperature axis at 0° K. Results here were somewhat inconclusive due to averaging difficulties. The shape of the decay constant versus temperature curve appears to be more shallow, intercepting in the vicinity of -400° K. As a by-product of the investigation the decay constant of naphthalene at room temperature may be given with considerable confidence as 0.070 μ-sec.

Values given in the last quarterly report for the decay constants of various phosphors may well be outside the limits given for them because of the statistical fluctuation difficulty which was not fully appreciated when they were obtained.

Scintillation Phosphors (M. Goodrich). The temperature dependence of the size of scintillation pulses from an anthracene crystal caused by the conversion electrons from Cs^{137} have been investigated with a scintillation spectrometer. The photomultiplier tube with crystal and source were enclosed in a tight brass can which was placed in a Dewar flask at various heights above

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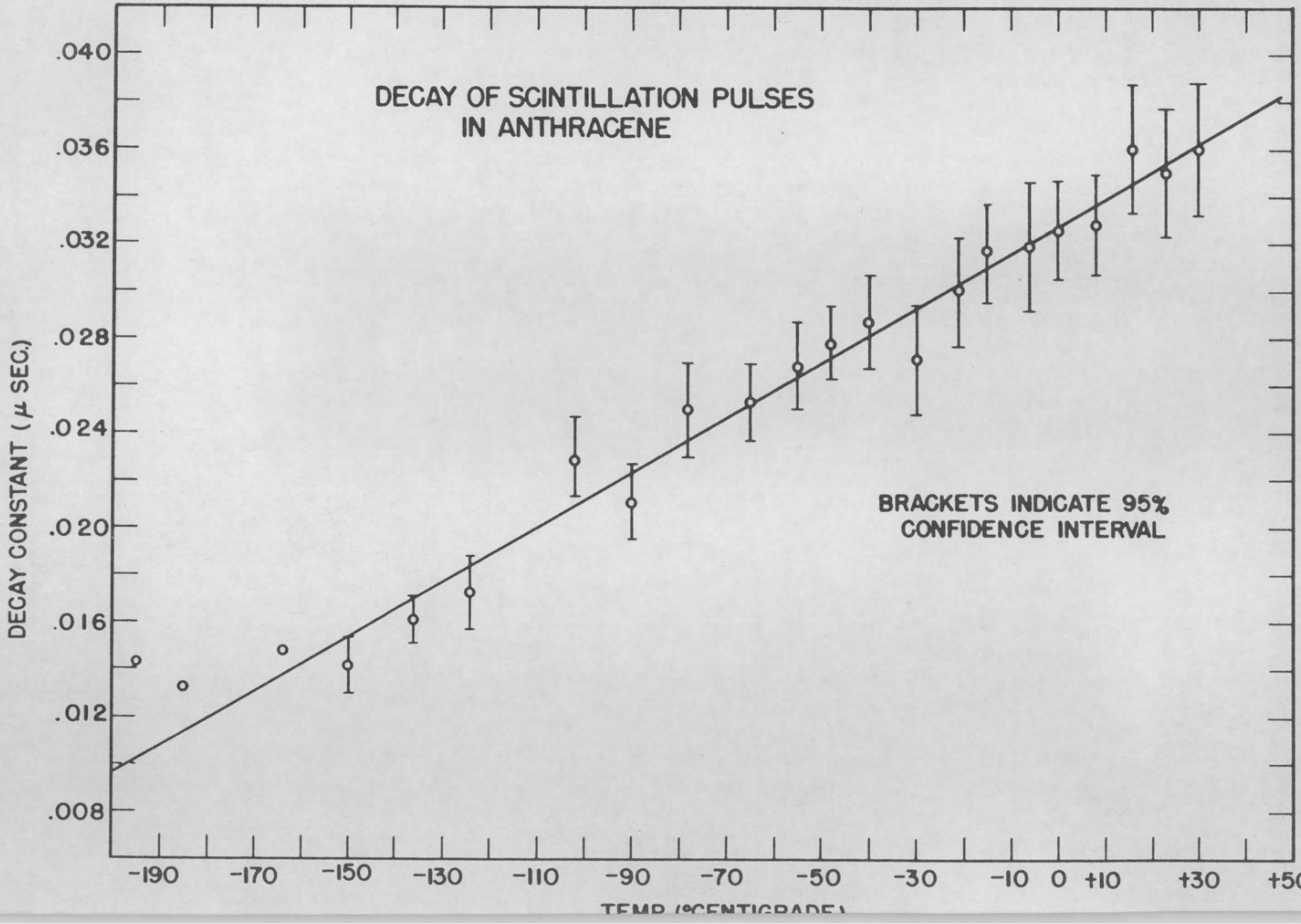
FIG. I



dry ice or liquid nitrogen, the temperature being measured by a copper-constantin thermocouple adjacent to the crystal. For a 1P28 photomultiplier the results, Fig. 2, show an essentially constant pulse size from room temperature to near liquid air temperature except for a dip above 0° C. Since previous measurements made in this laboratory with a 1P21 tube had indicated a considerably increased pulse size at low temperatures, a 1P21 tube was inserted and measurements made at 23° C and -60° C. At the lower temperature, the pulses were about 30% the larger, checking at least qualitatively the earlier results. The conflicting results with the two multipliers may be attributed to a difference in their spectral response due to difference in their glass envelopes. The 1P21 cuts off sharply at about 3200 Å while the 1P28 cuts off around 2400 Å. Assuming that the result with the 1P28 means that the pulse size is actually not a function of temperature in this range, the 1P21 results could be explained by a low temperature shift of the envelope transmission toward short wavelengths. Such a shift actually occurs in the region of 3200 Å and below as was determined qualitatively with the grating spectrograph of the Chemistry group through the kindness of Mr. C. Feldman. There is also the possibility that a low temperature shift of the scintillation spectrum toward long wavelengths exists and contributes to the apparent change in pulse size. Both of these explanations depend upon the scintillation spectrum being fairly strong in the region below 3500 Å, but, according to a report of Roth[1], anthracene gives prominent bands only at 4240 Å, 4440 Å, and 4700 Å. Measurements with an optical spectrometer of the scintillation spectrum of anthracene as a function of temperature need to be obtained to resolve the question.

Photomultiplier Tester (R. C. Davis, P. R. Bell, G. G. Kelley). A uniformly sensitive photocathode is a requirement for good resolution in scintillation spectrometry. Tubes may be tested for uniformity, and the effects of variation of electrode voltage and magnetic field may be noted easily using a device developed by this group. It consists of a Dumont Type 208 oscilloscope used as a light source, with a lens system for focusing the light from the face of the cathode ray tube onto the photocathode of a type 5819 photomultiplier. Another oscilloscope, inter-connected with the first, permits visual observation of the cathode sensitivity at all points on its surface. Two types of presentation are available. In the first the horizontal and vertical plates of the two units are connected together respectively and caused to produce a television-like raster by means of the two sweep generators. The signal from

[1] Louise Roth, Phys. Rev. 75, 983 (1949).

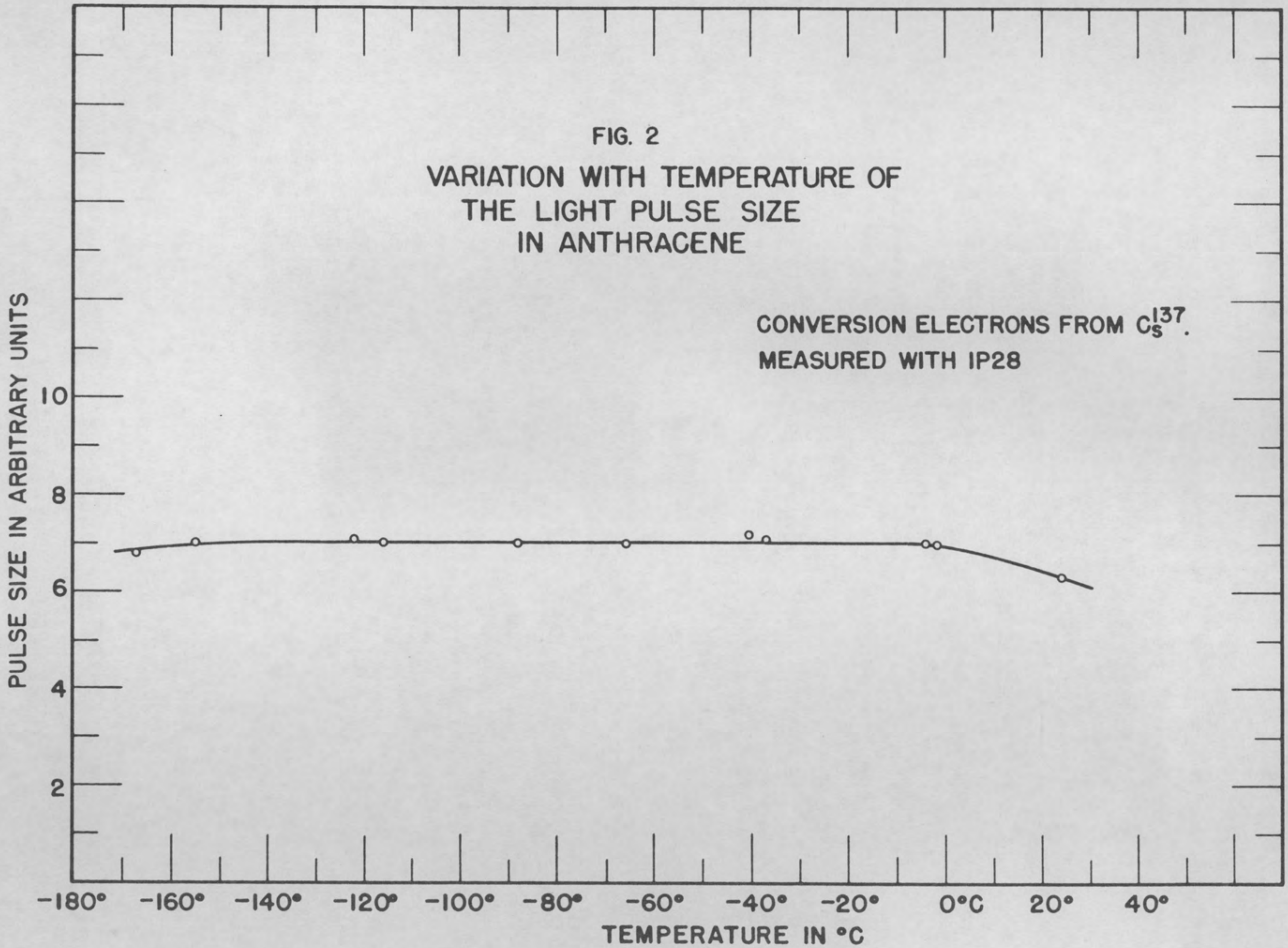


FIG. 2
VARIATION WITH TEMPERATURE OF
THE LIGHT PULSE SIZE
IN ANTHRACENE
CONVERSION ELECTRONS FROM Cs^{137}.
MEASURED WITH IP28
PULSE SIZE IN ARBITRARY UNITS
10
8
6
4
2
-180°
-160°
-140°
-120°
-100°
-80°
-60°
-40°
-20°
0°C
20°
40°
TEMPERATURE IN °C

the photomultiplier is fed through one of the vertical amplifiers to the grid of the observation tubes. Sensitivity of the photocathode surface is indicated by the intensity of illumination of the corresponding point on the observation tube. The other presentation, giving a more quantitative picture, is obtained by disconnecting the vertical plates of the observation tube from the vertical sweep and reconnecting them through the signal amplifier in normal fashion. Voltage from the vertical sweep amplifier is mixed with the signal from the photomultiplier in this signal amplifier. The result is a sensitivity contour map of the surface, in perspective.

A schematic of the device is given in Fig. 3 and typical results are shown in Fig. 4.

Resolution of Scintillation Spectrometers (M. Goodrich). During the past quarter attempts to increase the resolution of the scintillation spectrometer have resulted in a considerable improvement. The width at half maximum of a conversion line has been reduced to 12 to 14% of the energy of the conversion line.

Significant improvement was obtained by raising the photocathode to first dynode voltage from the 50 or 60 volts formerly used to 150 or 200 volts. This improvement is due to an increase in the average number of photoelectrons collected per incident photon and the resulting improvement in statistics. In the course of these tests it was discovered that small magnetic fields, of the order of 0.1 gauss had marked effects on the resolution. Coils were then set up to neutralize the earth's field and to check more carefully the effect of small fields. The various tubes were found to vary considerably in their sensitivity to fields (the tubes had been demagnetized by an a-c field). In general the resolution was found to be best for a particular magnetic field, in some cases zero and in some cases as high as 0.5 gauss or more. In Fig. 5 is shown a portion of the Cs^{137} spectrum around the conversion line for one of the tubes most affected. Since the sensitivity of the resolution to magnetic field is somewhat reduced at lower photocathode voltages, it seems likely that the higher photocathode voltage gives higher average collection efficiency for the photoelectrons but with poorer uniformity of the collection efficiency for the various parts of the photocathode and that the proper magnetic field improves the uniformity of collection.

The same tube was probed with a tiny crystal and found to require different magnetic fields for maximum pulse size for each point on the photocathode. The maximum pulse size so obtained was the same within the experimental error for

FIG. 3

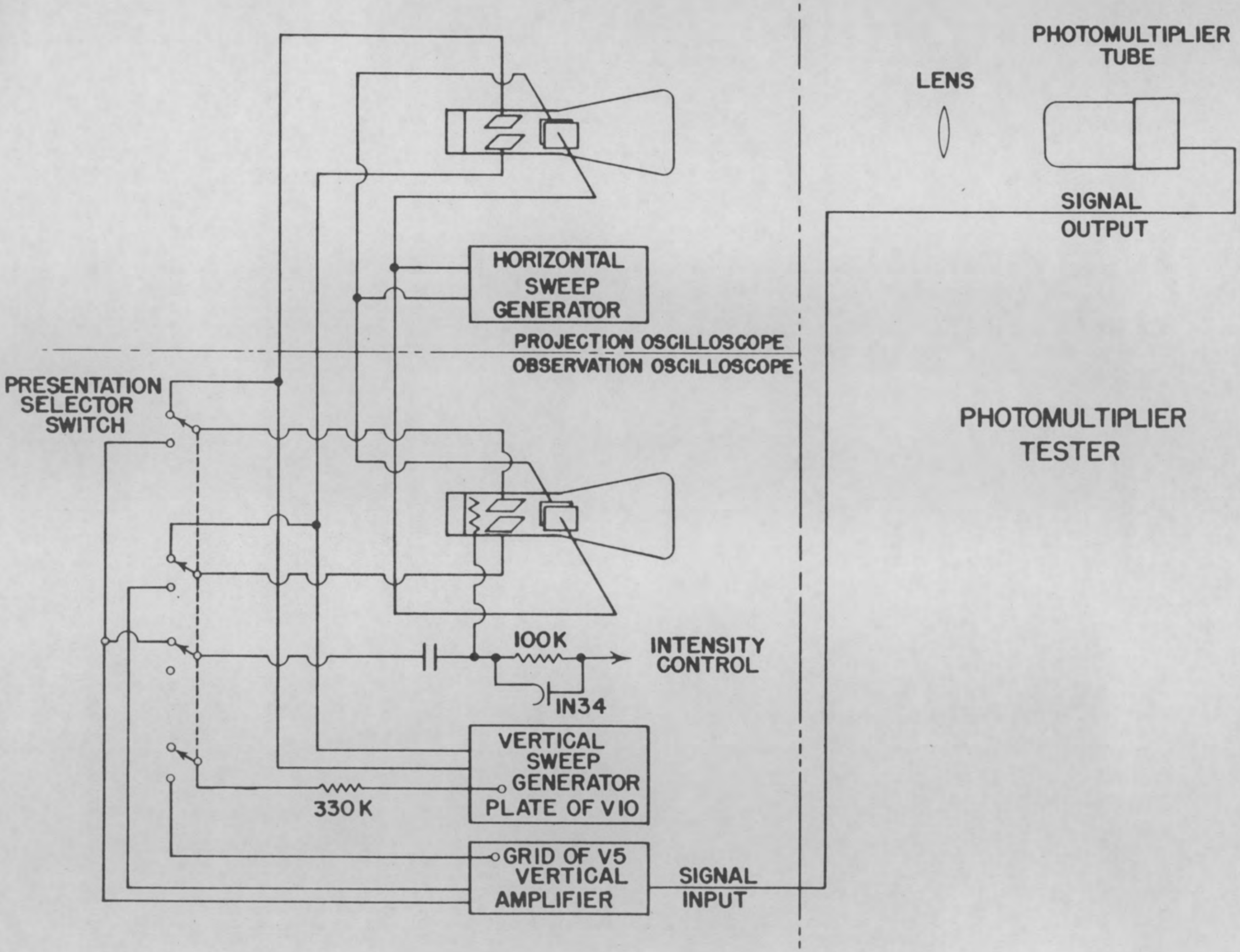
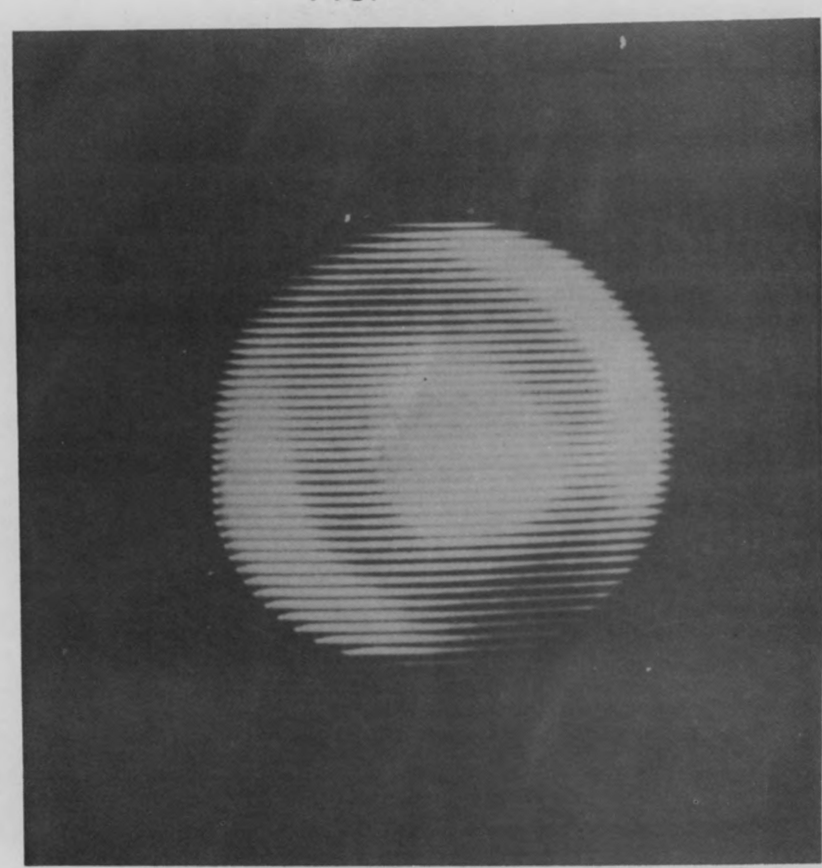
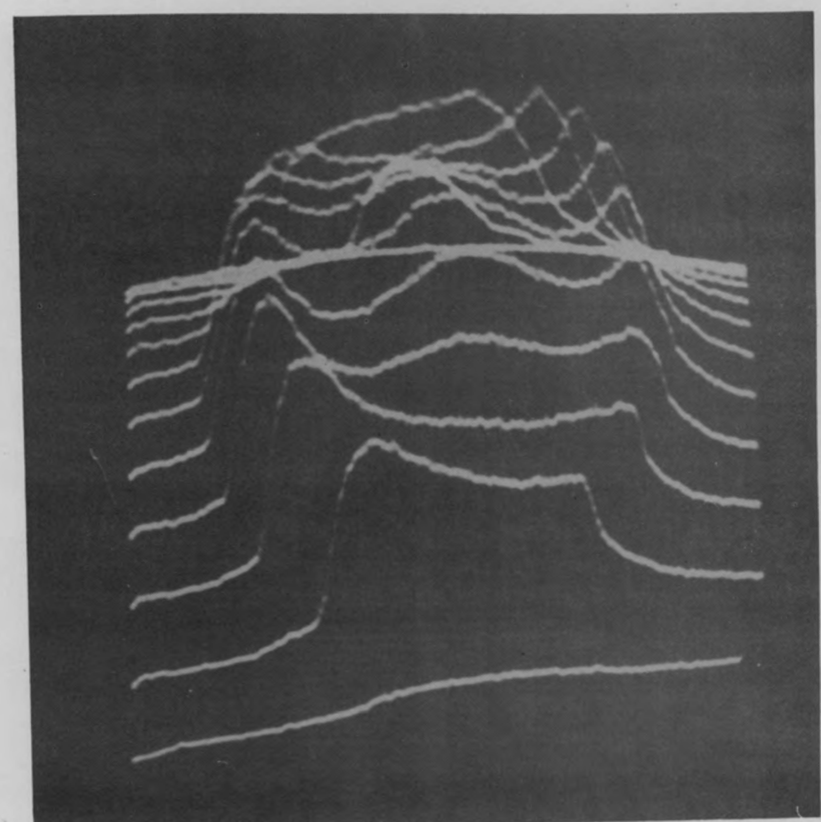

PHOTOMULTIPLIER TUBE
LENS
SIGNAL OUTPUT
HORIZONTAL SWEEP GENERATOR
PROJECTION OSCILLOSCOPE
OBSERVATION OSCILLOSCOPE
PRESENTATION SELECTOR SWITCH
PHOTOMULTIPLIER TESTER
100K
INTENSITY CONTROL
IN34
VERTICAL SWEEP GENERATOR
PLATE OF V10
330K
GRID OF V5
VERTICAL AMPLIFIER
SIGNAL INPUT

FIG. 4



TYPICAL PHOTOCATHODE USING THE INTENSITY MODULATED SCAN



SAME PHOTOCATHODE WITH PANORAMIC PRESENTATION

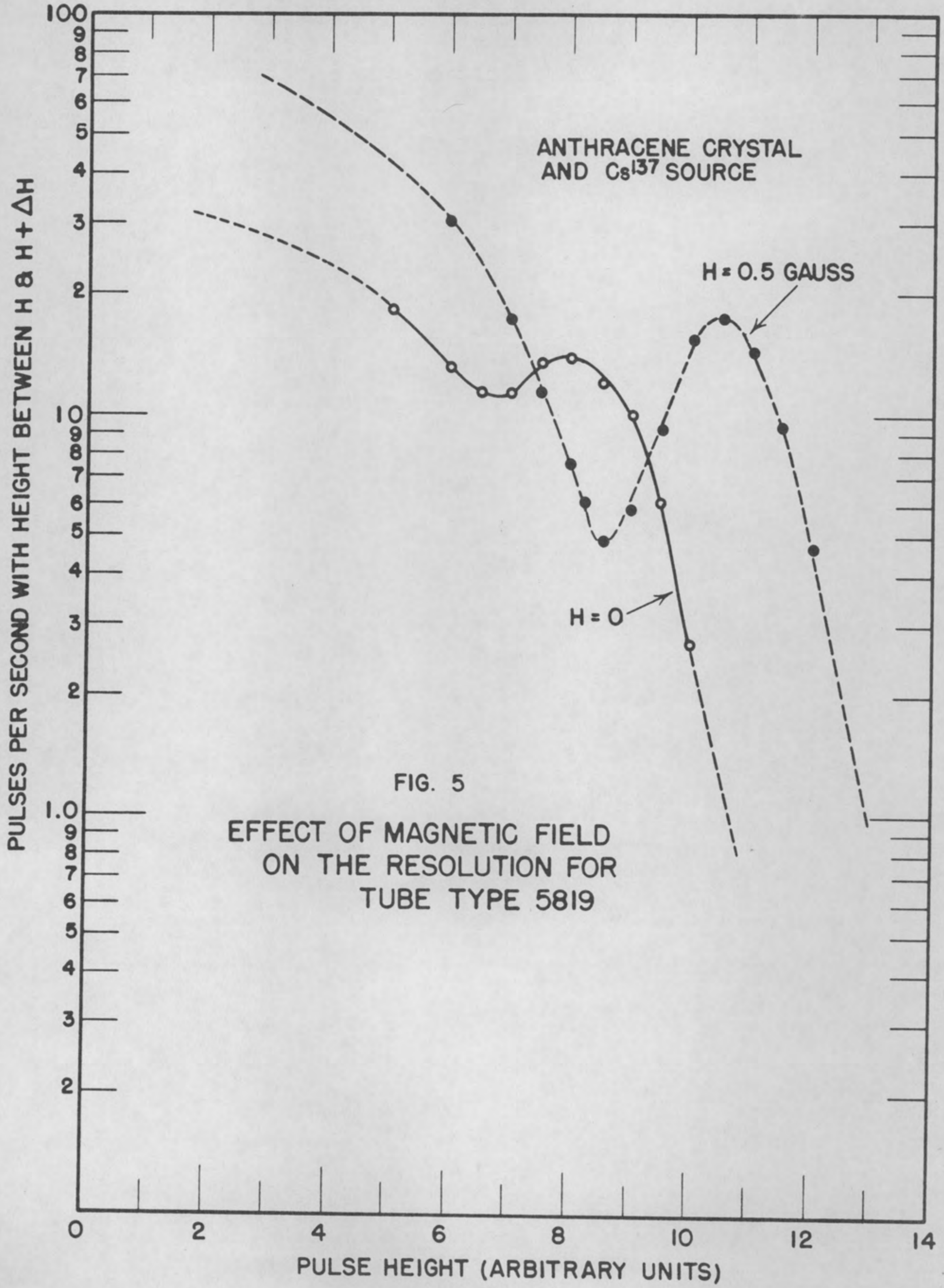


FIG. 5

EFFECT OF MAGNETIC FIELD ON THE RESOLUTION FOR TUBE TYPE 5819 all parts of the photocathode indicating that the efficiency of production of photoelectrons was uniform over the photocathode and that the spread in resolution above that due to statistics was for this tube caused almost solely by non-uniform focussing. While this is probably not true for all tubes, it suggests that non-uniformities of the photocathode itself may be less prevalent than poor focussing.

In principle, the variations over the photocathode surface in production and focussing of photoelectrons can be eliminated by distributing uniformly over the photocathode the light from all pulses. Then each scintillation pulse of the same size would deliver, within statistics, the same number of photoelectrons to the first dynode. Light pipes of lucite were used to accomplish this. Unfortunately the loss of light due to absorption in the body and on the surface of the light pipe was great enough to make the poorer statistics nullify any gains due to greater uniformity of collected photoelectrons. Recently somewhat better light pipes have been made by using more transparent material and more highly polished surfaces so that it is hoped that the nonuniformity of the focussing may be overcome in this way and still higher resolution obtained.

Scintillation Spectrometer Studies (P. R. Bell, J. Cassidy). The beta and gamma rays from K^{40} have been studied. The gamma rays were observed by surrounding the counter with several pounds of KCl (Fig. 6a) The spectrum of the Compton recoil electrons in the anthracene crystal is shown in Fig. 6a and b. This spectrum would be produced by a strong γ-ray of energy approximately 1.44 Mev. There is no evidence of annihilation radiation.

The K^{40} beta rays were measured by placing a thin source (3 mg/cm^2) of enriched KCl near the crystal. The observed beta spectrum and background are shown in Fig. 7a. The closed circles in Fig. 7b show the beta spectrum, the open circles are the data after correcting for the resolution of the instrument. Kurie plots are shown in Fig. 8. The spectrum appears to be third forbidden with an endpoint of 1.35 Mev.

The Er^{169} spectrum from a sample prepared by Ketelle has recently been measured, confirming his results on the lens spectrometer. The Kurie plot is shown in Fig. 9, and appears to be an allowed shape with an endpoint of 330 Kev.

A Remote Positioning Device for "Hot Lab" Work (T. E. Cole, P. R. Bell, E. P. Epler). A suggestion was made by E. P. Epler that some time could profitably be spent in developing a small variable speed motor for use in remote positioning devices for "hot lab" use. There are many applications which require such a device and to date each application has, in general, required the design of a new actuating mechanism; it is hoped that on further development the mechanism and circuitry described below will be sufficiently flexible to find wide application in work on this nature.

FIG. 6a

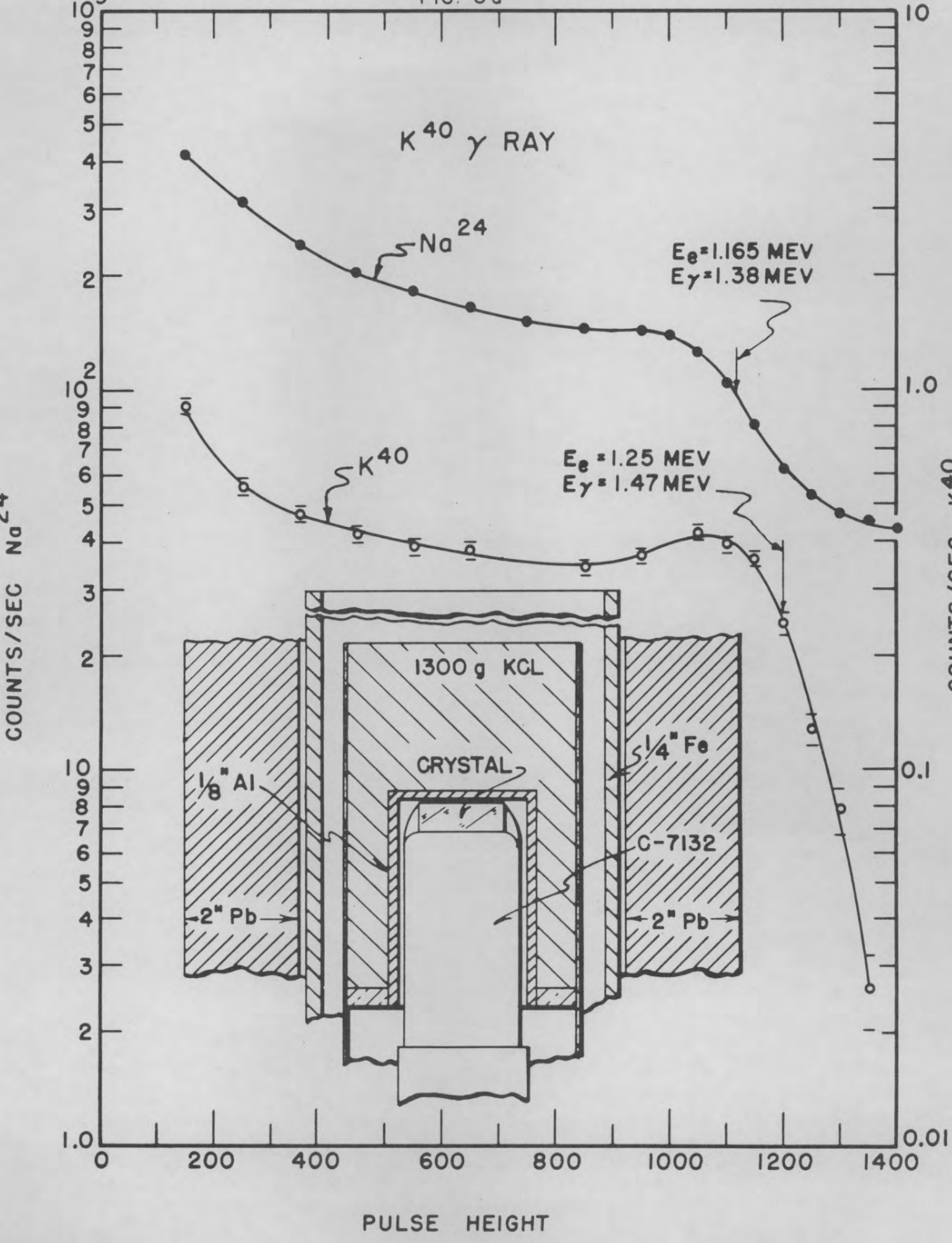

K40 γ RAY
Na24
K40
Ee=1.165 MEV
Eγ=1.38 MEV
Ee=1.25 MEV
Eγ=1.47 MEV
1300 g KCL
CRYSTAL
1/4" Fe
1/8" Al
C-7132
2" Pb
2" Pb
COUNTS/SEC Na24
COUNTS/SEC K40
PULSE HEIGHT
0
200
400
600
800
1000
1200
1400
1.0
10
10²
10³
0.01
0.1
1.0
10

FIG. 6b

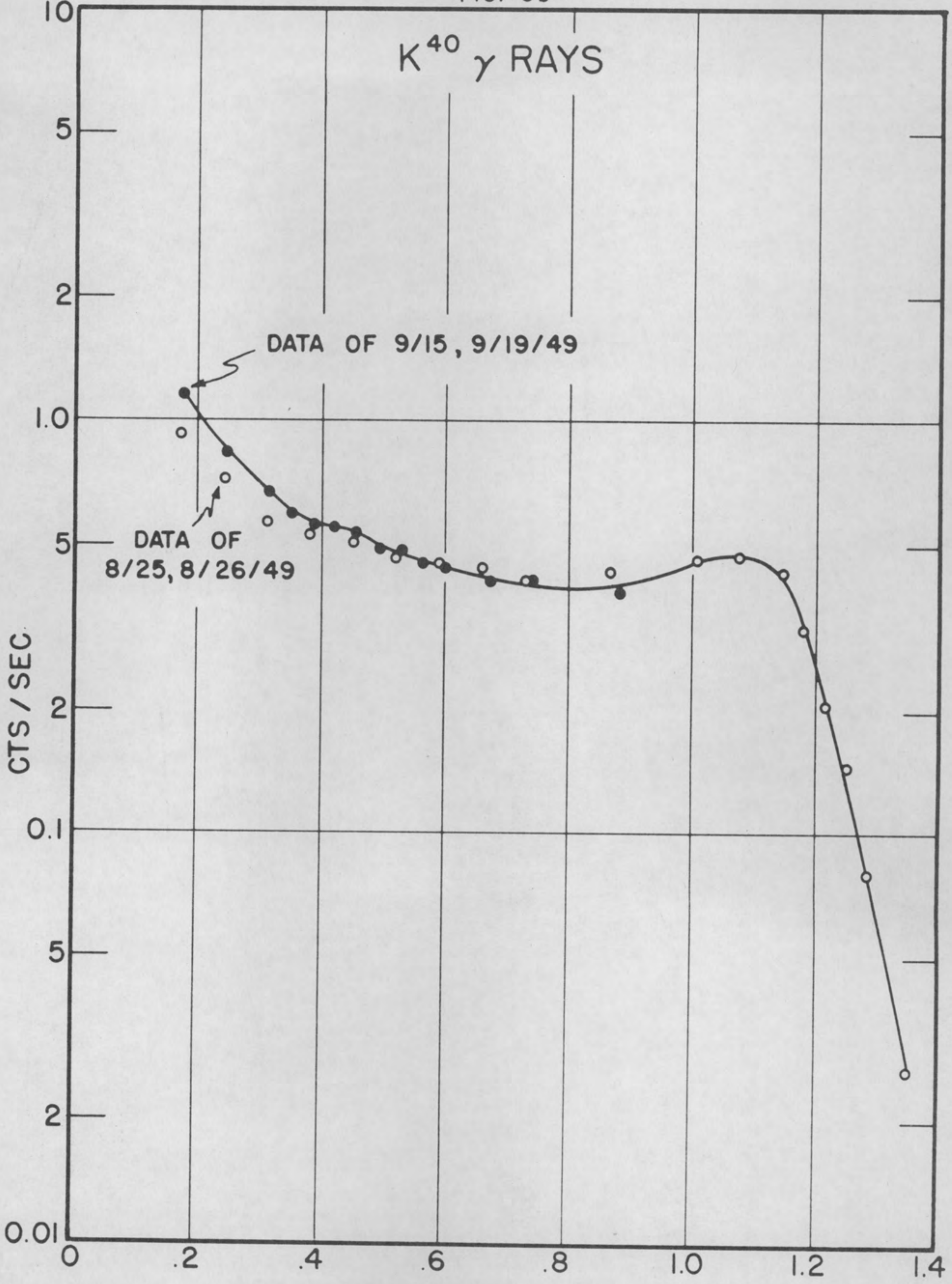

K^{40} γ RAYS
DATA OF 9/15, 9/19/49
DATA OF
8/25, 8/26/49
CTS / SEC
E MEV
10
5
2
1.0
5
2
0.1
5
2
0.01
0
.2
.4
.6
.8
1.0
1.2
1.4

FIG. 7a

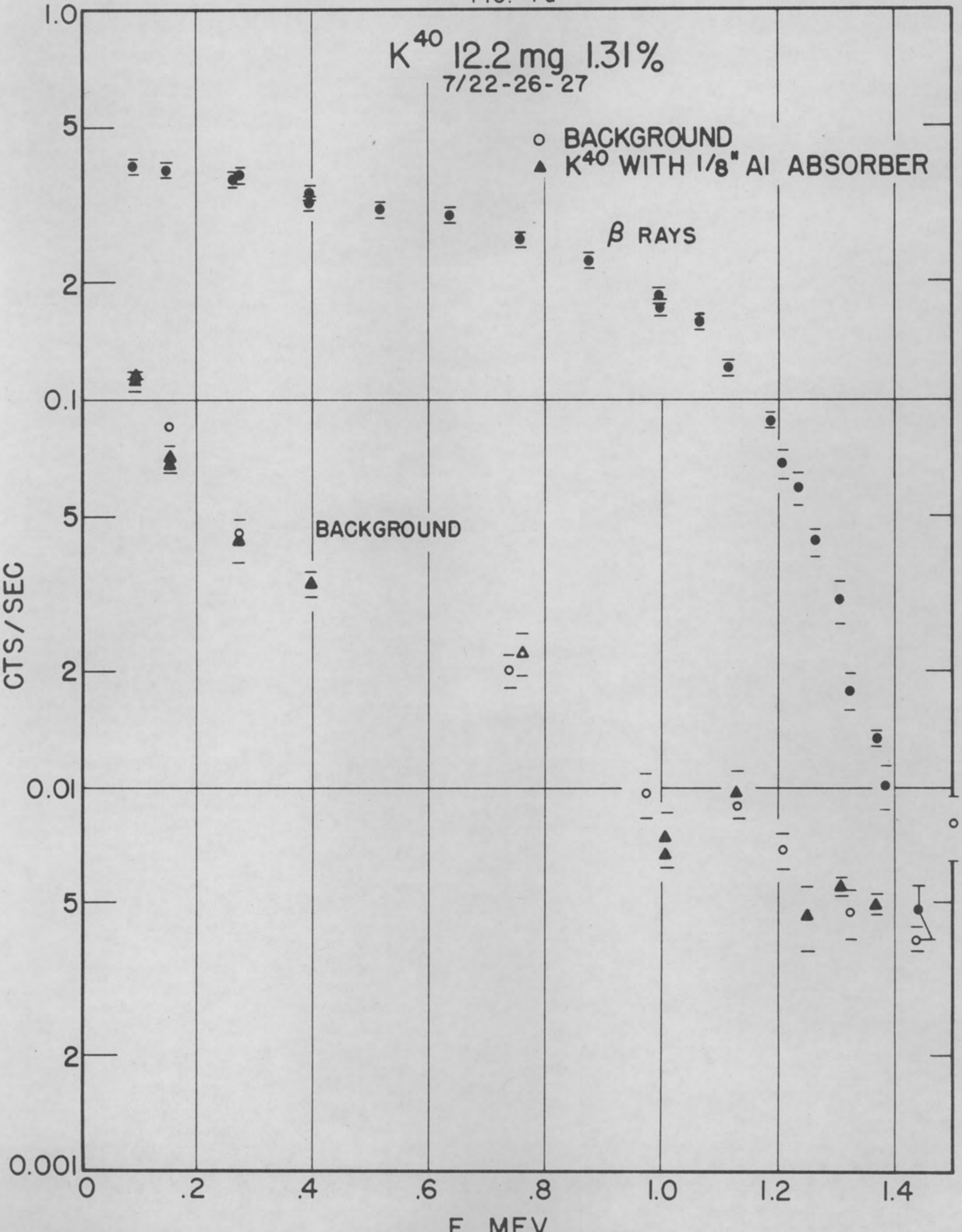

K^{40} 12.2 mg 1.31%
7/22-26-27
○ BACKGROUND
▲ K^{40} WITH 1/8" Al ABSORBER
β RAYS
BACKGROUND
CTS/SEC
E MEV
1.0
5
2
0.1
0.01
0.001
0
.2
.4
.6
.8
1.0
1.2
1.4

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FIG. 7b

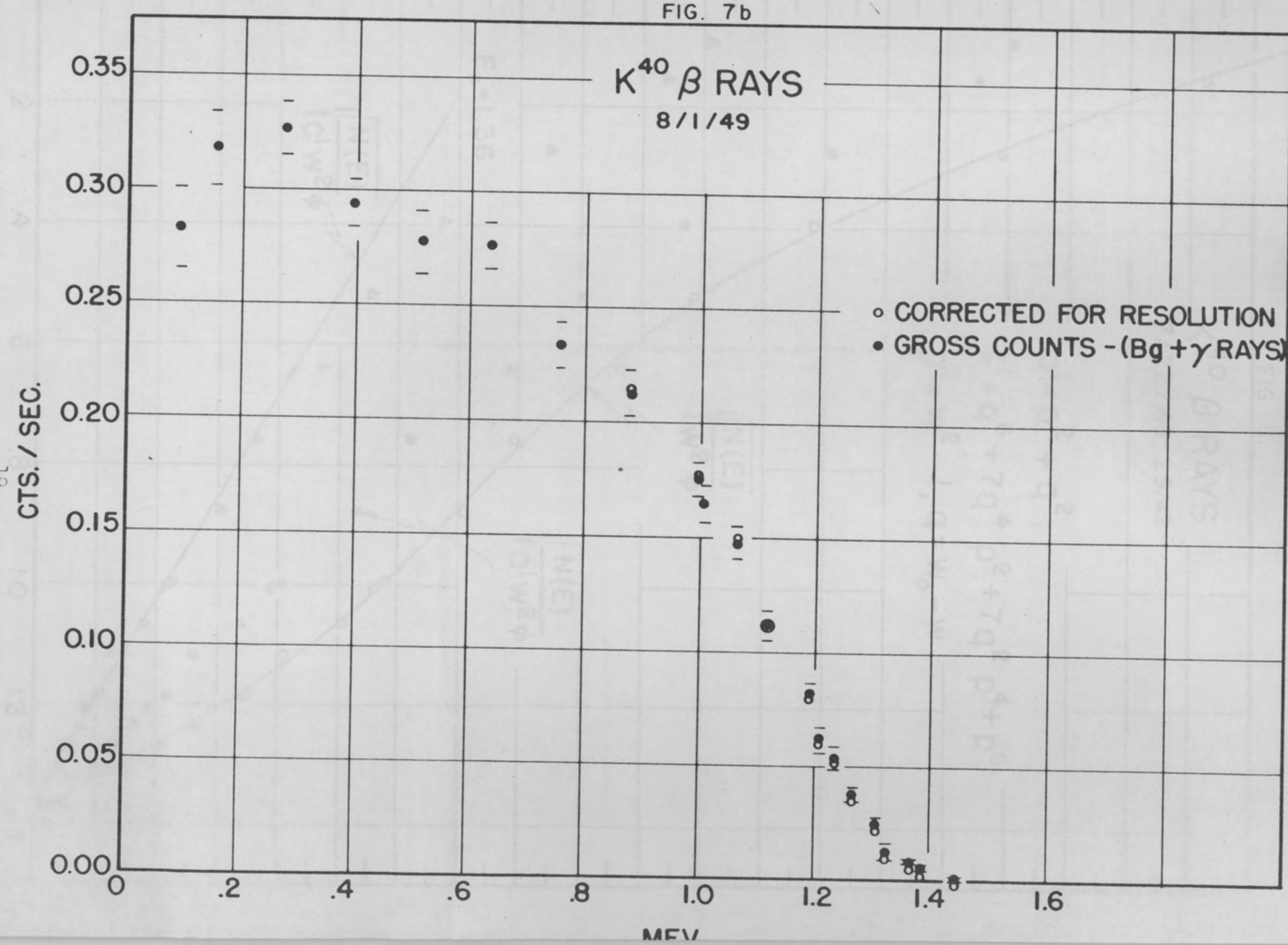


FIG. 8

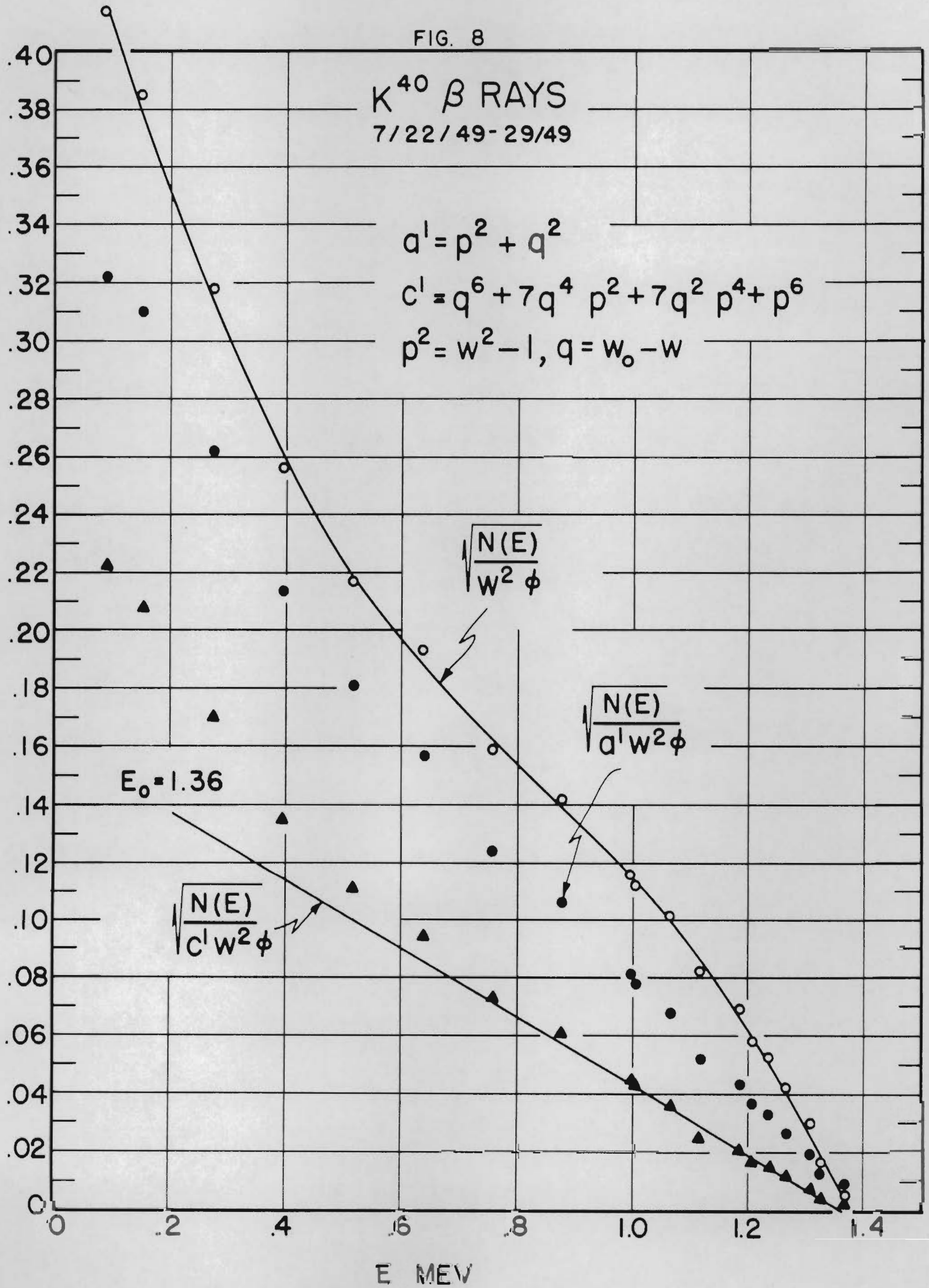
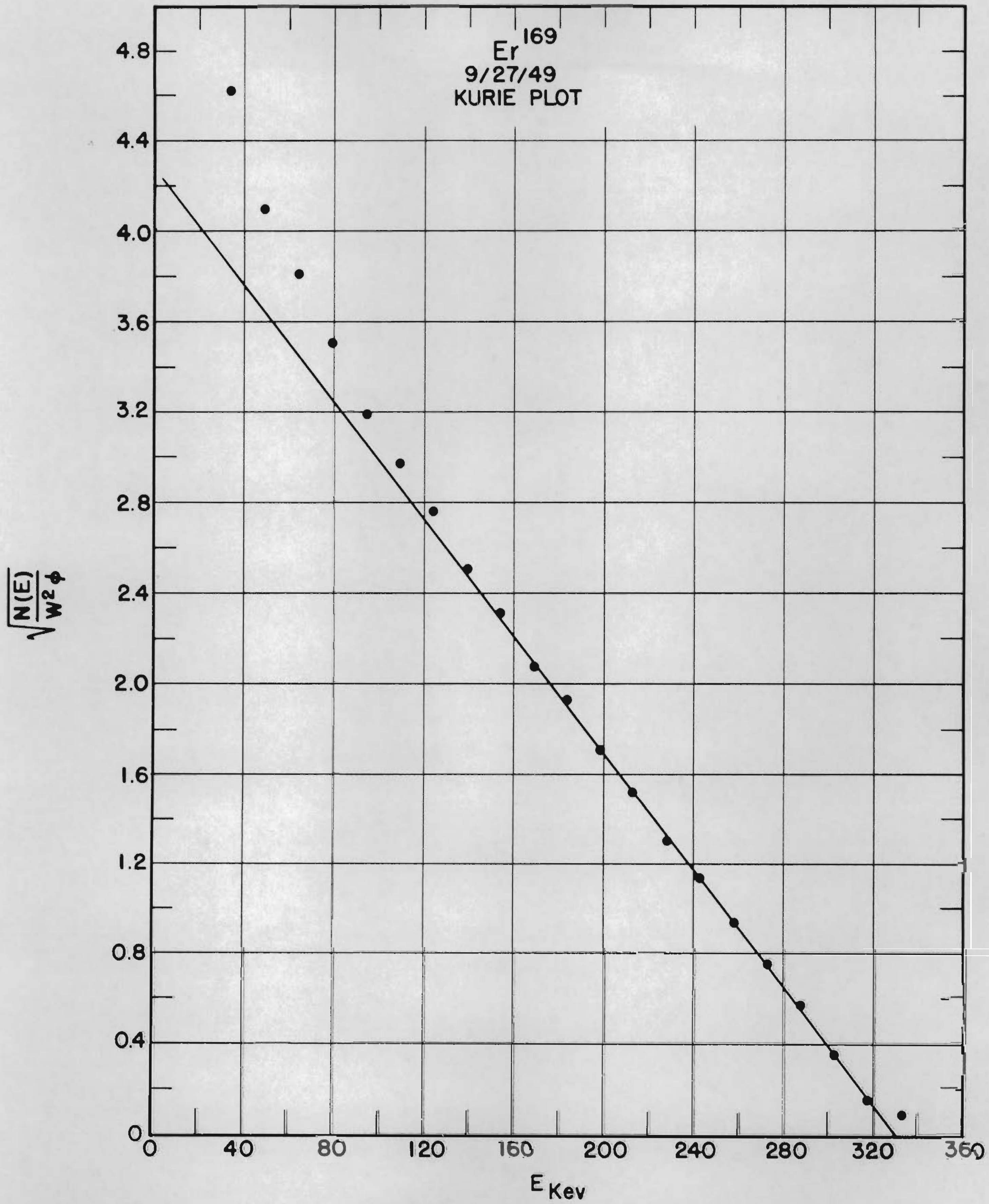

K40 β RAYS
7/22/49-29/49
a' = p² + q²
c' = q⁶ + 7q⁴ p² + 7q² p⁴ + p⁶
p² = w² − 1, q = w₀ − w
√(N(E)/(w² φ))
√(N(E)/(a' w² φ))
√(N(E)/(c' w² φ))
E₀ = 1.36
.40
.38
.36
.34
.32
.30
.28
.26
.24
.22
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
0
0
.2
.4
.6
.8
1.0
1.2
1.4
E MEV

FIG. 9



Er^{169}
9/27/49
KURIE PLOT
4.8
4.4
4.0
3.6
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0
$\sqrt{\frac{N(E)}{W^2\phi}}$
0
40
80
120
160
200
240
280
320
360
E_{Kev}

The motor is a Delco #5069600, 250 rpm, 27 v d-c permanent magnet field motor. A gear reduction is incorporated in the design of the motor and according to the manufacturers information the torque developed is 8 oz.in. continuous and 40 oz.in. stalled. The overall dimensions of the motor are approximately 1-3/8 in. in diameter and 3-3/4 in. long. This motor was chosen because of its small physical size, ease with which it could be driven and availability at small cost (war surplus).

A tentative circuit for controlling the motor has been constructed and works satisfactorily. The circuit is shown in Fig. 10. Reference to this figure will provide the essential details of operation, though modification of the circuit will be dictated by the specific application. The potentiometers labeled (1) and (2) are the control elements; if either is linked mechanically with the motor, assuming proper sense of rotation, the motor will move in such a way as to try to maintain the series resistance across the two potentiometers constant, and thus we have a positioning device. For a velocity device we need only one potentiometer since we utilize the back emf generated by the motor as a measure of the velocity.

P. R. Bell has proposed the use of two motors connected in series, one attached to the load and the other attached to the input potentiometer; this would give the device a sense of touch due to the fact that the torque output of the motors would be nearly equal and the motor on the input potentiometer would reflect the resistance seen by the load motor. This neglects friction, but it is believed that friction could be balanced out electrically.

Short-Lived Isomers (F. K. McGowan). Using sources of Yb^{177} (1.8 hr), delayed coincidences well above the random coincidence rate were detected. In Fig. 11 the number of delayed coincidences is plotted as a function of delay time. It appears from this curve that the disintegration of Yb^{177} leads to a metastable state Lu^{177*} which in turn decays to the ground state with a half-life of $(13 \pm 2) \times 10^{-8}$ sec. The half-life for Yb^{177} as listed in Seaborg's *Table of Isotopes* ranges from 1.9 to 3.5 hr. Normally the half-life would be difficult to obtain because of the Lu^{177} (6.8 da) daughter activity and Yb^{175} (100 hr) activity present in the sources. By counting delayed coincidences at a fixed delay as a function of time the coincidence rate decreases according to the decay of Yb^{177}. The decay was followed for 6 hours and the half-life of Yb^{177} appears to be 1.8 hr.

In a recent issue of the Phys. Rev. 76, 312 (1949), W. J. MacIntyre at Yale University reported a short-lived isomeric state in Hg^{198*} following the

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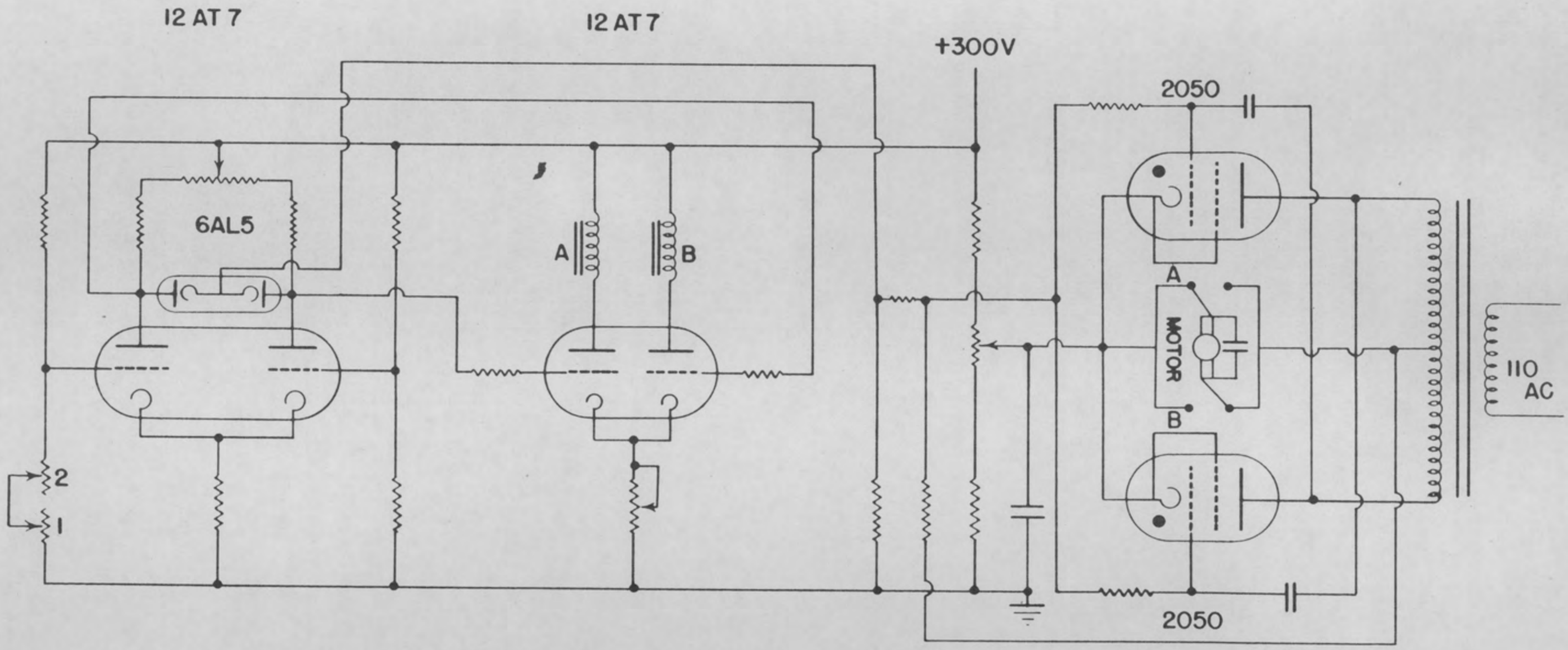
FIG. 10



AMPLIFIER FOR REMOTE CONTROL MOTOR

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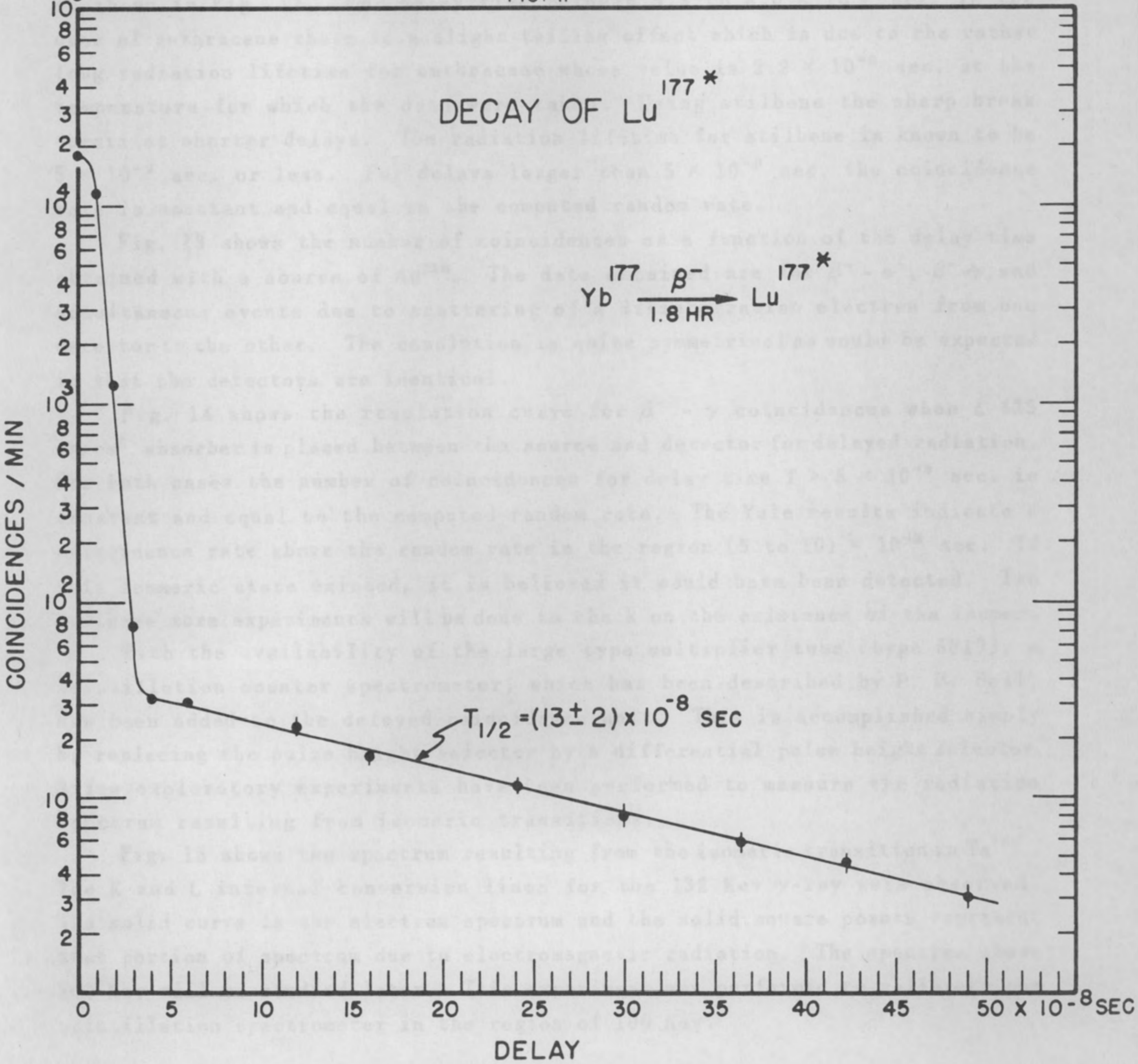
FIG. 11



β^- decay of Au^{198}. The half-life of the state was measured to be 2.3×10^{-8} sec. Previous measurements at this laboratory would indicate that no isomeric state with this half-life existed. Since the communication of this result it seemed desirable to repeat the experiment using stilbene scintillation counters. The improvement gained in resolution by using stilbene in place of anthracene is shown in Fig. 12. For delay time between 5.5 to 8.0×10^{-8} sec. in the case of anthracene there is a slight tailing effect which is due to the rather long radiation lifetime for anthracene whose value is 2.2×10^{-8} sec. at the temperature for which the data were taken. Using stilbene the sharp break occurs at shorter delays. The radiation lifetime for stilbene is known to be 5×10^{-9} sec. or less. For delays larger than 5×10^{-8} sec. the coincidence rate is constant and equal to the computed random rate.

Fig. 13 shows the number of coincidences as a function of the delay time obtained with a source of Au^{198}. The data obtained are for β^- - e^-, β^--γ, and simultaneous events due to scattering of a disintegration electron from one detector to the other. The resolution is quite symmetrical as would be expected in that the detectors are identical.

Fig. 14 shows the resolution curve for β^- - γ coincidences when a 435 mg/cm^2 absorber is placed between the source and detector for delayed radiation. For both cases the number of coincidences for delay time $T > 5 \times 10^{-8}$ sec. is constant and equal to the computed random rate. The Yale results indicate a coincidence rate above the random rate in the region (5 to 10) $\times 10^{-8}$ sec. If this isomeric state existed, it is believed it would have been detected. Two or three more experiments will be done to check on the existence of the isomer.

With the availability of the large type multiplier tube (type 5819), a scintillation counter spectrometer, which has been described by P. R. Bell, has been added to the delayed coincidence unit. This is accomplished simply by replacing the pulse height selector by a differential pulse height selector. A few exploratory experiments have been performed to measure the radiation spectrum resulting from isomeric transitions.

Fig. 15 shows the spectrum resulting from the isomeric transition in Ta^{181*}. The K and L internal conversion lines for the 132 Kev γ-ray were observed. The solid curve is the electron spectrum and the solid square points represent that portion of spectrum due to electromagnetic radiation. The spectrum above 200 Kev will be studied later. This experiment was performed to calibrate the scintillation spectrometer in the region of 100 Kev.

FIG. 12

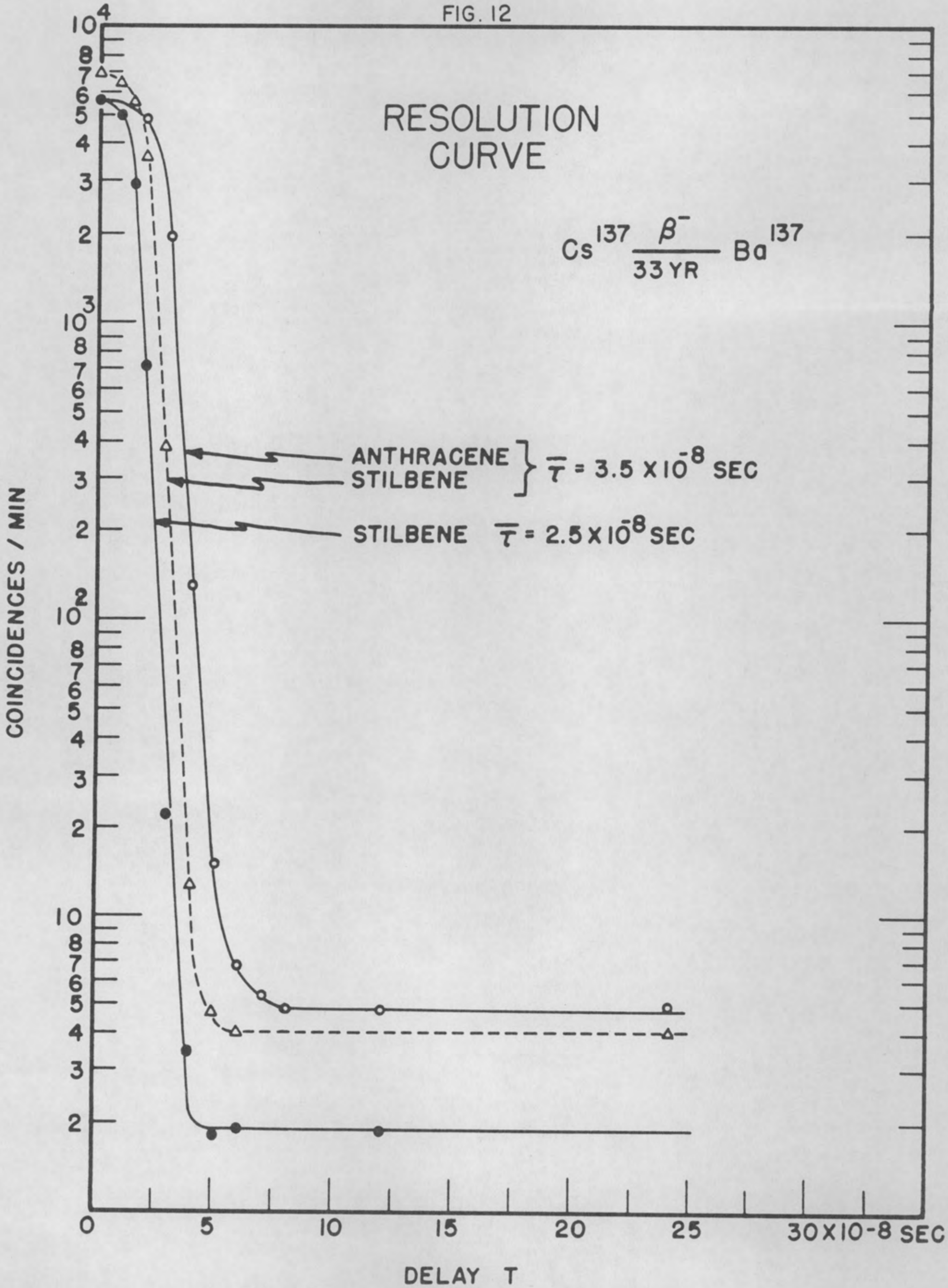

RESOLUTION CURVE
Cs137 β⁻ 33 YR Ba137
ANTHRACENE
STILBENE
τ̄ = 3.5 X 10⁻⁸ SEC
STILBENE τ̄ = 2.5 X 10⁻⁸ SEC
COINCIDENCES / MIN
10⁴
10³
10²
10
0
5
10
15
20
25
30 X 10-8 SEC
DELAY T

FIG. 13

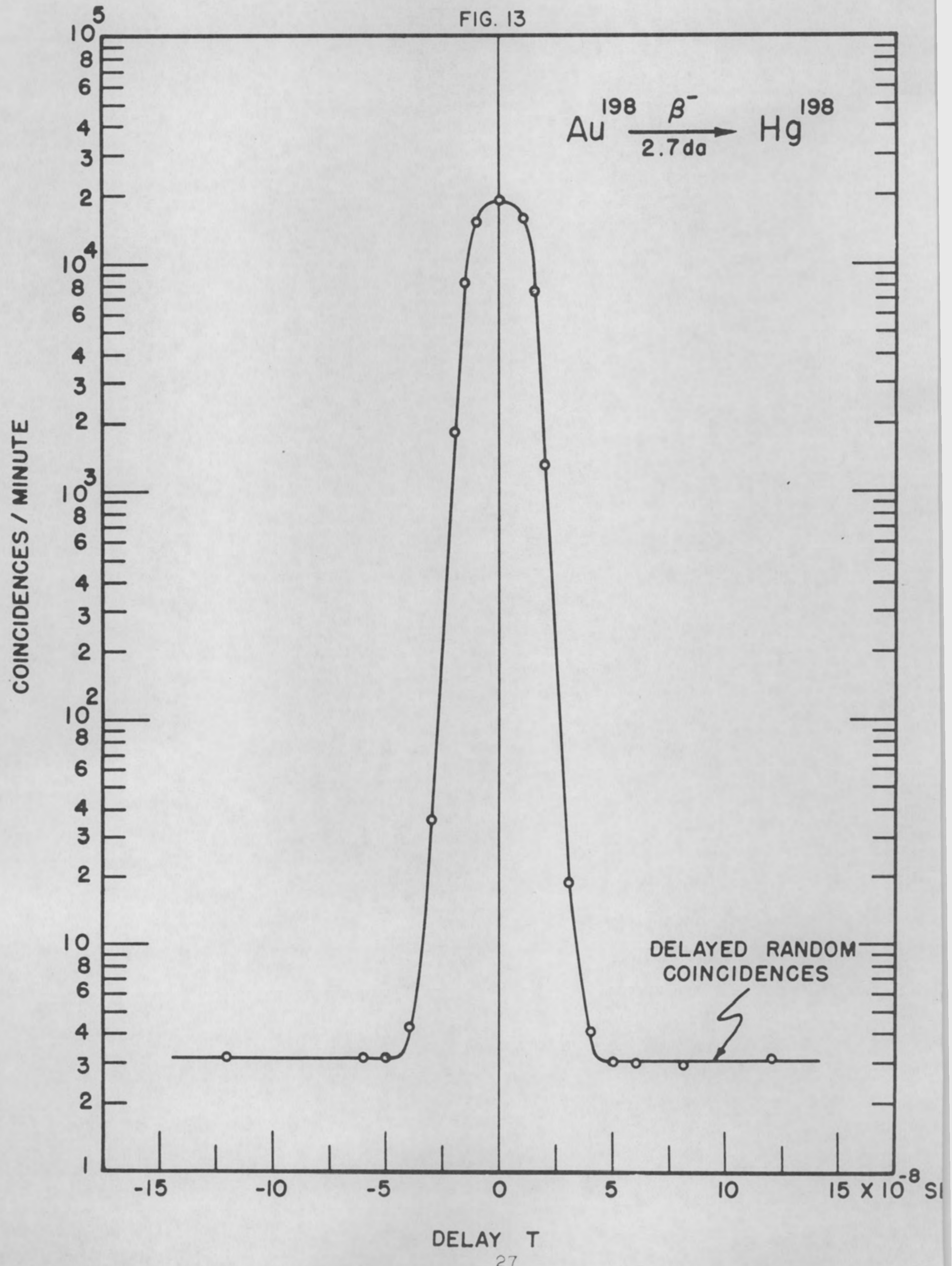

$Au^{198} \xrightarrow[2.7\,da]{\beta^-} Hg^{198}$
COINCIDENCES / MINUTE
DELAYED RANDOM COINCIDENCES
DELAY T
15 X 10^-8 SEC

FIG. 14

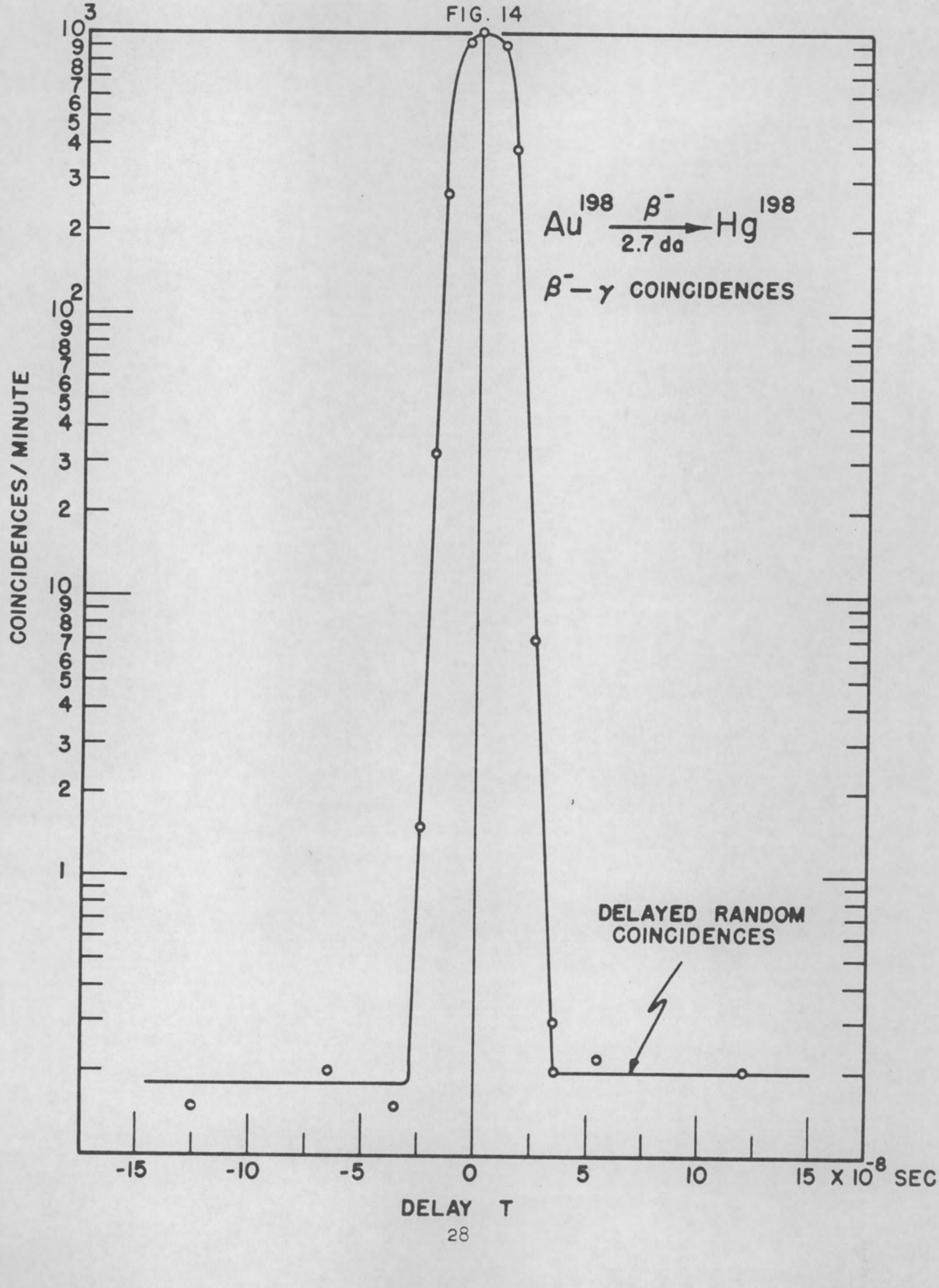

10^3
9
8
7
6
5
4
3
2
10^2
9
8
7
6
5
4
3
2
10
9
8
7
6
5
4
3
2
1
COINCIDENCES / MINUTE
$Au^{198} \xrightarrow[2.7\ da]{\beta^-} Hg^{198}$
$\beta^- - \gamma$ COINCIDENCES
DELAYED RANDOM COINCIDENCES
-15
-10
-5
0
5
10
15
X 10^{-8} SEC
DELAY T

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FIG. 15

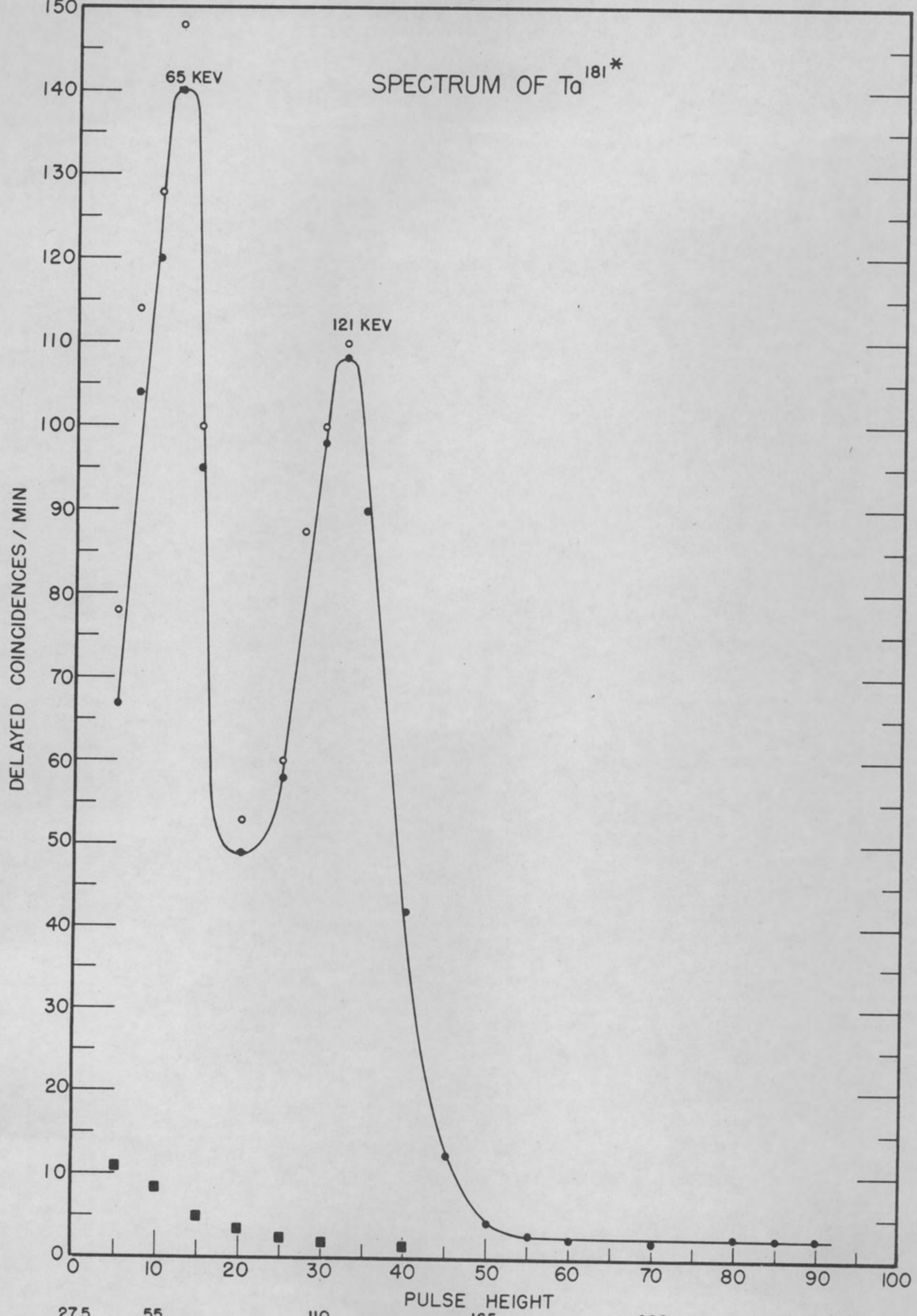


Fig. 16 is a spectrum of Cd^{111*}. The upper curve is the spectrum obtained counting single counts. The first peak is essentially the K and L conversion lines (not resolved) of the 148 Kev transition for the 48 minute isomer. There is possibly a slight bump due to K line of 247 Kev transition of the 8×10^{-8} sec. isomeric state. The lower curve is the spectrum of the short-lived isomeric transition obtained by counting delayed coincidences and now the K line is definitely observed. This line was also used to calibrate the spectrometer.

Fig. 17 is the spectrum of Lu^{177*} obtained with the delayed coincidence scintillation spectrometer. The K and L internal conversion lines correspond to a (150 ± 10) Kev γ-ray transition. From the energy and half-life of this isomeric state it appears that the radiation falls in the classification of either electric octopole or magnetic quadrupole. Internal conversion coefficients would, however, aid to fix the multipole order and electric or magnetic character of the transition.

The following radioisotopes have been investigated for short-lived isomeric states in the region 3×10^{-8} to 10^{-3} sec:

Re^{186}(91 hr) Os^{186}, Yb^{175}(100 hr) Lu^{175}, Lu^{177}(6.8 da) Hf^{177}, Nd^{147}(11 da) Pm^{147}, and Tb^{160}(73 da) Dy^{160}.

FIG. 16

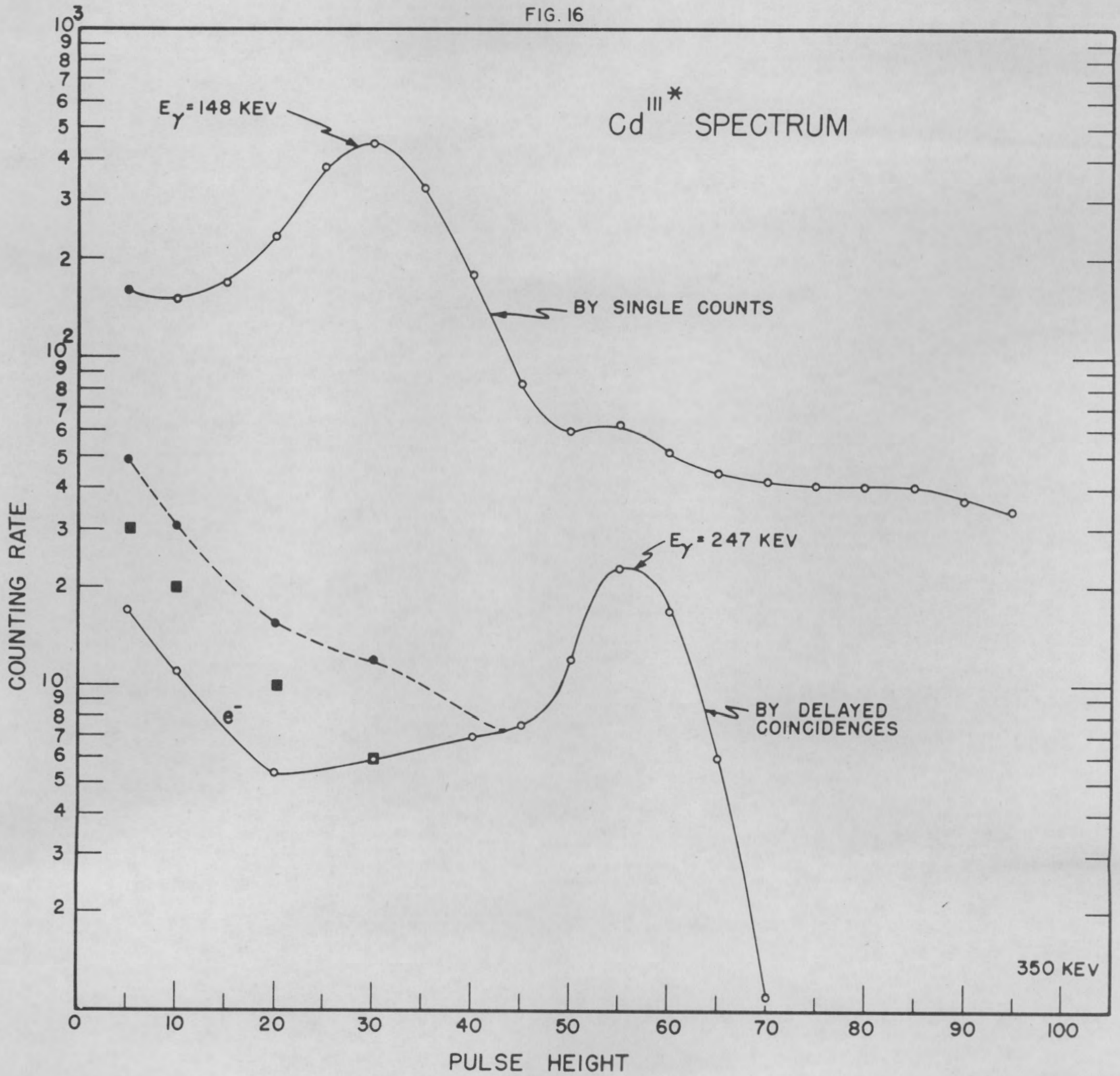
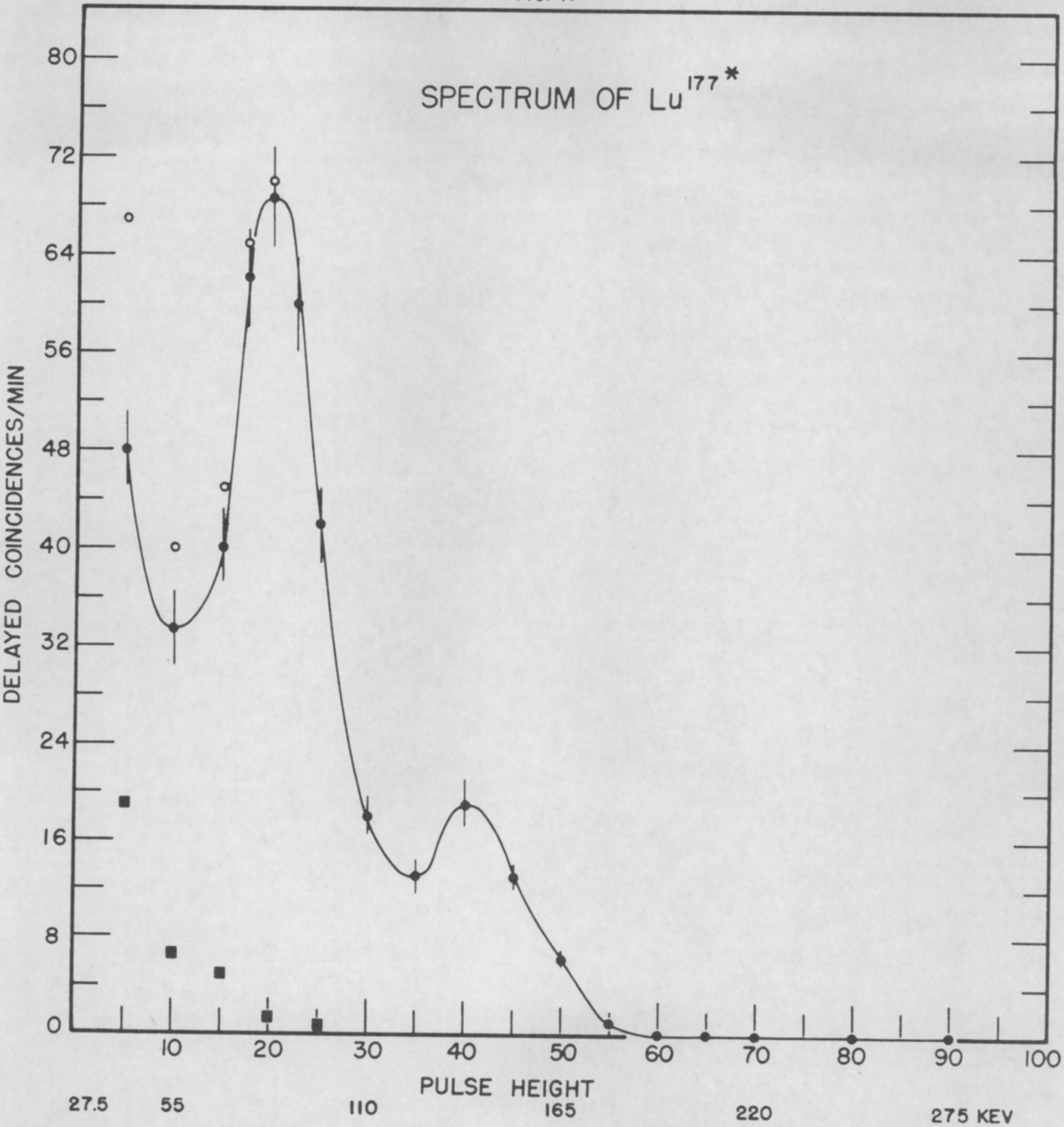

Cd III * SPECTRUM
Eγ = 148 KEV
BY SINGLE COUNTS
Eγ = 247 KEV
BY DELAYED COINCIDENCES
e⁻
350 KEV
COUNTING RATE
PULSE HEIGHT
10³
10²
10
0
10
20
30
40
50
60
70
80
90
100

FIG. 17


SPECTRUM OF Lu177*
DELAYED COINCIDENCES/MIN
0
8
16
24
32
40
48
56
64
72
80
10
20
30
40
50
60
70
80
90
100
PULSE HEIGHT
27.5
55
110
165
220
275 KEV

NEUTRON DIFFRACTION

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

STUDIES OF MAGNETIC SCATTERING OF NEUTRONS

The scattering of monochromatic neutrons by various paramagnetic and antiferromagnetic materials has been under continued study during the last period, and we report further data on new materials and further interpretative results of older data.

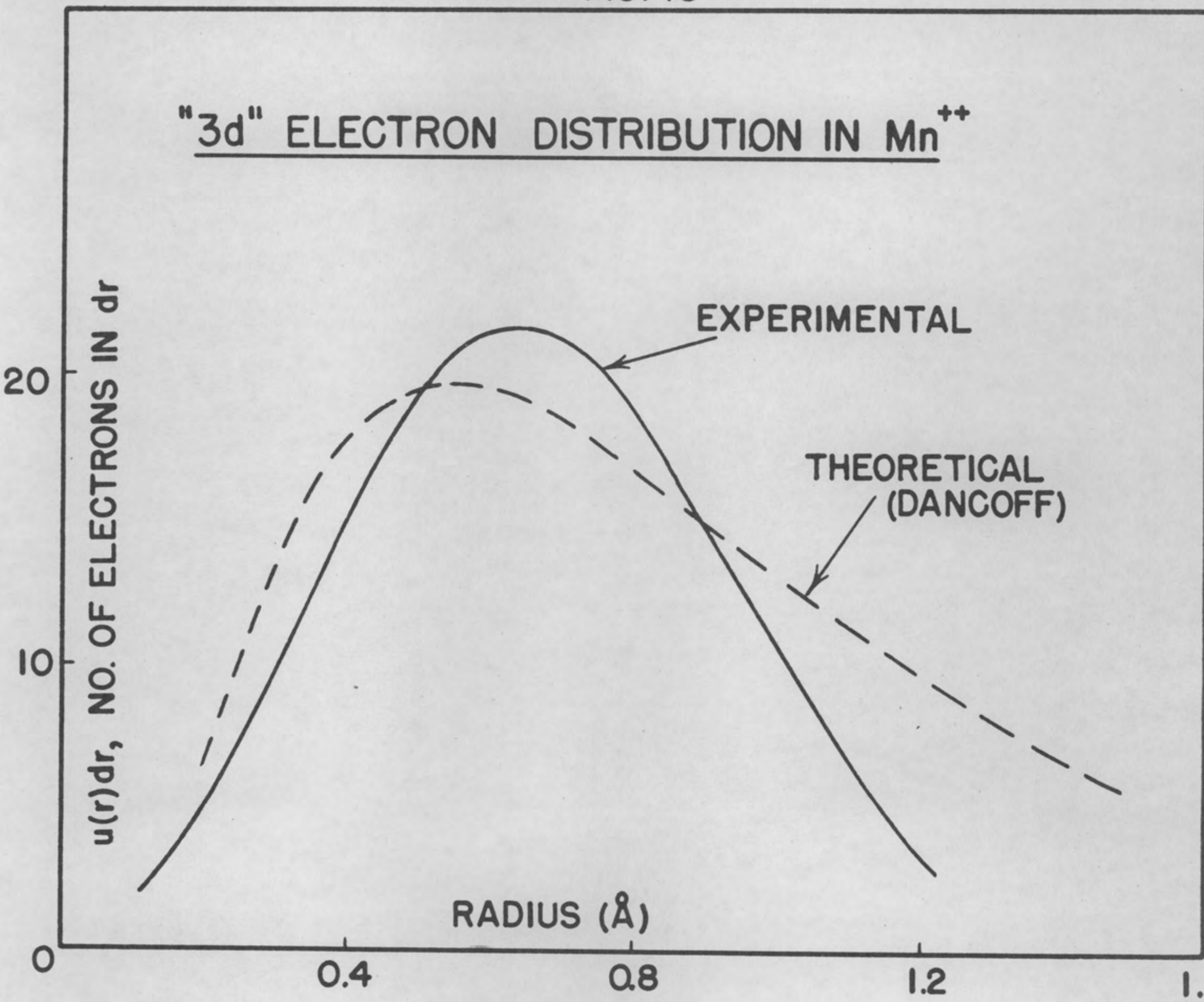
Magnetic Form Factor and Radial Distribution of 3d Shell. It was mentioned in the last quarterly (ORNL 366) that the magnetic scattering by MnF_2 at room temperature resembled closely the expected form factor diffuse scattering. The scattering has been studied with an MnF_2 sample held at 400° C and compared with the room temperature scattering to see if any residual short range coupling in the magnetic moments was introducing coherence into the room temperature results. The high temperature pattern was the same as the room temperature pattern so it appears that these represent accurately the magnetic form factor. Once this has been established it is possible to invert the form factor and determine the radial distribution of the five electrons in the 3d shell which are responsible for the atomic moment of Mn^{++}. From Compton and Allison, p. 464,

$$Z\ U(r) = 2r/\pi \int_0^\infty k\ f(k) \sin kr\ dk$$

where U(r) is the radial distribution of electrons at the distance r from the nucleus and f is the observed amplitude form factor as a function of $k = 4\pi\ (\sin\theta/\lambda)$ with 2θ being the scattering angle. This inversion has been carried out numerically[1] with the results shown in Fig. 18. The distribution is peaked at a little over 0.6 Å and falls regularly on either side of the peak. For comparison purposes, Dr. S. M. Dancoff has kindly calculated the theoretical distribution using a self-consistent field with exchange analysis and his results are also shown on the figure. In general the two curves agree satisfactorily in the inner region but the discrepancy in the outer region appears to be real. The uncertainty in the experimental curve has been investigated by

1 We are indebted to members of the ORNL Mathematics and Computing Panel for carrying through some of the numerical calculations.

FIG. 18


"3d" ELECTRON DISTRIBUTION IN Mn++
EXPERIMENTAL
THEORETICAL
(DANCOFF)
u(r)dr, NO. OF ELECTRONS IN dr
20
10
0
RADIUS (Å)
0.4
0.8
1.2

inverting a series of form factors which could conceivably fit the observed data and all of the radial distributions thus obtained fall off more rapidly at larger than the theoretical curve. Dr. Dancoff feels that this may be a result of his use of an isolated ion in the computation whereas the experimental data are obtained for an ion in a crystal where the distribution might be compressed due to the surrounding neighbor ions.

Magnetic Structure of MnO and MnSe. Neutron diffraction patterns for MnO at 80° and 300° K (above and below the antiferromagnetic Curie point of 122° K) have been given in ORNL 366. It has been found possible to account for the observed intensities of the magnetic reflections on the basis of a sub-cell type of structure. The Mn atoms in MnO are arranged in a face centered cubic lattice and this lattice can be broken down into four interpenetrating, simple cubic lattices. The fact that the repeating distance in the magnetic structure is 8.85 Å rather than the 4.43 Å of the chemical unit cell shows that neighboring atoms on the simple cube sublattice are arranged antiparallel in magnetic orientation. The intensity calculated for a magnetic reflection by one of the sublattices is found to be closely one-fourth of the observed intensity and this implies that the sublattices are scattering independently so that the intensities are additive. Thus the magnetic coupling between nearest neighbors (or between one sublattice and another) appears to be of no consequence whereas the coupling between next nearest neighbors (on the same sublattice) is very strong. This structure is portrayed in Fig. 19 where two of the sublattices are shown.

The antiferromagnetic structure of MnO is being studied by Drs. Anderson and Kittel of the Bell Telephone Laboratories and their exchange energy calculations have led them to expect strong next-nearest neighbor coupling and weak nearest neighbor coupling in complete accord with the above description.

MnSe possesses similar magnetic properties with a Curie temperature around 150° K and this material has been examined in the neutron spectrometer, again at room temperature and at liquid nitrogen temperature. The patterns obtained are exactly similar to those for MnO with extra magnetic reflections appearing at low temperature and indexed on the basis of a double size unit cell. Thus the magnetic structure for the selenide appears similar to that of the oxide.

FeO is also similar to MnO and MnSe in crystallographic structure and in showing an antiferromagnetic Curie point at 198° K and it has also been examined with neutron scattering. The pattern obtained at low temperature is, however, markedly different than those for the manganese compounds and presumably the

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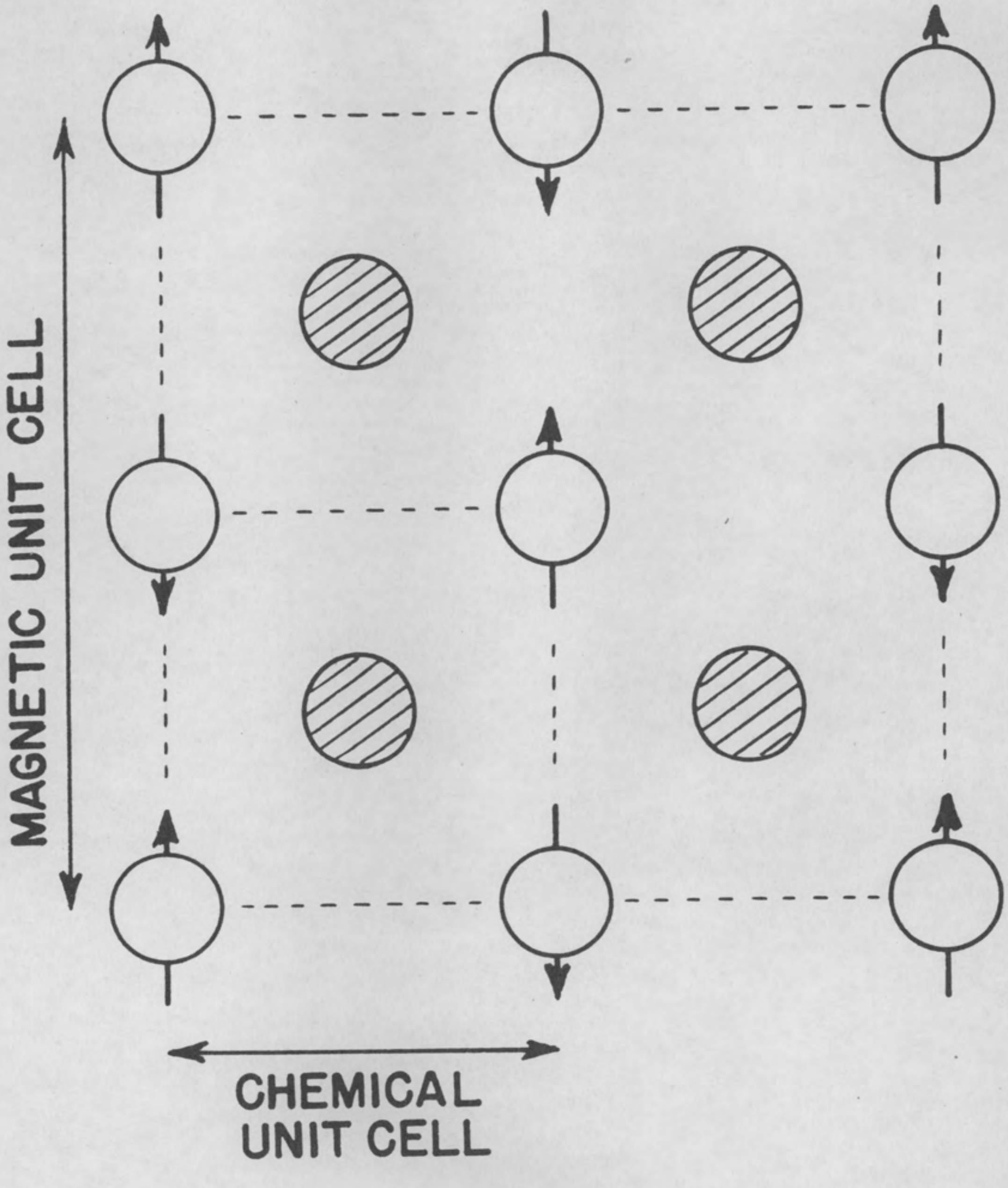
FIG. 19

Mn ATOMS IN Mn O



magnetic structure also is different. The interpretation of these data has not progressed far at this time and will be taken up later.

Magnetic Scattering by Fe_2O_3 Near the Antiferromagnetic Curie Point. The neutron diffraction pattern at room temperature of α-Fe_2O_3 (hematite) has been found to possess extra magnetic reflections. Magnetic susceptibility data for this material have suggested an antiferromagnetic Curie point of 675° C so that it seemed of interest to study the magnetic intensities obtained with the sample held in this temperature range. Fig. 20 shows patterns over the (111), (100) and (110) reflections for temperatures of 20°, 650°, and 710° C. The inner two reflections are magnetic reflections whereas the third is a nuclear scattering reflection. It is seen from the figure that the magnetic intensities have fallen down at the higher temperatures whereas the nuclear scattering has not decreased appreciably. Other temperatures are being examined and it will be interesting to see how sharply the intensities fall off in the vicinity of the Curie temperature.

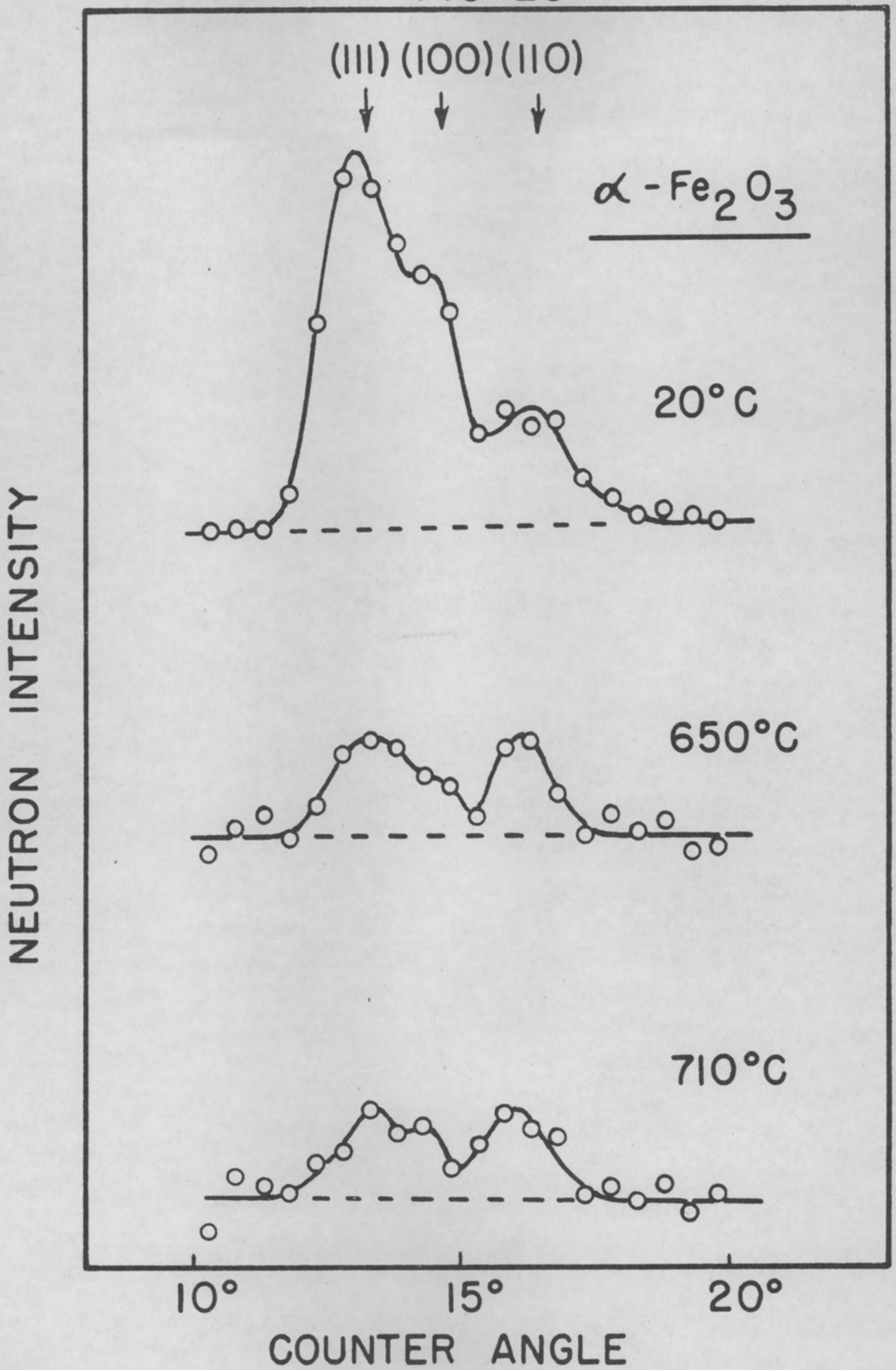
SCATTERING BY NUCLEI WITH ZERO SPIN

In determining the coherent scattering cross section of nuclei by measuring the intensity of diffraction peaks it is necessary to measure either the ratio of the neutron power in the peak to power in the incident beam or to measure the ratio of the scattering power of the unknown to the scattering power of a sample for which the coherent scattering cross section has been accurately determined by other means. With scattering samples containing a mixture of isotopes or for which there is spin dependent scattering, a transmission experiment will give an average over the isotopic and the parallel and antiparallel spin amplitudes of the sample. With a scattering sample consisting of single nuclear species having zero spin the coherent scattering cross section can be obtained from a transmission experiment with monoenergetic neutrons (correction being made for any absorption by the sample). The transmission scattering cross section for a single nucleus is given by

$$\sigma_{trans} = \lambda^2 N/8\pi \sum_{\theta=0}^{\theta=\pi/2} j_{hkl}\, d_{hkl}\, \sigma_{coh}\; e^{-2\pi i(hx+hy+lz)}\; e^{-2W(\theta)} +$$

$$\sigma_{coh} \sum_{\theta=0}^{\theta=\pi/2} (1 - e^{-2W(\theta)}) ,$$

FIG. 20


(111) (100) (110)
α-Fe_2O_3
20°C
650°C
710°C
NEUTRON INTENSITY
10°
15°
20°
COUNTER ANGLE

where W(θ) is the Debye-Waller temperature factor and the last term is the temperature diffuse scattering.

All of our measurements to date have been standardized against diamond with other materials furnishing quite satisfactory checks. In order to pin down the coherent scattering cross sections somewhat more accurately we have been making a careful study of some other zero spin nuclei.

$Ca^{40}O$. Powder diffraction patterns for dried samples of $Ca^{40}O$ have been obtained and also transmission measurements have been made. Both Ca^{40} and O are zero spin nuclei and hence the absolute coherent scattering cross section can be determined from the transmission measurements and the results can be compared with diamond through the diffraction peak measurements. We are not yet able to quote final accurate values for these but tentatively

$$\sigma_{Ca^{40}} = 3.45 \text{ barns and } \sigma_o = 4.2 \text{ barns.}$$

$Ca^{44}O$. The available amount of Ca^{44} does not permit the highest accuracy to be obtained for its cross section. The tentative value is $\sigma_{Ca^{44}} = 0.4$ barns and the scattering amplitude is positive.

Normal CaO. Since normal calcium consists primarily of Ca^{40}(96.96%) and Ca^{44}(2.06%) it would be expected that close agreement would be obtained between the measured coherent scattering cross section for normal calcium and the corresponding value calculated from the Ca^{40} and Ca^{44} cross sections only. The agreement obtained is within experimental error.

Th and ThO_2. Diffraction measurements have been made with powdered crystals of both Th and ThO_2. The results with Th show some oxide contamination and it will be necessary to obtain a purer sample. The ThO_2 results seem very satisfactory but the calculations have not yet been completed.

We hope that when these measurements have been completed our cross section measurements can be put on a more accurate basis.

NEUTRON CROSS SECTIONS

Neutron Polarization (C. P. Stanford, J. I. Hoover). The immediate object of the nuclear polarization low temperature program is to study the transmission of polarized neutrons by polarized nuclei.

The neutron polarization program has proceeded to the point where we have available a neutron beam of approximately 5/8 in. diameter at the position of the proposed (same sized) nuclear polarized sample, with a counting rate of about 10,000 counts per minute and a polarization of 70%. This beam of polarized neutrons was procured by passing a neutron beam from the pile through 5 cm of iron placed between the poles of a strong electromagnet. The 70% polarization corresponds to 85 neutron spins pointing in one direction per 15 neutrons with spins in the opposite direction. A considerable amount of effort has been devoted to increasing both the counting rate and polarization to their present values.

Although the counting rate given seems very adequate, the present use of an arrangement of Pyrex Dewar flasks in the low temperature apparatus cuts the counting rate to 100 counts per minute. This rate is considered to be barely acceptable, considering the period it seems feasible to maintain the low temperatures needed for adequate nuclear polarization in the magnetic field available for this purpose. Steps are being taken to reduce the number of neutrons absorbed by the Dewar flasks by reducing the pyrex wall thickness or by constructing them of more transparent substances such as soft glass or metal.

A second magnet with accompanying power supply has been constructed and tested. It is planned to use this magnet as an analyzer, since we feel that during the course of the work it shall very probably become necessary to know the state of polarization of the neutron beam as it passes through magnetic fields of varying intensity.

Cross Section of He^3 *(T. E. Stephenson).* A sample of He^3 was transferred to a cylindrical steel container suitable for measurements with the neutron crystal spectrometer. The sample contained 73% He^3 at a total pressure of 63 cm Hg. The diameter of the sample was 2.4 mm and its length 2.8 in. Measurements were taken from .03 ev to 0.3 ev. For several reasons the results obtained on this sample are considered to be of doubtful reliability, and are therefore being withheld until additional measurements can be taken on another sample.

Cross Section of Gold (L. W. Cochran). The pile oscillator absorption cross section measurements of H. Pomerance use the absorption cross section of gold as a reference standard. Although gold is a much used project reference standard and its cross section has been measured several times, it was thought advisable to measure the cross section of a sample of the same material used in the pile oscillator measurements. Transmission measurements of a 5.795 gm per cm^2 gold foil were taken with the crystal spectrometer in the region 0.04 to 0.20 ev.

The total cross section may be represented by an equation of the form

$$\sigma_T = \alpha(E_0/E)^{1/2}\,[1 + (2E/E_0)] + \sigma_s$$

in which σ_T is the total cross section and σ_s is the scattering cross section. This expression is a simplified form of the Breit-Wigner equation. It is used here rather than the usual $1/v$ relation so that the resonance in gold at 4.80 ev can be taken into account. The data were fitted to the above expression by R. R. Coveyou and R. Lewis of the Computing Panel using 4.80 ev for the value of the resonance energy E_0, and $\Gamma = 0.5$ ev. Values of $\alpha = 6.85$ and $\sigma_s = 7.59$ were obtained. A summary of observed total cross sections and corresponding values calculated from the formula using these constants is given in the following table:

ENERGY ev	σ_T OBSERVED (barns)	σ_T CALCULATED (barns)
0.0409	83.2	83.1
0.0721	64.8	65.2
0.104	56.2	56.2
0.146	49.5	49.2
0.211	43.4	43.1

Values calculated by means of the equation for E = 0.025 ev are $\sigma_T = 103.5$ barns, $\sigma_s = 7.6$ barns. This value of the scattering cross section agrees with the value 7.5 barns for the coherent scattering cross section determined by the neutron diffraction group.

LOW TEMPERATURE PROGRAM

L. D. Roberts, J. W. T. Dabbs, Jr.,
C. F. Squire, J. K. Leslie, J. Kahn

Previous to the past quarter, the low temperature program at ORNL has consisted primarily of equipment development, installation and testing. During the past three months, however, a number of experiments have been done. In the following paragraphs, we will first describe our further work on instrumentation and then our work on magnetic cooling.

1. *The Coefficient of Expansion of Chrom Alum.* In order to cool other materials with a paramagnetic salt, it is necessary to make metallic contact to the salt. To see if this can adequately be done, we decided to measure the average coefficient of expansion of chrom alum from room temperature to liquid nitrogen temperature, $\sim 77°$ K. This has been done using a single crystal of chrom alum about one inch thick. We obtained a value of 11×10^{-6}. Since copper is 14×10^{-6} in this temperature range, the thermal contact between a cylinder of the alum and a surrounding copper shell would improve when cooled to liquid nitrogen temperatures, i.e. the copper would contract faster than the alum, thus shrinking down on it and making a better contact. The excellence of this contact has been borne out by cooling experiments to be described later.

2. *Temperature Measurement.* An alternating current bridge of the Hartshorn type has been found most suitable by the Leiden Laboratory for the measurement of the real and imaginary components of the magnetic susceptibility—and thus the temperature—of paramagnetic salts cooled by demagnetization. This involves the construction of a variable mutual inductance. A suitable instrument cannot be purchased, and its construction and calibration appeared to present many problems and promised to be very time consuming. It occurred to us that we could, by use of a cathode follower circuit, effectively substitute a variable resistance for a variable mutual inductance. This has been done, and at the present time the bridge can be balanced to 10^{-7} henry and covers a range of a factor of 10^5. The circuit consists simply of a fixed mutual inductance feeding the grid of a triode connected as a cathode follower. The cathode resistor is a potentiometer of very high precision. By varying the potentiometer setting one obtains effectively a variable mutual inductance. So far the development has proceeded quite well. The sensitivity is at present limited by the pick-up of the 5th and 6th harmonic of 60~ power line frequency.

Shielding is being improved and sources of disturbance are being removed so that we shortly hope to be able to increase our amplifier gain, and hence bridge sensitivity, to the Johnston noise limit.

3. *Liquefaction Rate Meter.* One part of the Collins Helium Liquefier is a gasometer which contains a supply of low pressure helium gas. During liquefaction, since the liquid has a specific volume very small compared to gas at NTP, one can determine liquefaction rates by the rate at which this large volume is reduced. We have designed and constructed a rate meter which gives a voltage proportional to the rate of liquefaction by means of a small (5 volts per 100 rpm) generator attached to the gasometer by a suitable combination of wires and pullies. The installation of this rate meter has markedly increased the ease of operation of the liquefier.

4. *Liquefier Operation.* During the past quarter the liquefier has been operated on 18 different occasions with a total production in excess of 200 L of liquid helium. This has been used by cryogenic groups in the Chemistry Division of ORNL and at K-25 as well as by ourselves. On the whole the liquefier operation has been very acceptable.

5. *Magnet Operation.* As mentioned in the last quarterly report a large electromagnet has been installed. This has been used extensively and has been found satisfactory in every respect. At present we have a maximum of but 30 KW for magnet excitation and the fields obtainable for several operating conditions are tabulated below.

	Magnet Current	
Magnet gap	70 Amps	100 Amps
1½ in.	17.5 KG	18.8 KG
1¾ in.	16.5 KG	17.8 KG
2 in.	13.5 KG	15.5 KG

The magnet resistance is about 3.52 ohm.

A new motor generator set is now being delivered which will deliver about 300 KW. Only about half of this can be dissipated in the above magnet, but this should result in a field of $\sim$ 25 KG over a 2 in. gap, a very acceptable situation indeed.

It is interesting to note that, using a solenoid magnet like F. Bitter's, with which he obtained 100 KG at 1700 KW but with a slight design modification, we should be able to obtain close to 45 KG. This would be particularly interesting, should the laboratory wish to attempt nuclear magnetic cooling.

6. *Dewar Flask Development.* Our present technique of using glass Dewar flasks leads to a magnet pole gap of 2 in. Using glass, this cannot be reduced, but on the other hand, it is very important to obtain a higher field than the 2 in. gap permits. With our present overall operating conditions, a 2 in. gap leads to minimum temperature obtained by the adiabatic demagnetization of chrom alum of about 0.08° K while a 1¾ in. gap would give a temperature of 0.006° K and 1½ in. gap would correspond to a temperature of 0.003° K. We have built an all-metal Dewar with a novel liquid nitrogen temperature radiation shield which has a working space of 1.1 in. on the inside and which will fit into a magnet gap of 1½ in. A rate of evaporation of liquid helium of about 45 cc per hour was obtained. This is large but possibly acceptable. We have also made a combination of two Dewar flasks, the inner one being our usual glass type and the outer one—containing the liquid nitrogen heat shield—of metal. This gives a 1.1 in. inside working space and leads to a magnet pole gap of 1¾ in. A satisfactory helium evaporation rate of 20 cc per hour should be obtained. Preliminary tests indicate that the latter combination should be a most suitable one and it will be put into service immediately.

7. *Adiabatic Demagnetization.* During the past quarter a number of adiabatic demagnetizations have been made. We have done some preliminary work with cesium titanium alum investigating the magnetic properties of this salt. A temperature of 0.02° K was obtained in these experiments, but the work has not yet been carried far enough to give a quantitative report of the interesting magnetic properties of this salt.

Using chromium potassium alum we have obtained a lowest temperature of 0.08°, this result agreeing very well with results obtained at Leiden for our operating conditions. However, we had a rather large heat leak of $\sim$ 400 ergs/minute. This corresponds to a temperature rise from 0.08° K to 0.09° K in $\sim$ 30 minutes for our sample size. It should be possible to reduce this heat leak by more than a factor of ten. The trouble, we feel, has been due to an insufficient pumping out of the helium exchange gas, which is used to transfer the heat of magnetization from the alum to the surrounding liquid helium bath. As a result, we have constructed what is perhaps the fastest pumping system ever used for this purpose, and we have every reason to hope that this equipment will adequately remove the exchange gas, giving us a cold time of 3-6 hours.

A study of heat transfer through chrom alum has been made as follows. Two ~ 15 gram samples of chromium potassium alum were compressed into copper cups. The samples were of cylindrical shape, with hemispherical ends, 5/8 in. diameter and about 1½ in. long, and were made by compressing the powdered salt into the cups at about 10,000 pounds/sq in. These cups were connected by a silver tube ¼ in. diameter, with a 0.015 in. wall and 8 in. long. This dumbbell arrangement was then set up in the equipment for adiabatic demagnetization in such a way that the temperature of each of the salt samples could be observed. Initially both samples were at 1.2° K. Then one of the samples was cooled to 0.08° K by demagnetization and the temperature of each sample was plotted *vs* time. Two very nice curves were obtained of the hot sample cooling down and the cold sample warming up. The temperature difference between the two samples fell nicely on an exponential curve, after this ΔT was less than ~0.2° K, i.e. after the specific heats of the two samples were about the same. The relaxation time was 5.6 minutes. This relaxation time is of a reasonable order of magnitude for nuclear alignment experiments.

8. *Plans for Future Work.* As was indicated by one of us, at the Los Alamos symposium on low temperature physics last May, the difficulty in aligning nuclei at low temperatures is fundamentally the difficulty of transferring heat through chrom alum at low temperatures. Nothing that has been done anywhere alters this point, and it is our intention to make every effort to obtain a suitable chrom alum "ice cube" with a better heat transfer rate. The approach that we plan to investigate next is to build up a sort of club sandwich of many thin layers of chrom alum and copper foil, each copper foil being connected to a common heavy heat conductor of copper. There is reason to hope that this will transfer heat adequately down to 0.01° K. With the exception of this unit, apparatus is now complete or near completion which should enable us to align nuclei such as indium at 0.01° K and 20 KG, or nuclei like gadolinium or copper at 0.1° K and using hyperfine structure. The alignment obtained will be observed using polarized neutrons. The problem of

aligning the neutrons has been solved, and is described elsewhere in this report.

9. *Summer Visitors.* The members of the permanent staff of the ORNL low temperature group take great pleasure in acknowledging the inspiration and most effective support given them by Prof. C. F. Squire of Rice Institute during the past quarter. He has taken an active part in every phase of the work described above.

SEMI-CONDUCTORS

K. Lark-Horovitz, J. C. Pigg

It is possible to account for permanent changes in Germanium semi-conductors as due to new impurity centers produced in the lattice sites by transmutations.

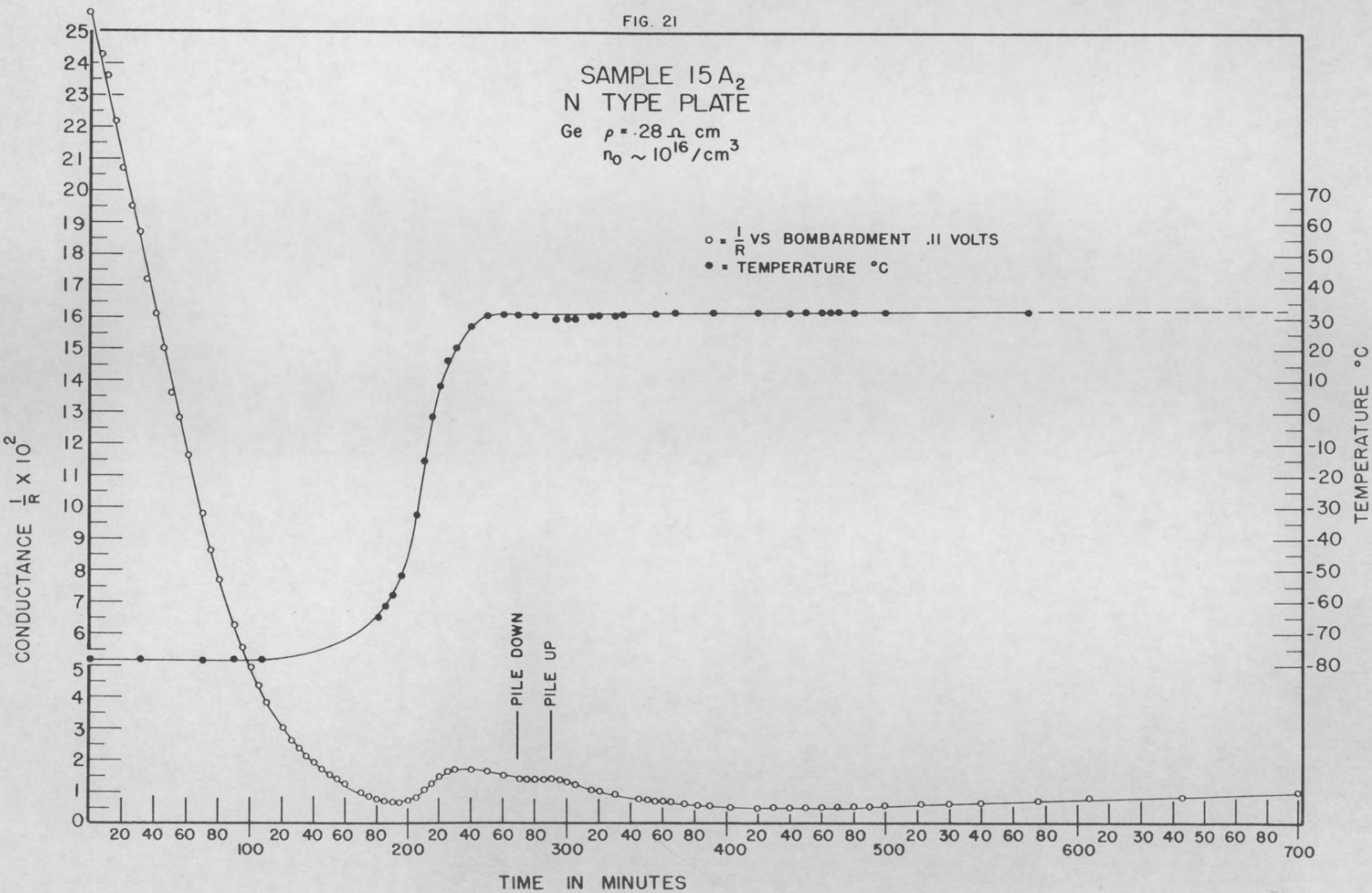
Therefore experiments have been started using Germanium semi-conductors, both polycrystalline as well as single crystals[1] with known number and sign of carriers, to be irradiated by fast and slow neutrons. By heat-treating the sample after irradiation it is possible to heal lattice defects and interstitials due to collision with fast neutrons and the remaining carriers must then be due to impurities produced by transmutation. Using single crystals it should be possible to produce in this way "ideal" semi-conductors where only lattice scattering and impurity scattering determine the resistivity.

In all the irradiation experiments the self-healing at room and elevated temperatures is a factor which is difficult to estimate. Therefore experiments were undertaken irradiating the semi-conductor at dry-ice temperature and following the resistance changes as a function of irradiation and temperature. In some of the very high resistance samples (20 ohm-cm and more) the effect of irradiation at the low temperature is so strong that after a few minutes a resistance peak is reached and then the resistivity as a function of irradiation decreases again. After the temperature has increased the resistance increases again, reaches another maximum and then decreases, as shown in Fig. 21.

This effect, observed in all experiments where irradiation continues during the period when the semi-conductor is warming up from dry-ice temperature to about 20° C is due to the following causes: (a) the number of carriers at low temperature is smaller than at high temperature and therefore neutralized in a shorter time; (b) self-healing is not as effective at low temperatures as at high temperatures and therefore the number of effective new energy levels produced due to collision per unit time is greater. Finally, as the temperature rises the resistance will change as a function of temperature and increases usually with increasing temperature in this temperature range. A theoretical analysis can only be carried out when a large number of samples and of a greater variety has been measured. This irradiation was followed by exposure in the pile until the samples had received an integrated neutron flux of more than 10^{18}.. After the appropriate period the samples will be measured as to resistivity and Hall effect, then heat-treated to 400° C and the number of impurity centers determined from Hall effect measurements.

1 We are indebted to Mr. W. E. Taylor of the Purdue Semi-Conductor Group for the preparation of the samples and to Mr. J. W. Cleland for making the necessary electrical measurements to characterize the samples.

FIG. 21


SAMPLE 15 A2
N TYPE PLATE
Ge ρ = .28 Ω cm
n0 ~ 10^16 / cm^3
○ = 1/R VS BOMBARDMENT .11 VOLTS
● = TEMPERATURE °C
CONDUCTANCE 1/R X 10^2
TEMPERATURE °C
PILE DOWN
PILE UP
TIME IN MINUTES

As has been reported before, Germanium rectifiers of the IN38 or IN47 type are sensitive indicators of the fast neutron flux because of the depletion of the barrier layer. A large number of such rectifiers has been tested at various temperatures to be used eventually as fast flux indicators[2]. Some of the rectifiers have already been investigated in the reactor at dry-ice temperature to check certain predictions of rectifier theory. The behavior at low temperature indicates that field effects and injection play an important part in the behavior of the rectifier.

A cuprous oxide rectifier has been irradiated at constant temperature and it was found that the forward resistance increases upon irradiation.

A special shutter has been constructed so as to allow short irradiations of rectifiers and their withdrawal for determination of the complete I-V characteristic. An experiment of this type carried out on a cuprous oxide rectifier showed an increase in resistance in both directions for voltages over 1 volt, but a more complicated behavior at lower applied voltages.

2 We are indebted to Dr. R. P. Metcalf for assistance in these measurements.

NEUTRON DECAY EXPERIMENT

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

In our last progress report (ORNL 366, p. 55) we presented experimental evidence which was in agreement with the supposition that neutrons decay into protons with the emission of beta particles. The conclusions were based upon coincidence measurements between (1) discharges in a beta proportional counter, and (2) pulses from a secondary electron multiplier so arranged as to count the protons. In simple experimental tests, the coincidences came and went as they should if they depended directly upon the presence of slow neutrons. Since these observations, our efforts have been directed along the following lines:

(1) The plateaus of the beta proportional counters have been improved by changing them from static filling to the flowing gas type. This is most conveniently done by operating at atmospheric pressure.

(2) It has appeared to be important to arrange that "instantaneous" coincidences cannot be recorded; that is, the 0.2-0.6 microseconds required for proton acceleration should be a requisite for the recording of a pulse.

(3) In attempting to put (2) into effect, we have run against the difficulty that our atmospheric pressure counter is too slow in response. Measurements have shown that its firing time is as long as 2 microseconds. Clearly this must be drastically reduced, and at the moment of writing we are planning to accomplish this by reverting to low filling gas pressure, but at the same time keeping the flowing feature.

NUCLEAR PHYSICS

Short-Period Activities with the Fast Pneumatic Tube (E. C. Campbell, W. M. Good, K. G. Robertson). In order to obtain more information about the energies of radiations emitted by substances having half-lives in the range of 0.1 to 10 seconds induced by irradiation in the pile an anthracene scintillation spectrometer has been assembled. Preliminary observations have shown that the method has promise for this application due primarily to the large solid angle which can be accepted as compared with conventional spectrometers. First, tests were made with a 1P21 multiplier phototube and a small anthracene crystal about 2 mm thick. Integral curves of pulse height distribution were made for the 2.5 second (isomeric) activity in erbium, and for the He^6 and F^{20} activities. In agreement with expectations the maximum size scintillation pulses from the soft (about 200 Kev) conversion electrons from Er were much smaller than those from the more energetic He^6 and F^{20} activities. It appears also that to study radiations having high energies it will be necessary to use thicker crystals in order to preserve the linear relation between energy and pulse height. No attempt has been made to obtain an accurate energy calibration of the instrument because it is planned to substitute the better 5819 phototube in the spectrometer. Shielding and mount for this tube have been completed.

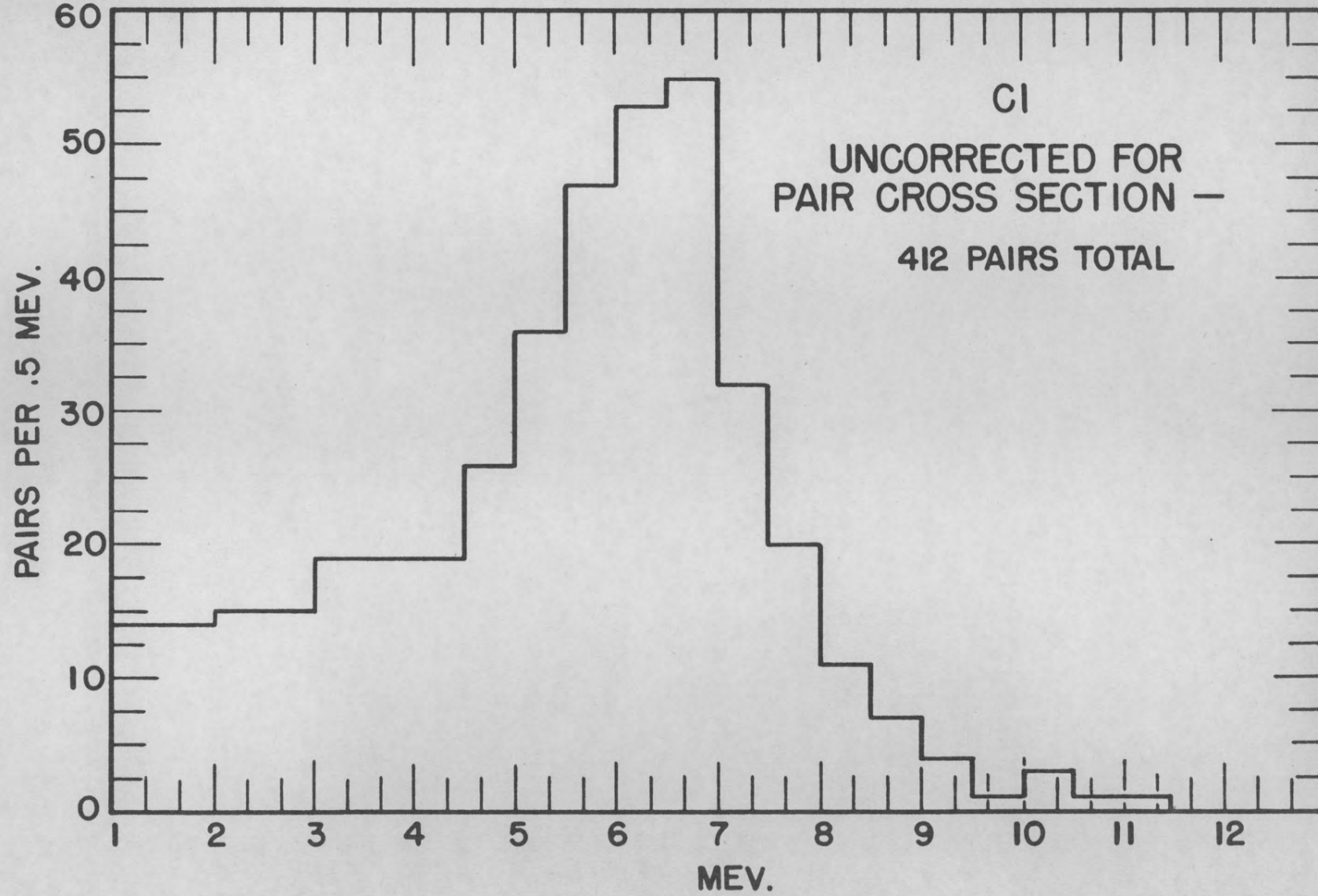
Of the several different methods possible for obtaining the differential pulse-height spectrum from a scintillation counter, the one which seems to be most convenient for studying short-life activities is that suggested by P. R. Bell. In this method the scintillation pulses (suitably lengthened) are displayed on a fast oscilloscope with triggered sweep. A time-exposure photograph of the oscilloscope screen then exhibits a density variation due to the superposed pulses which depends on the pulse-height distribution. Such photographs taken by Dr. Goodrich demonstrate the feasibility of this method for studying the activity in Cesium 137, in which the conversion line on the photograph is seen to be well resolved. An adaptation of this method in which the film is slowly moved during the exposure is suggested in order to distinguish which portion of the observed spectrum belongs to a short-life activity and which belongs to a long-life background. Apparatus for testing this method on short period activities is being assembled.

Cloud Chamber Study of the Energy Distribution of Pairs from Chlorine Capture Gamma Rays (C. D. Moak, J. W. T. Dabbs, Jr.). The histogram of the pair-distribution observed in the cloud chamber measurements on Cl is shown in

Fig. 22.

Measurements of the neutron-flux used and certain comparisons between pair-frequencies and Compton electron frequencies lead us to believe that an unaccountably large fraction of the pairs is being lost in the experiment. This question immediately causes some doubt as to whether the sampling over the energy spectrum is good. Until all the losses are accounted for, the spectra inferred from these data must remain in question. To date the losses have been only partially accounted for, and a report on the capture γ-ray spectrum from Cl cannot be completed until it is known how the sampling affects the observed distribution.

FIG. 22


60
50
40
30
20
10
0
PAIRS PER .5 MEV.
CI
UNCORRECTED FOR
PAIR CROSS SECTION —
412 PAIRS TOTAL
1
2
3
4
5
6
7
8
9
10
11
12
MEV.

VAN DE GRAAFF

W.M. Good, C.D. Moak, J.B. Dial, W.E. Kunz, G.C. Phillips,

R. Lamphere

Since the last report, the following progress has been made in (a) the improved performance of the 2.3 Mev machine, and (b) the conversion of the 2.3 Mev machine to a positive ion machine.

Improving the Performance of the 2.3 Mev Machine. The initial performance of the 2.3 Mev machine was poor because of excessive current and voltage instability. In addition, a check on the calibration of the panel voltmeter was necessary. The scheme of voltage calibration was to get the shape and approximate value of the voltage calibration characteristic by bending the electron beam in a magnetic field and precision determine one point by means of the (γ, n) reaction on beryllium. The electron beam bending indicated a linear characteristic above about 400 Kev as expected. However, because of poor geometry no reliance could be placed on the absolute energy values by this method. However, the qualitative information combined with the calibration point given by the (γ, n) reaction on beryllium makes a knowledge of the voltage developed by the machine rather certain. The machine has generated voltages up to about 2.4 Mev.

The instabilities first observed in the machine were due to the failure of the resistors dividing the voltage down the column. Partly for procurement reasons, but principally to gain flexibility in the machine as well as acquire familiarity, the resistor control was replaced by corona control. This has the advantage of continuous control of the bleeder current down the column. The conversion, however, was followed by a "gunking up" of the machine and a deterioration of the neoprene tube connectors. These effects were attributed to the increased abundance of ozone from the corona control. It is believed that the machine can now be put into reliable operation, and the experience gained used to great advantage. The next step, which is now under way, is electronic voltage control to smooth out the 2% fluctuation inherent in the machine at present. It should be noted that the machine has run for sustained periods at 1.8 Mev and 200 μa.

Conversion to a Positive Ion Machine. Detailed information about performance of the present ion sources awaits the completion of the transformer rectifier voltage supply, now nearing completion. A test section of the proposed tube has been completed and has satisfactorily passed its leak tests. The next operation is that of determining the voltage breakdown characteristic of the section. The special pressurized chamber for conducting the breakdown tests is complete so this phase of the operation can proceed shortly. If the section stands up satisfactorily, work on the tube will commence at once. The upper pulley has been re-designed with a generator capable of furnishing the power requirements of the apparatus under the top terminal. The generators for this pulley are due to arrive shortly. Studies are continuing on the discharge characteristics of CO_2 for use as a filling gas, and also on methods of water removal.

THEORETICAL PHYSICS

M. E. Rose

Since the last quarterly report there have been some rather striking developments in the work on theoretical physics. The specific problems under attack are:

(1) Internal conversion in the L-shell and a continuation of work on K-shell internal conversion. This has been the major effort. Out of this work there will come the material to attack all the problems of what may be called relativistic electron physics and radiation (see below).

(2) The effect of finite nuclear size on beta-decay. This work is almost finished.

(3) The ratio of L to K orbital electron capture. This work is finished.

*(4) Finite size of nucleus in internal conversion (*N. Tralli*).*

*(5) Pair formation (*J. L. Jackson*).*

The following is a skeletal outline of work done and results obtained on the problems.

Internal Conversion. As stated previously the L-shell internal conversion requires the numerical calculation of screened relativistic electron wave functions for bound states of atoms throughout the periodic table and for continuum states, again for Z (atomic number) ranging from 10-90, for energies up to 5-6 Mev and all angular momenta from ½ to 13/2 inclusive. The problems which come up and their present status is described below:

(a) The atomic potential. The potential V in which the electrons move is a sum of three parts: electrostatic part with screening, an exchange potential and for the continuum a hole potential taking into account the subtraction of the self interaction. The model is that of Thomas-Fermi-Dirac. It is not likely that one can do better than this for the present status of the general relativistic electron theory. There is considerable evidence that this model will give results of the accuracy we require. The computation of at least the electrostatic part of the potential has been carried out by other authors for 10 values of Z but there are gaps in the r dependence and it is perhaps better, from the point of view of the machine (Mark III perhaps) to recalculate the fields for the values of Z to be used in the internal conversion work. At present the only problem here is to find a interpolatory-iterative method for the quantity which plays the role of the eigenvalue.

(b) The ground state wave functions. The V discussed in (a) is to be inserted in the Dirac equations. The methods of numerical integration have been examined and it seems clear that the Milne method is quite suitable. The chief difficulty is obtaining an accurate wave function (pair) when one doesn't have an accurate eigenvalue. Good starting eigenvalues were obtained by a comparison of four computed values obtained by Reitz with experimental values. This procedure allows an accurate interpolation for other L_I eigenvalues. For L_{II} and L_{III} the experimental splittings are added. In this way two neighboring trial eigenvalues are obtained. It is then necessary to devise a rapidly convergent procedure for "closing in" on the true eigenvalue after the trial values are used in the integration of the wave equation. Such a method has been developed (3-shot method) and is currently being tested on the IBM installation by Mrs. Dismuke. This method allows for accurate interpolation and should work quite well.

(c) Continuum wave functions. Here the only problem is one of normalization which requires integration out to very large distance and it was necessary to develop more accurate asymptotic formulae for the relativistic wave equation in terms of an arbitrary potential.

(d) In addition, considerable work was done on the following: computation of integrands of matrix elements for the cases computed by Reitz, interpolation methods for the screened potential data, perturbation and variation-iteration methods for obtaining trial eigenvalues. The first mentioned work was of considerable importance in giving us an idea of what regions were important and how this depended on various parameters (energy, angular momentum, etc).

The low Z-values for the K-shell were finished at Harvard on the Mark I. It was found necessary to add additional energy values. This work will be done along with the L-shell and, in fact, the entire K-shell can be repeated *with screening* on the Mark III (if this machine becomes available) with no extra coding and within one day of machine time. The question of making the Mark III available was recently discussed at a meeting between Professor Aiken of Harvard, Mr. Wertheimer and the writer.

Summarizing, the principal problems of methodology for the internal conversion are solved and the details which remain are concerned mostly with small effects which, it is felt, should be taken into account in a precision job such as one wishes to do for the L-shell and such as was done for the K-shell.

The internal conversion work will involve the computation of 40 bound state wave functions and at least 1400 continuum wave functions. With these it will be possible to attack the problems of low energy bremstrahlung, photoelectric absorption, Auger effect (fluorescence yield), nuclear capture of orbital electrons. For bremstrahlung errors of 15% for high energies and as much as 100% for low energies are incurred by the presently available methods of solution. Pair formation and pair annihilation as well as Compton scattering require negative energy state solutions which we do not plan to obtain but the methodology developed is applicable directly to this job.

Finite Size of Nucleus in Beta Decay. It has been shown that the Fermi factor, representing the effect of the nuclear field on electrons and positrons, has to be corrected by a factor which arises because of the finite size of the nucleus. This factor is not *a priori* small. From the results obtained thus far, ft values will be changed appreciably for all heavy emitters and the shape of allowed spectra will be changed by a readily observable amount for heavy emitters with end points of 2 Mev or more. Results for positrons are now being computed. Forbidden transitions will be considered later. None of the results thus far obtained are in contradiction to the experimentally well-investigated spectra. They do bear on the problem of forbidden spectra with allowed shapes and on the question of nuclear matrix elements.

Orbital Electron Capture. The ratio of L_I to K capture in A^{37} as measured by Hanna, Kirkwood and Pontecorvo is between 8 and 9%. The hitherto existing theoretical approaches to the calculation of this ratio gave 12.5% for unscreen Coulomb wave functions and 6% for Coulomb functions with Slater screening constants. Using Reitz's L_I shell wave functions ($Z = 29$ to 92) we extrapolate to find L_I/K capture = 8.2% and using Hartree wave functions for A we find 8.1%.

Finite Size of Nucleus in Internal Conversion. N. Tralli investigated the effect of the finite size of the nucleus on internal conversion. The effect on radiation potentials and on both ground state and continuum wave functions was considered. It is to be expected that the effect is small and so far as the work was carried, the expectation was confirmed. The work was necessarily terminated since Mr. Tralli worked as a summer visitor. A report (ORNL 460) has been prepared.

Pair Formation. An attempt was made by Mr. J. L. Jackson to develop approximate Dirac wave functions which will take the Coulomb field partially into account. This would be an improvement on the Born approximation and would constitute an alternative approach to that of Sommerfeld and Maue. The attempt proved abortive. The Sommerfeld-Maue wave functions were used in the calculation of the internal pair formation process but in the time available no results were obtained. Certain results of interest on Green functions were obtained and these have been described in a report which has been prepared. Mr. Jackson collaborated in the calculation of the L to K ratio of orbital electron capture.

PUBLICATIONS

"Internal Pair Formation", M. E. Rose, *Phys. Rev.* 76, 678 (Sept. 1, 1949)

"Production of C^{14} in a Nuclear Reactor", L. D. Norris and Arthur H. Snell, *Nucleonics*, Vol. 5 #3, pp. 18-27.

"Neutron Irradiated Semiconductors", W. E. Johnson and K. Lark-Horovitz, *Phys. Rev.* 76, 442 (Aug. 1, 1949).

"Beta-Decay of In^{115}", P. R. Bell, B. H. Ketelle and J. M. Cassidy, *Phys. Rev.* 76, 574 (Aug. 15, 1949).