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PHYSICS DIVISION

A. H. Snell, Director
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QUARTERLY PROGRESS REPORT

for Period Ending June 15, 1950

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INTRODUCTION AND SUMMARY

The following report covers the unclassified work of the Physics Division for the period March 15 - June 15, 1950. The classified work is reported separately in ORNL 781.

Symposium on Nuclear Physics of the Light Elements. On June 8 and 9, the Physics Division sponsored a Symposium on the nuclear physics at present being done with high voltage tubes and electrostatic generators. About fifty people from other laboratories in the United States and Canada attended. The program was as follows:

Opening Announcements	A. H. Snell, Oak Ridge National Laboratory
Chairman, June 8	R. G. Herb, University of Wisconsin
Some Results on Ground States and Excited States from Magnetic-Analysis Experiments	W. W. Buechner, Massaschusetts Institute of Technology
Interaction of Tritons with Protons and Tritons	A. Hemmendinger, Los Alamos Scientific Laboratory
Study of Nuclear Energy Levels by Fast Neutrons	H. H. Barschall, University of Wisconsin
Energy Levels in Some Light Nuclei as Obtained by Neutron Thresholds Excitation Curves, Gamma Ray Energies, and the Energies of Disintegration Particles	T. W. Bonner, Rice Institute
Chairman, June 9	S. K. Allison, University of Chicago
Cross Sections of Thermonuclear Reactions in the Carbon Cycle	W. A. Fowler, California Institute of Technology
Gamma-Ray Angular Distributions and Proton Scattering	R. F. Christy, California Institute of Technology

Scintillation Spectrometry. The resolution of the scintillation spectrometer has been improved to the extent that a conversion electron line at 626 Kev has a full width at half maximum of 12 percent. Additional improvements with known phosphors probably can be only rather minor.

A large number of solution phosphors have been tested, the best of which are variants of the terphenyl-xylene combination. One percent of other organic phosphors mixed with pure anthracene seems to have only deleterious effect upon pulse size. Thallium-activated sodium idodide gives very satisfactory performance as a phosphor, and gamma spectra have been obtained with it from 330 day Cd, Hg^{203}, Cs^{137}, Co^{60}, K^{42}, Na^{24}, Na^{22}, Cu^{64}, and a Po-Be neutron source (C^{12} excited state at 4.4 Mev). The K^{40} gamma ray was remeasured at 1.46 ± .01 Mev; fewer than two positrons are emitted per 10^5 beta particles. The existence of a natural activity in lanthanum is confirmed, but a reported activity in cerium appears to arise from thorium contamination.

Short-Lived Isomers. A metastable level with a half-life of 5.7×10^{-9} sec has been discovered and studied. As regards shortness of decay period, this sets a record for activities discovered in the Territories south of the Canadian border.

Short Lived Activities. A krypton-filled proportional counter has been used to reveal the presence of X rays from various short-lived activities.

The Total Cross Section of Holmium. Holmium has been found to have the rather large cross section of 16 barns for paramagnetic scattering at 0.03 ev.

Neutron Diffraction. Observations on the directional intensity of magnetic scattering from powdered Fe_3O_4 have confirmed predictions of the Halpern-Johnson theory, as opposed to predictions of Bloch and Eckstein.

An investigation of Fe-Cr alloy has failed to reveal a superlattice; the alloy structure appears to be disordered. Chromium is found to scatter with positive phase and with a cross section of 1.7 barns.

Uranium dicarbide is found to have a crystal structure similar to that of calcium carbide.

Low Temperatures. In the nuclear alignment work, the susceptibility of manganous ammonium sulphate has been studied as a function of H. The object of the measurements was to obtain information about the limiting magnetic field below which demagnetization in the main experiment would result in a loss of nuclear alignment through loss of alignment of the electronic magnetic vector.

Irradiation of Semiconductors. Irradiation of copper oxide rectifiers leads to a rapid decrease in conductivity in the forward direction, until a value corresponding to that of the backward direction is approached. Attempts are being made to explain the observed changes in conductivity for bulk Cu_2O in terms of P-N conversion.

Preliminary experiments indicate that it may be possible to transform N-type germanium semiconductors into intrinsic semiconductors by introducing just the right number of gallium impurity atoms by transmutation with neutrons.

Properties of Bonded Wire Resistance Strain Gauges. A report is given on the techniques and usefulness of bonded wire strain gauges in measurements of thermal expansion coefficients. For accurate measurements, a variety of precautions must be observed in their use.

Theoretical Physics. Work on the effect of the finite size of the nucleus upon beta-decay has continued, and, although numerical results are not yet at hand, it is apparent that the effect may be appreciable for some transitions in the heavier elements ($Z > 60$), revealing itself in a modification of ft values and in the shape of the spectrum.

PUBLICATIONS

The following contributions by members of the Physics Division have appeared in the public journals between March 1, and July 1, 1950:

"Polymorphism of Calcium Orthosilicate," M. A. Bredig, *J. Am. Ceramic Soc.*, **33**, 188-192 (1950).

"Transmutation-Produced Semiconductors," J. W. Cleland, K. Lark-Horovitz and J. C. Pigg, *Phys. Rev.* **78**, 814 (1950).

"Fast Neutron Bombardment Effects in Germanium," J. H. Crawford, Jr., and K. Lark-Horovitz, *Phys. Rev.* **78**, 815 (1950).

"Radioactive Decay of the Neutron," Arthur H. Snell, Frances Pleasonton and R. V. McCord, *Phys. Rev.* **78**, 310 (1950).

"Pair Production and Photoelectric Effect in Scintillation Phosphors," P. R. Bell, *Science*, (June 4, 1950).

"Measurement of Gamma Rays of K^{40}," P. R. Bell and Judith M. Cassidy, *Phys. Rev.* **79**, 173 (1950).

"Transmutation-Produced Germanium Semiconductors," J. W. Cleland, K. Lark-Horovitz, and J. C. Pigg, *Phys. Rev.* **78**, 814-815 (1950).

"Fast Neutron Bombardment Effects in Germanium," J. H. Crawford, Jr., and K. Lark-Horovitz, *ibid*, 815-816.

PHYSICAL ELECTRONICS

SCINTILLATION SPECTROMETRY

P. R. Bell J. M. Cassidy
W. H. Jordan R. C. Davis

The energy resolution and accuracy of measurement of energy have been considerably improved both for beta and gamma rays.

Energy Resolution. It has been shown by the measurements of Hopkins[1] that the resolution now obtained is near the maximum possible with phosphors known today. The width of peaks produced in anthracene by monoenergetic electrons (~ 12% full width at 1/2 maximum for 626 Kev) can be accounted for by the statistical variation of the number of photoelectrons produced at the photocathode, including the effects of the multiplication process.[2] The photo efficiency of RCA-5819 tubes often is within a factor of two of theoretical perfection so that little improvement in resolution can be expected from this direction. The light emission from anthracene and NaI-TlI is in the region of the maximum sensitivity of the antimony-cesium photosurface and is also largely transmitted by the tube envelope and by the lucite used as a diffusive light piper.

Measurement, both by Hopkins and Bell, of the number of photoelectrons emitted from the photocathode of a good 5819 tube with good optical conditions by a light flash in anthracene produced by a known energy electron gives the apparent efficiency of the phosphor. It was found that between 400 and 500 photoelectrons are produced per Mev of energy loss in anthracene. The pulse size for commercially available sodium iodide-thallium (Harshaw) is very nearly the same although some specimens of NaI-TlI have been produced by R. C. Davis and by R. Hofstadter that give a pulse nearly double this size.

If the optical efficiency of the scintillation counter is assumed to be about unity and the efficiency of the phototube about 0.1 (one photoelectron released for 10 incident photons), the anthracene and NaI-TlI energy efficiency from beta ray to photoelectron is about 1%. An interesting side result is

---

(1) Hopkins, J. I., Forthcoming in *Rev. Sci. Inst.*

(2) Morton, G. A., *Pulse Size Distribution from a Secondary Emission Multiplier*, MonP 333 (July 10, 1947); Morton, G. A. and Mitchell, J. A., "Performance of 931-A Type Multiplier as a Scintillation Counter," *Nucleonics* 4, No. 1, 16 (1949).

that the efficiency of good ZnS-Ag (Patterson D) phosphor for alpha particles is nearly the same as that of anthracene for electrons, when considered on a photoelectrons out to particle energy in basis.

Phosphors

a. *Anthracene.* Anthracene from several sources has been tested. University of Rochester anthracene, very recent Harshaw anthracene and our own give very nearly identical pulse sizes. Earlier Harshaw anthracene (late '49) gave somewhat smaller pulses (70%). A number of samples prepared by the Chemistry Division of ORNL were tested. Some early samples gave wide low peaks for mono-energetic electrons; later samples grown by the reflux method gave better results but even the latest gave pulses somewhat too small although the samples were extremely clear and free from cracks and quite colorless. A method for improving the performance of very large anthracene crystals which always have a number of cracks has been long in use although it has not been reported before. The crystal is suspended over a container of Canada balsam dissolved in xylene or toluene inside a vacuum desiccator. The desiccator is pumped with a fore pump until the solution boils vigorously for four or five minutes. The crystal is then tilted into the solution and after a short time air is let into the desiccator. The crystal is removed from the solution and the outside cleaned off with toluene. Crystals so treated give much better pulse distributions, probably due to the better optical transmission.

b. *Solution Phosphors.* Certain substances do not follow the general behavior of fluorescent substances in solution. A fluorescent substance generally yields less and less light as its solution becomes more and more concentrated, giving little or no fluorescence in the pure liquid substance (this explains the sudden cessation of fluorescence in anthracene when it melts). This self quenching of fluorescence is very slight for fluoranthene and terphenyl. Solutions of these substances give moderately large pulses in dilute solutions in organic solvents.[3] Figures 1a&b shows the curves given by various substances in various solutions. Note the amplifier gain is different for various solutions. The exciting radiation is Cs^{137} beta rays. For comparison, part of a curve for solid anthracene is given. Complete results are listed in Table I. The best solution, terphenyl in m-xylene (0.5 g/100 cc), gives pulses three or four times smaller than anthracene.

A solution phosphor 2-1/4 in. in diameter and 7 in. long was tested. The resolution obtained was similar to that of smaller volumes of solution. This counter gave a background count of

(3) Reynolds, G. T. "Liquid Scintillation Counters." *Nucleonics* 6, No. 5, 68 (1950).

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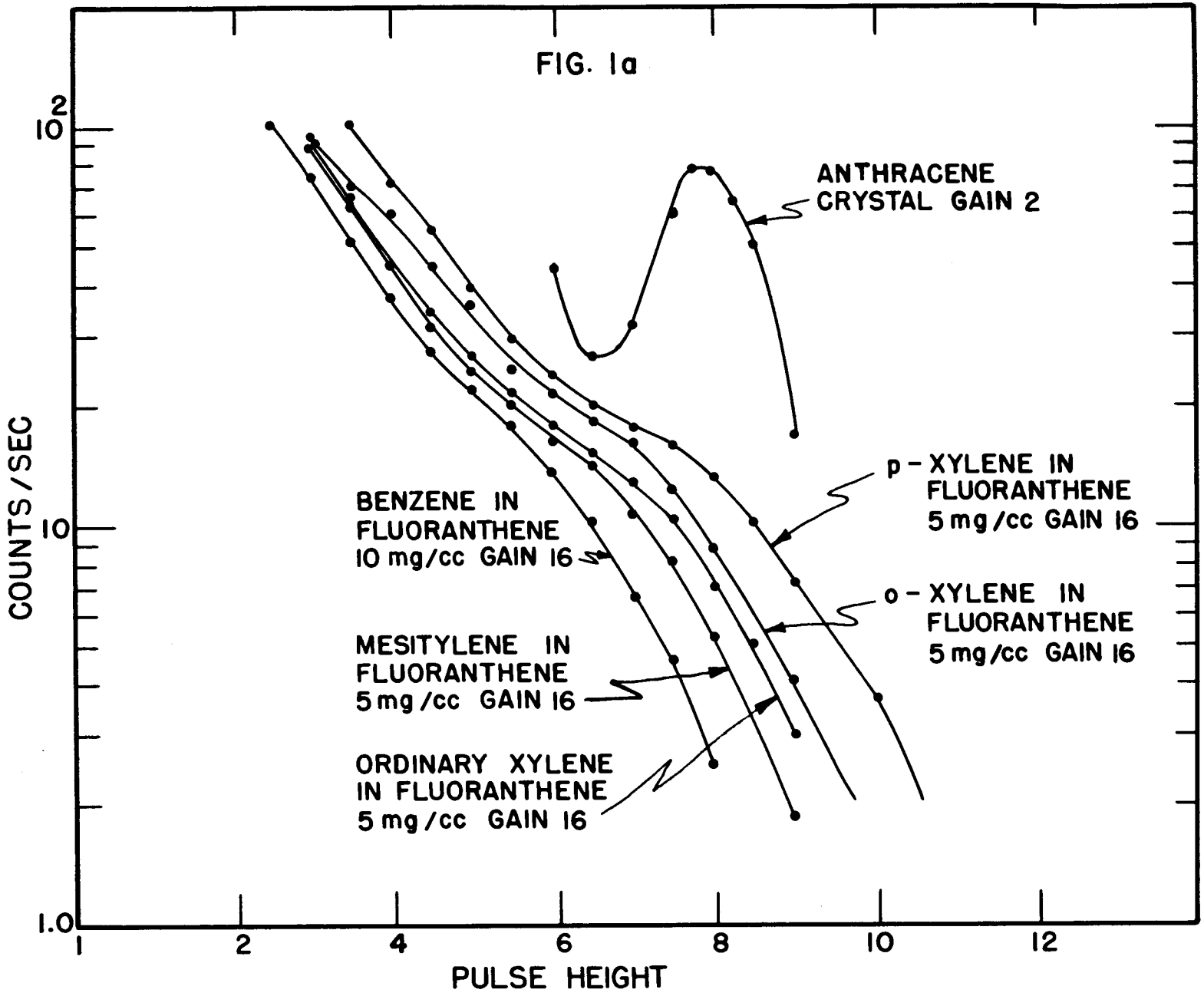

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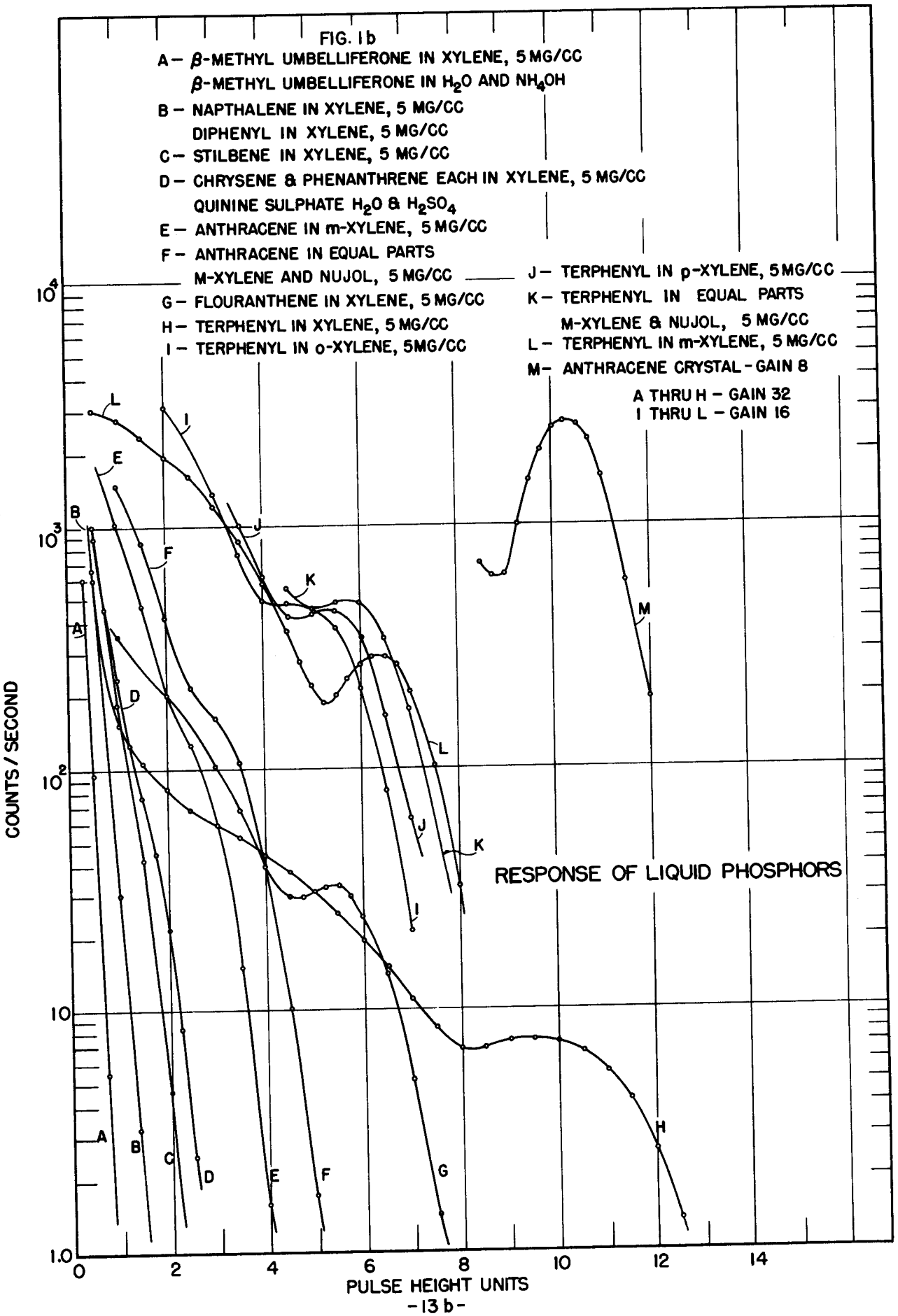

TABLE I

Phosphor	Pulse Height
Anthracene crystal	1.00
M-xylene and terphenyl	.34
M-xylene, nujol and terphenyl	.32
P-xylene and terphenyl	.30
O-xylene and terphenyl	.28
Ordinary xylene and terphenyl	.27
Xylene and fluoranthene	.15
Anthracene with equal parts m-xylene and nujol	.093
M-xylene and anthracene	.075
Quinine sulphate, H_2O and H_2SO_4	.053
Ordinary xylene and chrysene	.053
Ordinary xylene and phenanthrene	.053
Ordinary xylene and stilbene	.040
Ordinary xylene and naphthalene	.029
Ordinary xylene and diphenyl	.029
Ordinary xylene and β-methyl umbelliferone	.016
β-methyl umbelliferone, H_2O and NH_4OH	.016
P-xylene and fluoranthene	.15*
O-xylene and fluoranthene	.13*
Mesitylene and fluoranthene	.125*
Benzene and fluoranthene	.110*
Ordinary xylene and fluoranthene	.128*

* Measured with ultra-violet photomultiplier type C-7140.

50 counts per second in the physics counter room shielded with 2-1/2 feet of concrete. None of these counts were due to the phototube, of course, since the discriminator was set to count pulses of 100 Kev and greater (equivalent electron energy in the solution).

c. *Solution phosphors with solvents containing high Z substituents.* Tests were made with chloroform and ethyl iodide as solvents and extremely small pulse sizes were observed. Examination of other solvents is in progress.

d. *Anthracene mixtures.* Mixtures of anthracene and about 1% of various other organic phosphors were made and crystals grown from them by R. C. Davis. These crystals were all good and transparent but all of them gave smaller pulse height than anthracene. Table II gives the results compared with pure anthracene whose pulse height is taken at 1.00.

TABLE II

Anthracene +	Pulse Height
Anthracene	1.00
1% trans-stilbene	.63
1% Pyrene	.88
1% Fluoranthene	.88
1% Fluorene	.52
1% Phenanthrene	.84
1% Naphthalene	.75
1% Terphenyl	.78

e. *Sodium iodide, thallium activated.* After the stimulating letter by S. E. A. Johansson,[4] further study of the sodium iodide phosphors was begun after a long lapse. A single crystal of NaI with about 1/2 to 1% thallium impurity, made by the Harshaw Chemical Company, was obtained. A cylinder 1-1/2 in. diameter and 1 in. high was ground with carborundum paper and finished with metallographic emery paper. The crystal was inserted into

(4) Johansson, S. A. E., "Measurements of the Energy of Beta- and Gamma-Rays with a Scintillation Counter," *Nature* 165, 396 (1950).

a fitting lucite box with 1/16 in. thick sides and the box end filled with the standard 1-1/2 in. diameter, 3/4 in. high lucite light piper and the two parts joined with ethylene dichloride. The space between the crystal and the lucite box was filled with dry mineral oil. All of the work had to be done in the dry box since the NaI-TlI is extremely hygroscopic. This crystal assembly was attached to a 5819 photomultiplier with Canada balsam and covered by an aluminum reflector. The results obtained appear in Figs. 2 to 7. Samples of various substances were placed close to the crystal with sufficient absorber between sample and crystal to remove the beta rays, if any, that were emitted. Peaks arising from the photoelectric process are observed from 22.2 Kev (Ag Kα X-ray) to 4.44 Mev (excited state of C^{12}). These peaks are at a pulse height corresponding to the gamma ray energy since the X-rays or Auger electrons from the iodine atom from which the photoelectrons come are detected with substantially 100% efficiency and are, for all practical purposes, simultaneous with the photoelectron. The sum of all the pulses is thus recorded by the amplifier.

Figure 2 shows the response to the radiations from 330 d cadmium. The Ag K X-rays give a good peak despite their low energy. The gamma ray energy is not too well known but is reported at 88.4 Kev. This gamma ray is largely internally converted accounting for the small intensity of this peak. Another weak gamma ray can be seen between the two peaks.

Figure 3 is the pulse spectrum produced by 51.5 d Hg^{203}; the well known gamma ray at 279 Kev and the Hg K X-rays produce good peaks. The turn up at low pulse size is due to the L X-rays. The Compton electron distribution can be seen below the X-ray line breaking off at 450-550 pulse height divisions. The gamma ray of Cs^{137} at 0.661 Mev gives the curve of Fig. 4. Here the curve is plotted on linear paper rather than the usual semi-log. The full width at half maximum for the peak is about 11%, approximately the same as for anthracene. The broad peak at 350 pulse height is due to gamma rays leaving source (near the crystal) and producing a Compton scattered photon in the surrounding lead shield. Those scattered photons that reach the crystal must proceed almost directly backward, and hence are almost monoenergetic and near the minimum energy (0.184 Mev) for a single Compton scattering for the .661 Mev initial energy. The turn up at low pulse height is largely due to Ba K X-rays.

The effect of collimation on the detected pulse spectrum can be seen in Fig. 5. Curve 1 produced by a 1/2 mc source of Co^{60} at several feet shows many degenerate gamma rays produced by back scattering, making the curve rise at low energies. The two gamma rays (1.17 and 1.33 Mev) are clearly resolved however.

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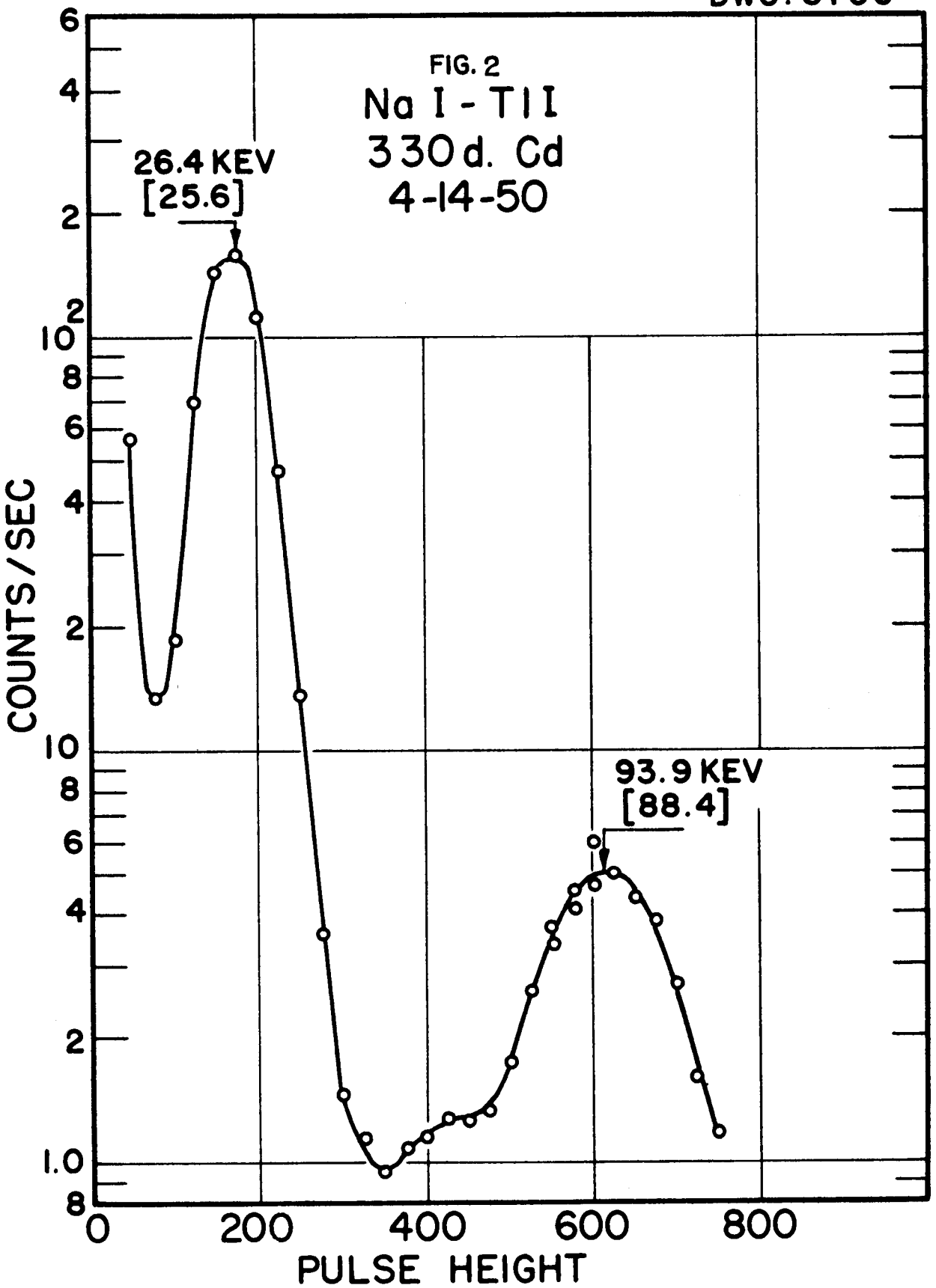

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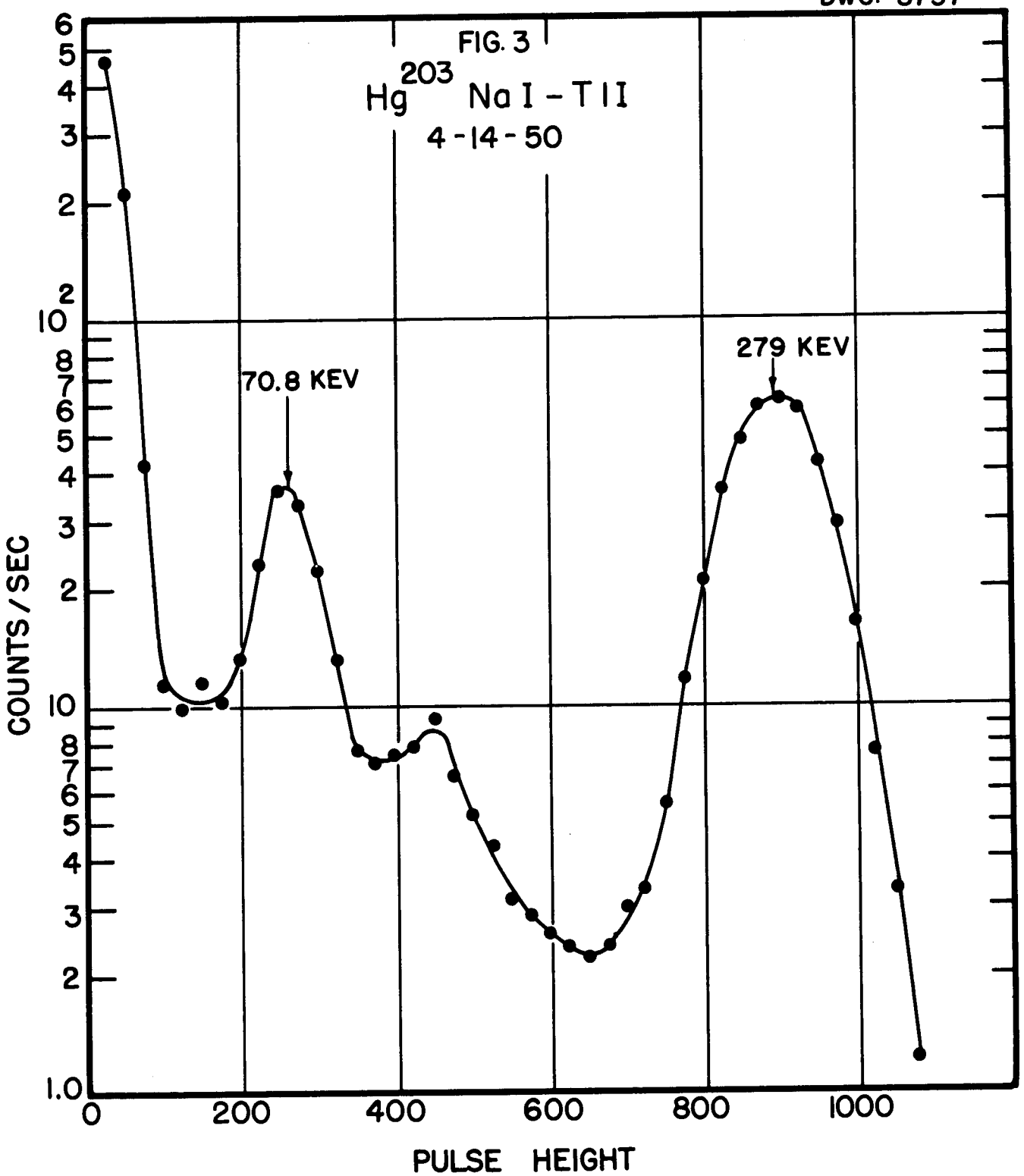

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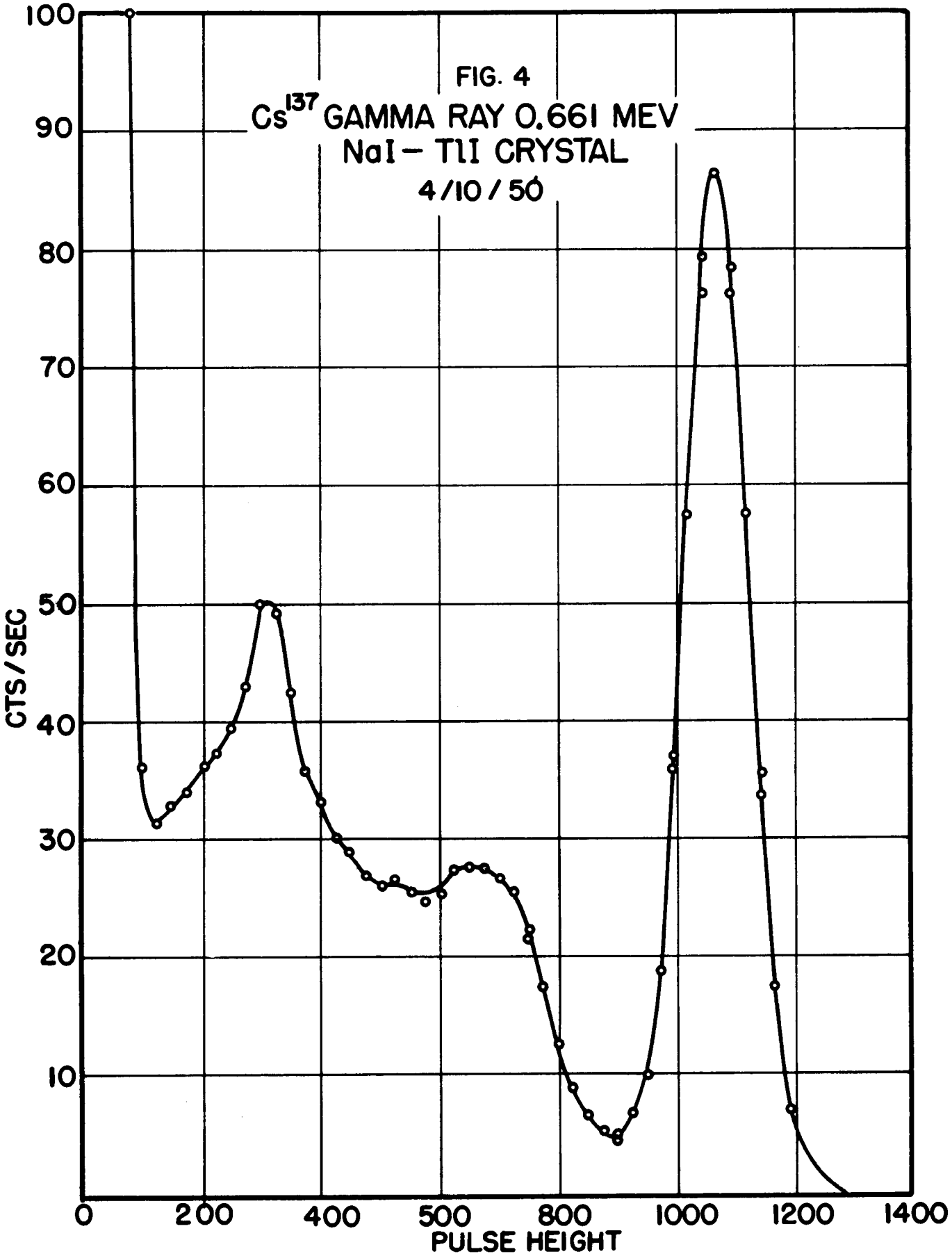

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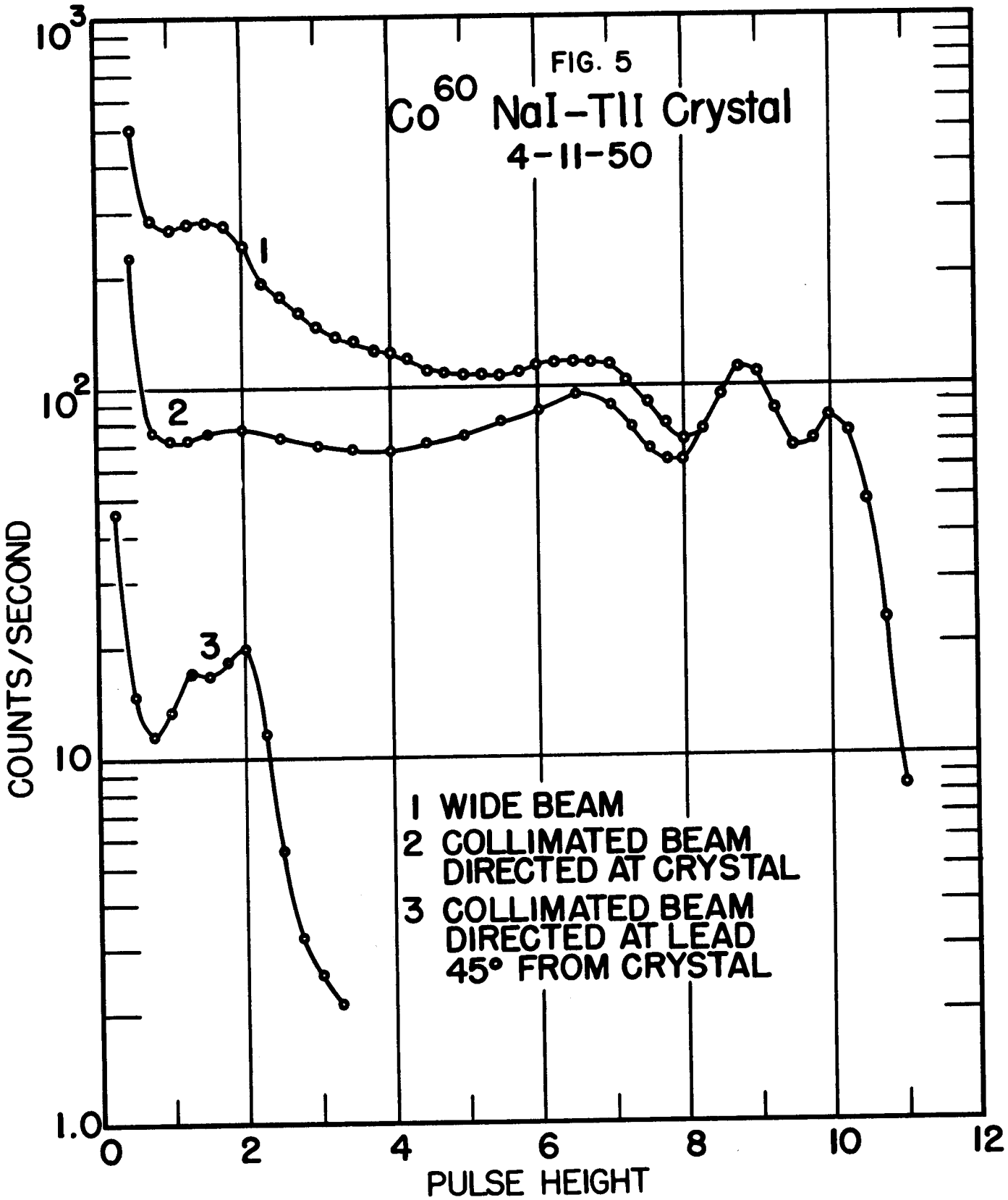

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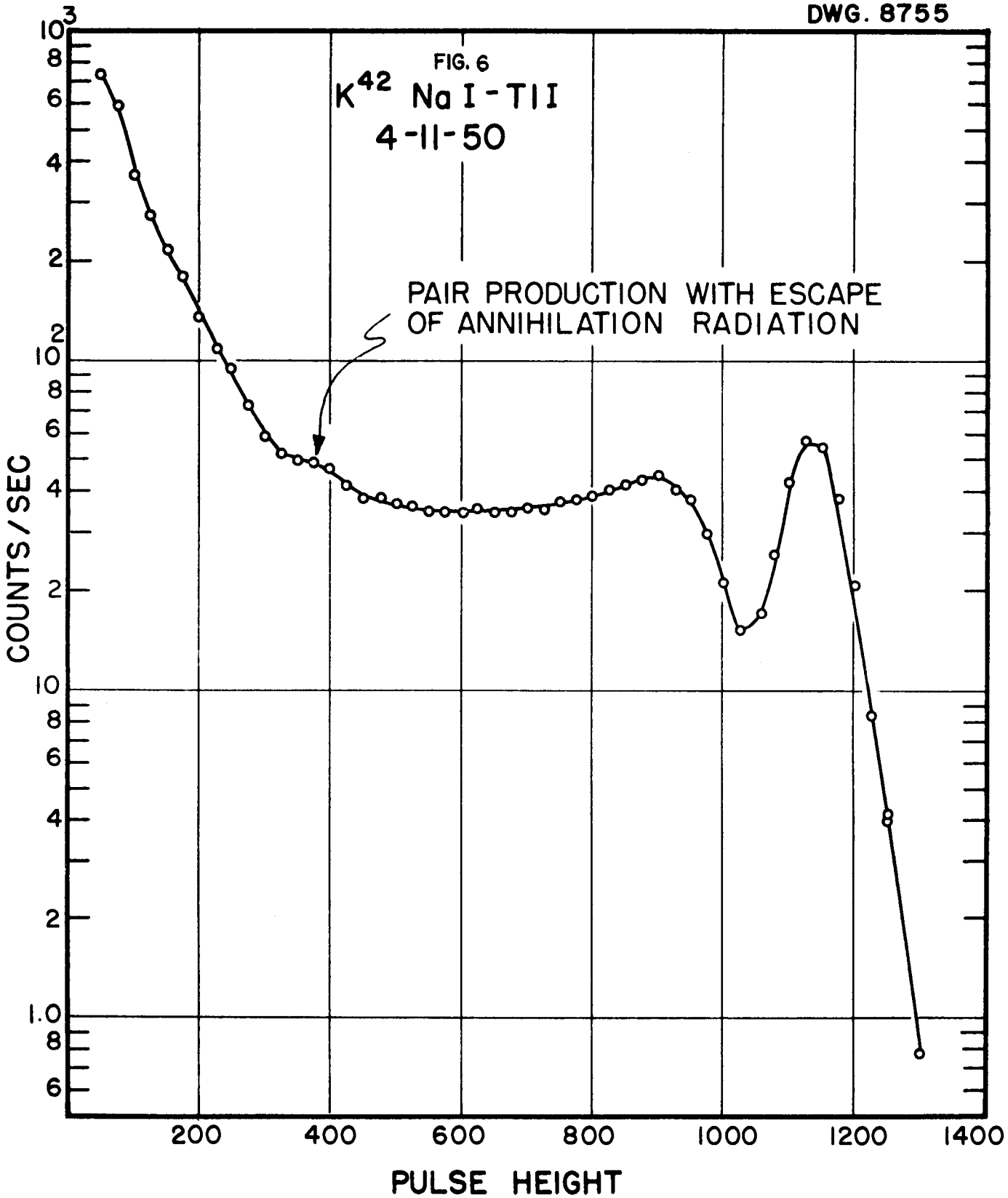

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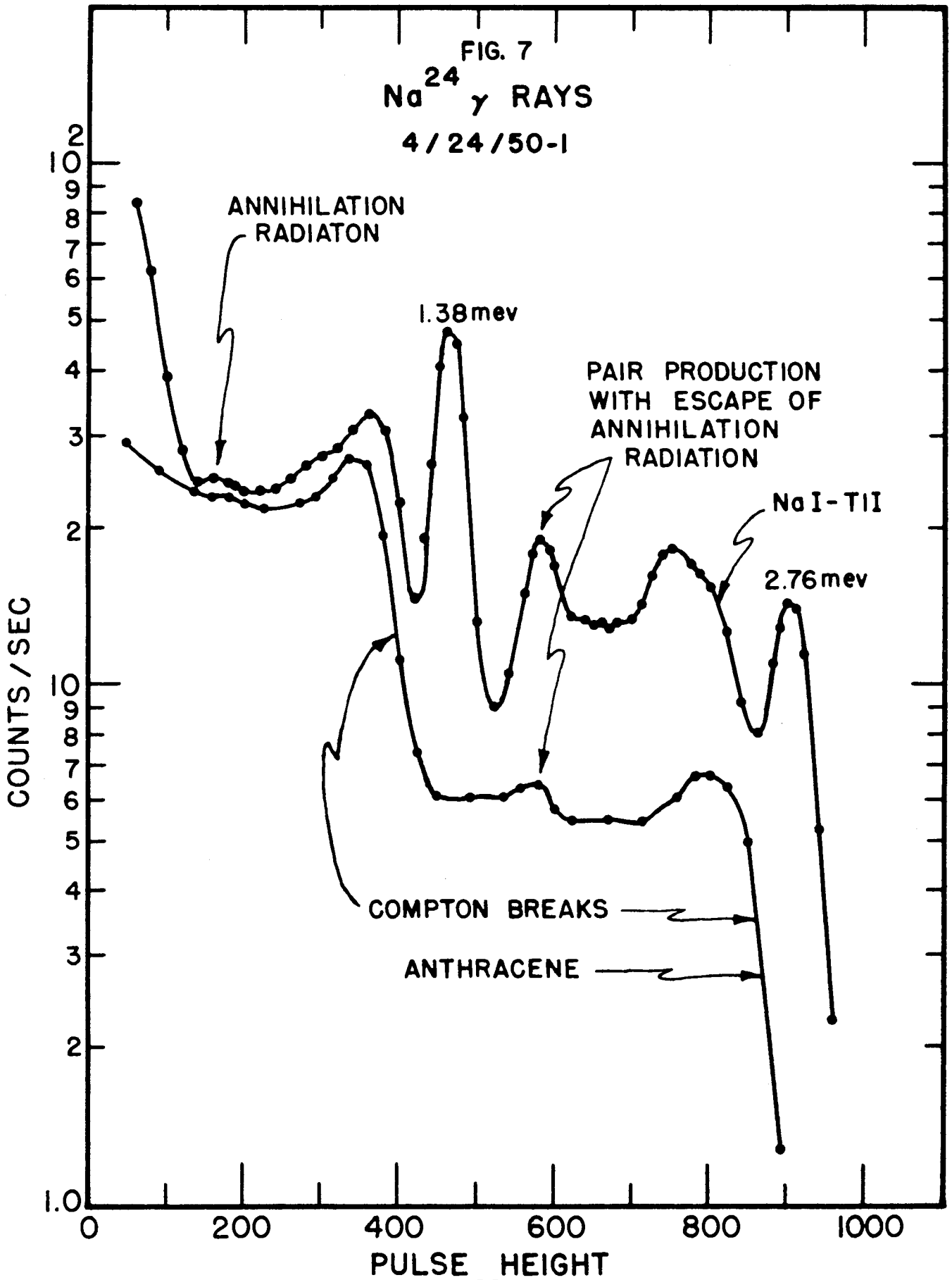

When a 3/8 in. diameter hole 4 in. long in a thick lead block is used to collimate the beam from this source (closer to give same number of counts per second at the peak) the low energy excess is largely removed (curve 2). When a collimated beam is turned so that it misses the crystal and strikes the lead shield wall nearby, the lower curve 3 is obtained. This consists almost entirely of Compton scattered photons. The counting statistics were not sufficient to make the double humped peak shape significant.

A higher energy gamma ray (K^{42} 1.51 Mev) gives a smaller photo peak compared with the Compton response (Fig. 6). The source was at a considerable distance and required a thick absorber to stop the beta rays (3.5 Mev) so that degenerate radiation is fairly strong. At this energy a new process begins to appear with appreciable strength. Pair production within the phosphor is responsible for the peak at 0.5 Mev. The pairs stop in the crystal giving a pulse equal to their total kinetic energy, 1.02 Mev less than the gamma ray energy. The positron annihilates and if the two 0.511 Mev annihilation photons chance to escape, the lower energy peak is produced. If one or both photons are completely or partially detected a pulse lying between this peak and the photoelectron peak results.

Pair production becomes quite prominent for the high energy gamma ray from Na^{24} (2.76 Mev). Figure 7 shows the response both for anthracene and NaI-TlI, to the gamma rays of Na^{24}. The sodium iodide responds in a complicated way to the 2.76 Mev ray. The peak at 1.7 Mev is the response to the pairs when the annihilation radiation photons chance to escape completely. The lower energy hump of the broad peak at 2.2-2.4 Mev is produced by the chance complete detection of one annihilation photon with escape of the other. When both photons are absorbed completely the pulse produced falls on the peak produced by the photo effect. The whole region between 1.7 and 2.7 Mev is considerably elevated due to pulses of intermediate size due to partial detection of one or both annihilation protons. Pairs are also produced in the shield by gamma rays that do not reach the crystal; some of the annihilation radiation from these pairs reaches the crystal and produces the peak at 0.51 Mev.

The lower curve in Fig. 7 for the same radiation on an anthracene crystal shows of course only the Compton distribution for the two gamma rays and a very weak pair production peak as would be expected from the low Z elements of the crystal.

As the gamma ray energy increases, the photoelectric process becomes less efficient and the pair production more efficient so that the triple peaked response for a single gamma ray becomes lopsided with the upper energy peak weakest.

Measurements with NaI-TlI Phosphors. Figure 8 is the pulse distribution produced by a polonium-beryllium neutron source. The five curie source was inserted in an 8 in. cubical block of paraffin and the block covered with 1/4 in. of B_4C plastic. The shield was used to prevent activation of the NaI crystal. As can be seen from Fig. 8 only one gamma ray is emitted by the source. From the three peaks this gamma ray energy appears to be 4.44 ± .03 Mev. There appear also several other weak peaks. The peak at 2.24 Mev and the Compton distribution beginning shortly below it are due to the capture gamma ray of hydrogen in the paraffin; the energy agrees well with the 2.23 Mev reported by Chalk River. The next lower peak is that of the nuclear gamma ray of Po and the lowest peak is that from the excited state of Li^7 from the boron reaction. The lower two are very inaccurate due to their crowdedness and being on a steep slope. The calibration for these measurements was obtained from the well known gamma ray of ThC at 2.62 Mev. A sample of ordinary thorium was used to obtain this line.

This measurement of the excited state of C^{12} is of some interest and has been sent as a Letter to the *Physical Review* to appear in the July 15 issue. Shortly after this result was obtained, Pringle, Standil and Roulston reported a similar measurement.(5) There is quite a remarkable coincidence here since the same calibration radiation is used as well and their reported energy of 4.40 ± .05 Mev agrees well with ours. They found a weak higher energy gamma ray which we do not confirm. Figure 9 shows the pulse spectrum from 4.4 to 8 Mev. Two very weak peaks exist but are probably due to capture gamma rays from neutron leakage. When part of the boron shield was removed the strong peak at 6.4 Mev on the upper branch of this figure is found; this is the lower pair peak from a gamma ray at 7.4 Mev. The gamma ray appears to be produced by capture in the iron magnetic shield of the spectrometer. No appreciable number of pulses appear above an equivalent energy of 8 Mev.

The excited state of C^{12} has been measured also by measuring the neutron groups emitted in the $Be^9(\alpha,n)C^{12}$ reaction by Bradford and Bennett(6) who obtain 4.44 to 4.46 Mev for the gamma emitting level depending upon the method of calculation used.

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(5) Pringle, R. W., Standil, S., and Rouston, K. I., "The Gamma-Rays from $Be^9(\alpha,n)$," *Phys. Rev.* 78, 627 (1950).

(6) Bradford, C. E. and Bennett, W. E., "Neutron Groups from $Be^9(\alpha,n)C^{12}$," *Phys. Rev.* 78, 302 (1950).

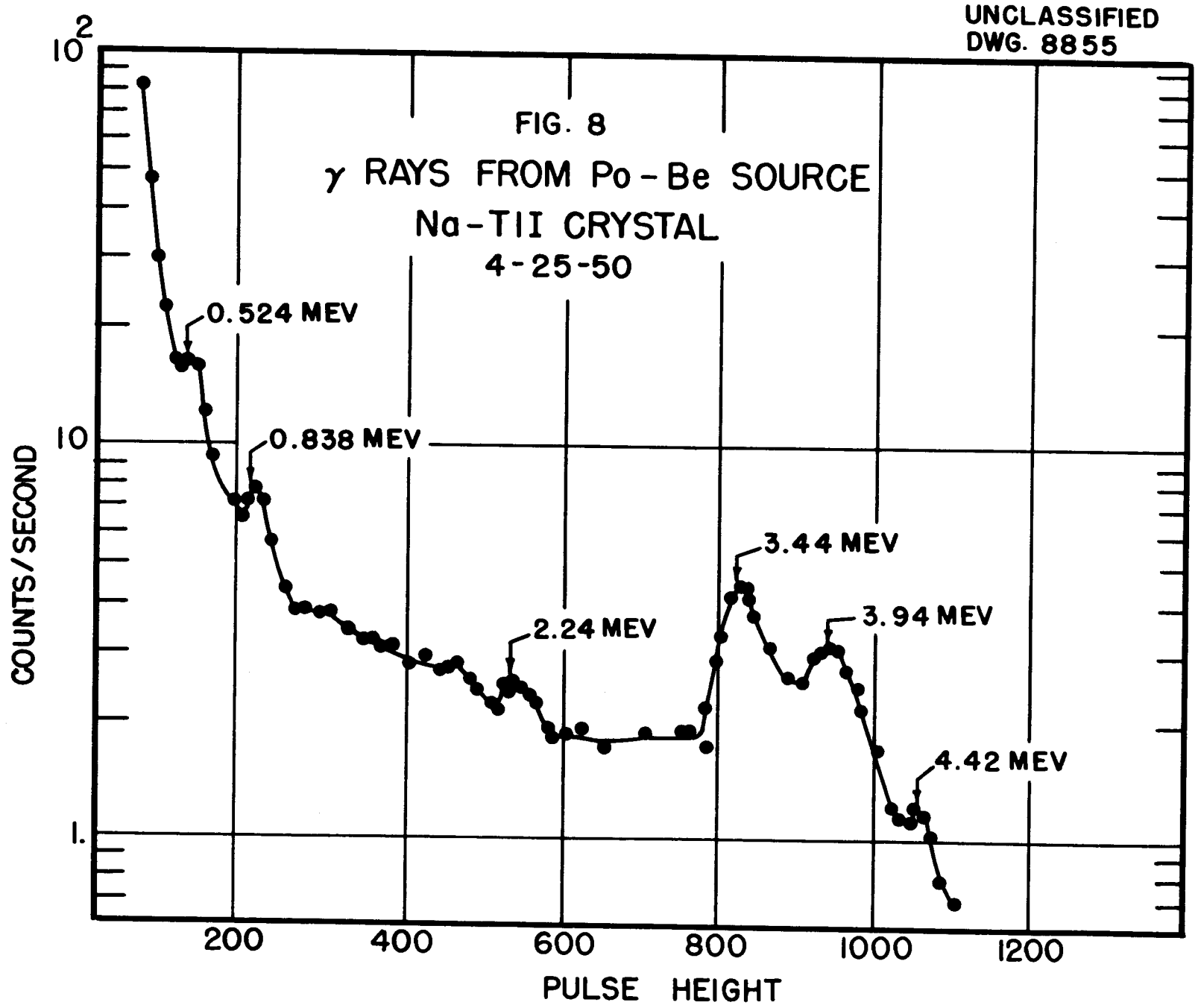
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FIG. 8
γ RAYS FROM Po-Be SOURCE
Na-TII CRYSTAL
4-25-50
0.524 MEV
0.838 MEV
2.24 MEV
3.44 MEV
3.94 MEV
4.42 MEV
10^2
10
1.
COUNTS/SECOND
200
400
600
800
1000
1200
PULSE HEIGHT

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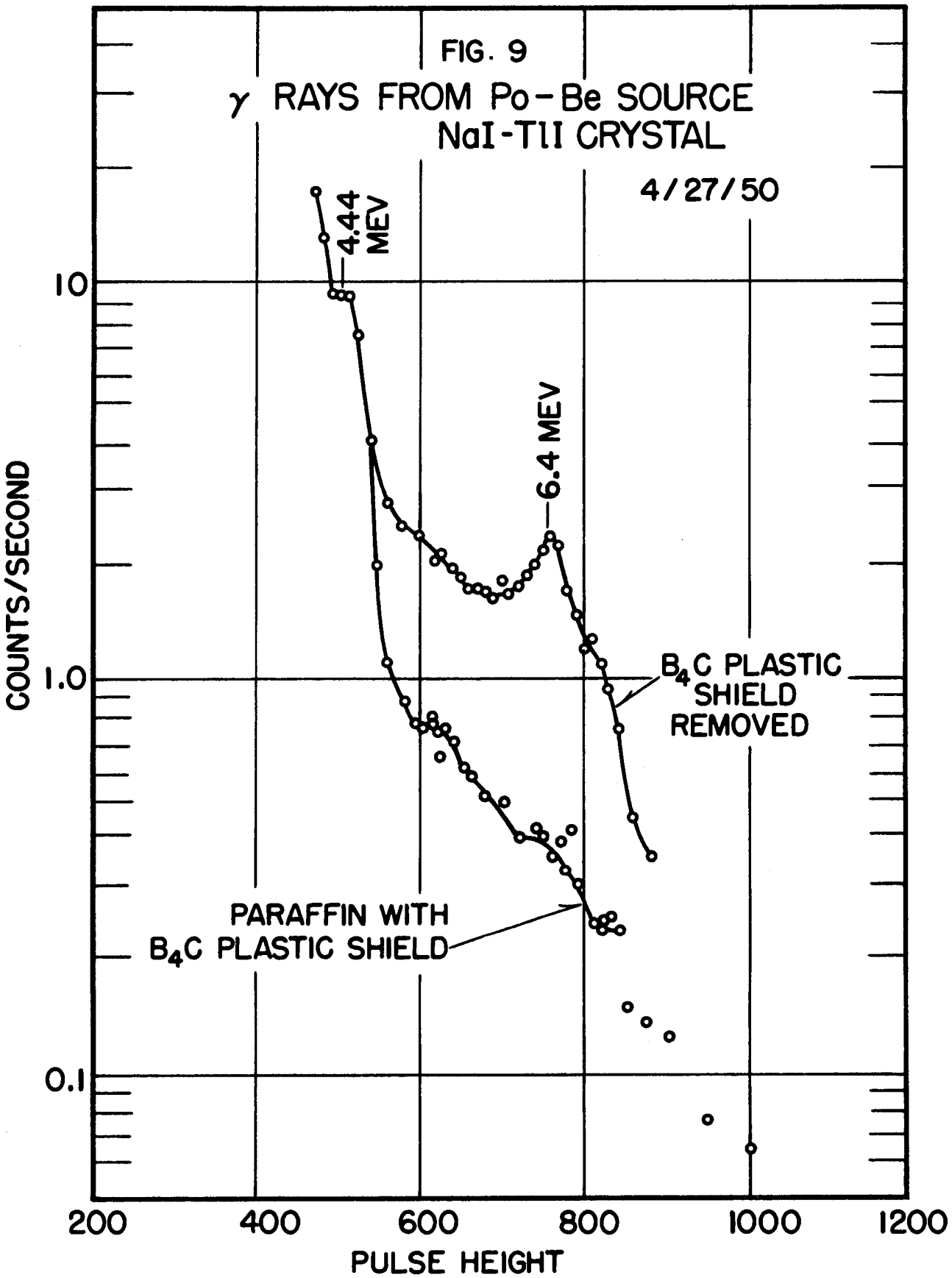

K^{40} Gamma Rays. The gamma rays of K^{40} are of unusual interest so they were rerun with the NaI crystal. They had previously been run on anthracene and reported in the *Physical Review* [Vol. *77*, 409 (1950)]. Figure 10 shows the pulse distribution found for ordinary KCl. By careful comparison with the gamma rays of K^{42}, Na^{24} and Zn^{65} the gamma ray of K^{40} seems to be 1.462 ± 0.01 Mev. Careful examination of the curve in the low energy region discloses a pair of weak and overlapping peaks. As in the case of K^{42} which is near in energy, a peak (somewhat weaker and lower in energy in this case) is to be expected from pair production. After an appropriate size and shape of peak is substracted, a peak about 0.2 counts per second high remains at 0.5 Mev. This seems to be due to annihilation radiation and is probably all due to pairs produced outside the phosphor as in the case of Na^{24} (Fig. 7).

If one assumes this peak is entirely due to positrons emitted by K^{40} by transition to the ground state of A^{40}, one obtains an upper limit for the occurrence of this process. By using appropriate values of the efficiency it is found that not more than two positrons are emitted for 10^5 beta rays from the K^{40} - Ca^{40} transition.

From our previous work(7) the beta ray transition has been shown to have the unique third forbidden shape and a maximum energy of 1.36 ± 0.05 Mev. This has since been confirmed by Alburger(8) who gets 1.36 ± .03 Mev and the same shape. The shape combined with the known spin change of four units shows that the transition is parity allowed. The mass difference between the ground states (neutral atoms) of Ca^{40} and A^{40} have been measured by several groups. Sailor(9) finds 0.27 ± 0.21 millimass units while Roberts and Nier(10) get a difference of 0.32 ± 0.08 millimass units, both finding Ca^{40} heavier.

Combining these with our gamma ray measurement the decay scheme shown in Fig. 11 results. The absence of any considerable amount of positron transitions to the ground stage of A^{40} with 640 Kev of kinetic energy available makes it extremely improbable that there are any K captures to the ground state of A^{40}.

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

(8) Alburger, D. E., "Beta-Ray Spectrum of K^{40}," *Phys. Rev.* 78, 629 (1950).

(9) Sailor, V. L., "Energy Levels in Ca^{41} and the Mass Difference Between A^{40} and Ca^{40}," *Phys. Rev.* 75, 1836 (1949).

(10) Roberts, T. R. and Nier, A. O., "The Ca^{40} - A^{40} Mass Difference and the Radioacity of K^{40}," *Amer. Phys. Soc. Bull.* V 25, No. 3, p. 7 (1950).

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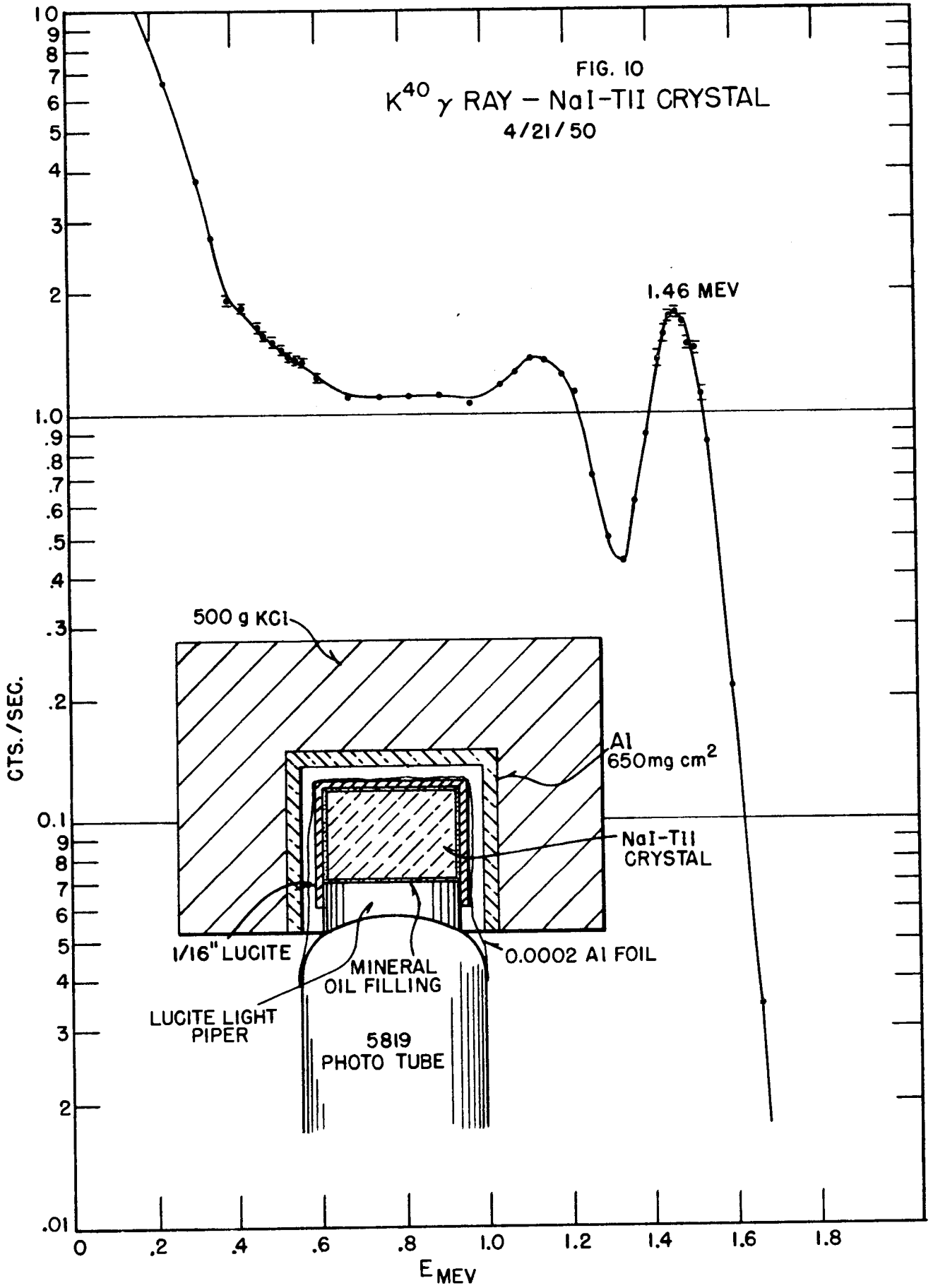

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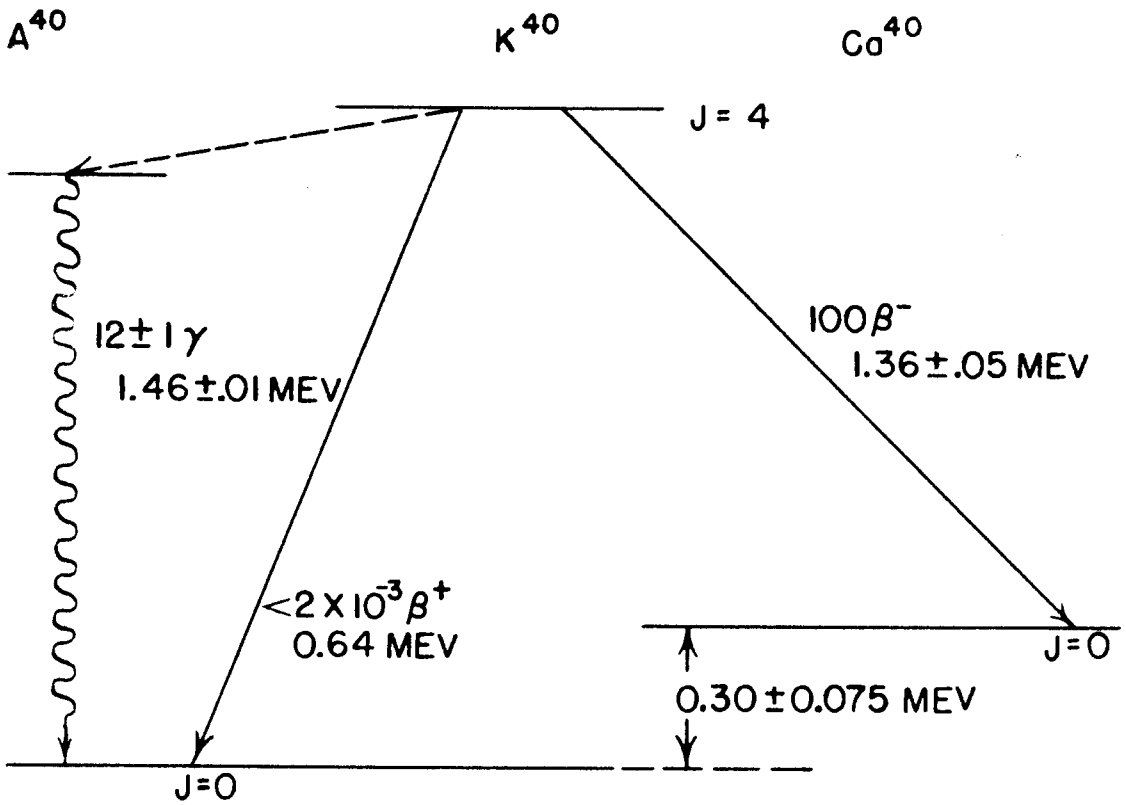
FIG. 11



It is somewhat surprising to find so few positrons since the degree of forbiddenness was expected to be the same as for the beta ray.

Activities in the Rare Earths. An attempt was made to find gamma ray activities among the rare earths. The reported activity of lanthanum[11] was found but the two prominent gamma rays at 1.0 and 0.54 Mev correspond moderately well with the two prominent lines in the spectrum produced by a carnotite sample which presumably contained largely the uranium series in equilibrium (Fig. 12). The two peaks similar to the lanthanum peaks occur at 0.63 and 1.2 Mev. The energies are sufficiently different that they are probably not identical. The extremely pure lanthanum was produced by D. H. Harris in the Chemistry Division.

A ten gram sample of Nd_2O_3 produced by Spedding and five grams of praseodymium nitrate (City Chemical Company) were run and no high energy gamma rays were found in either sample. A large sample (92 g) of CeO_2 produced by Harris was measured and a very weak complex spectrum was found. This spectrum coincides with that of thorium. Figure 13 shows both curves. The peak near 1 Mev does not appear in the cerium curve probably as an accident of the spacing of the points. The characteristic 2.62 Mev triad of peaks is conclusive evidence. Probably there is no gamma radiation from cerium above 100 Kev. Samples of several other rare earths are on hand and are being measured.

Annihilation of Fast Positrons. The ability of the scintillation spectrometer to measure a weak high energy gamma ray in the presence of a strong low energy one makes possible the measurement of the annihilation of fast positrons. The probability of annihilation of fast positrons is quite low so that a large number of 0.51 Mev quanta are found for every one of higher energy. Part of the fast annihilation spectrum lies below 0.51 Mev and is hidden. Copper 64 is the best positron emitter available to us and its use is limited by the presence of a weak nuclear gamma ray at 1.35 Mev.[12] Figure 14 shows the spectrum obtained with samples of Cu^{64} enclosed in a positron absorber of lucite and of lead. The nuclear gamma ray is quite clear. We find 1.33 ± 0.03 Mev for the energy of this gamma ray.

The region between the Compton break for the gamma ray and the foot of the 0.51 Mev annihilation peak is filled by a pulse distribution that seems to

(11) Pringle, R. W., Standil, S., and Roulston, K. I., "The Natural Activity of Lanthanum," *Phys. Rev.* 78, 303 (1950).

(12) Deutsch, M., "Gamma-Rays from Cu^{64}, Annihilation of Swift Positrons, and Experiments on Orbital-Electron Capture," *Phys. Rev.* 72, 729 (1947).

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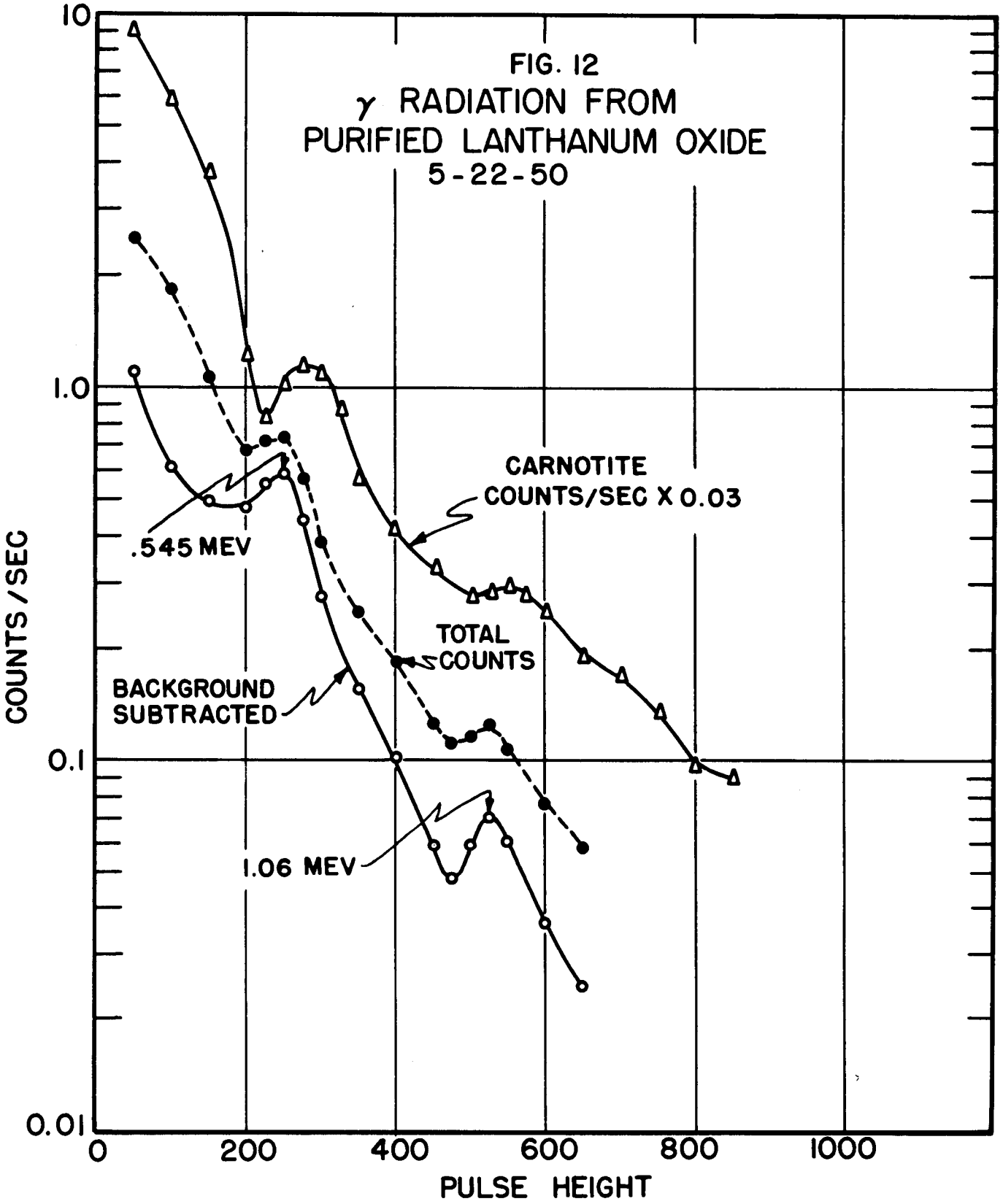

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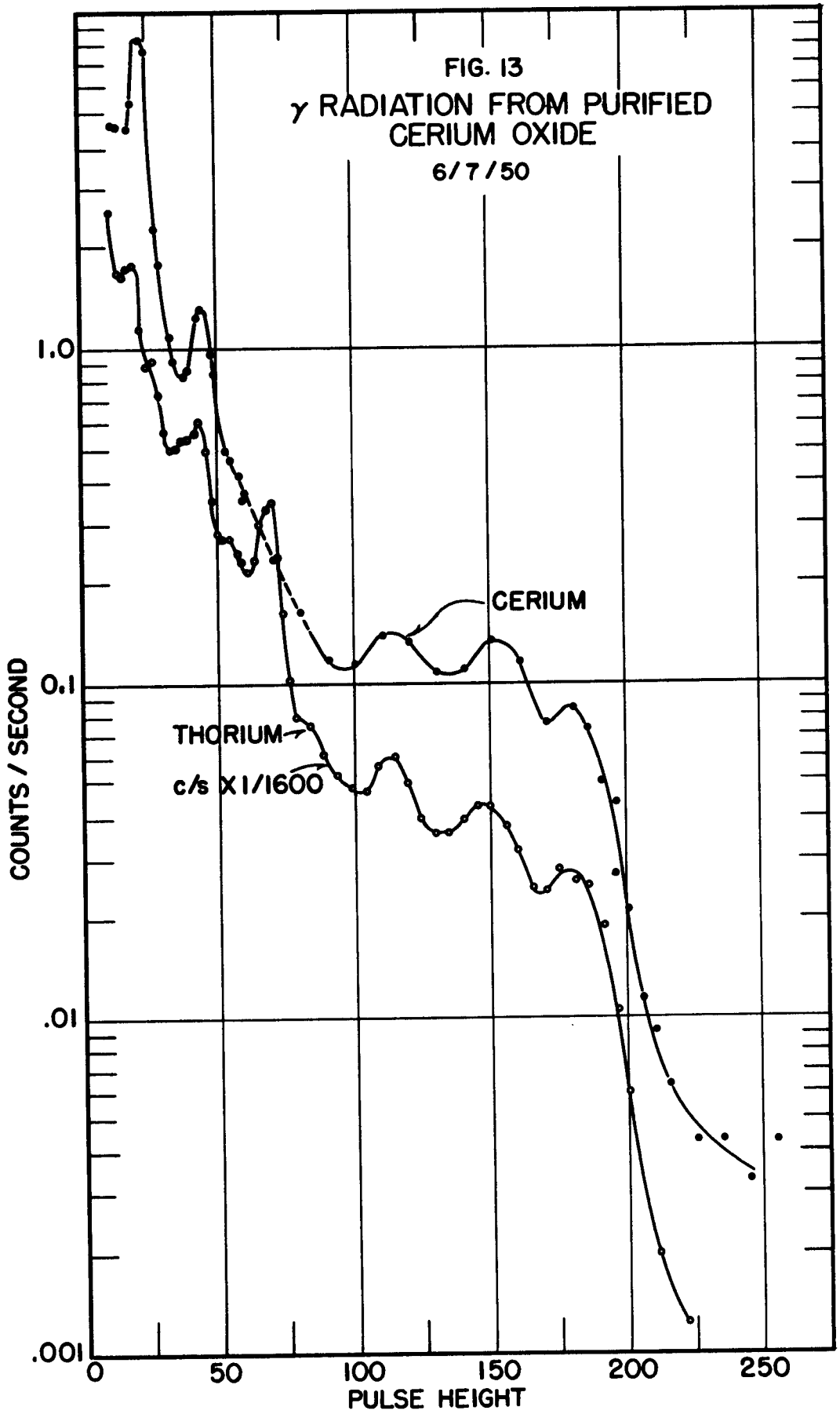

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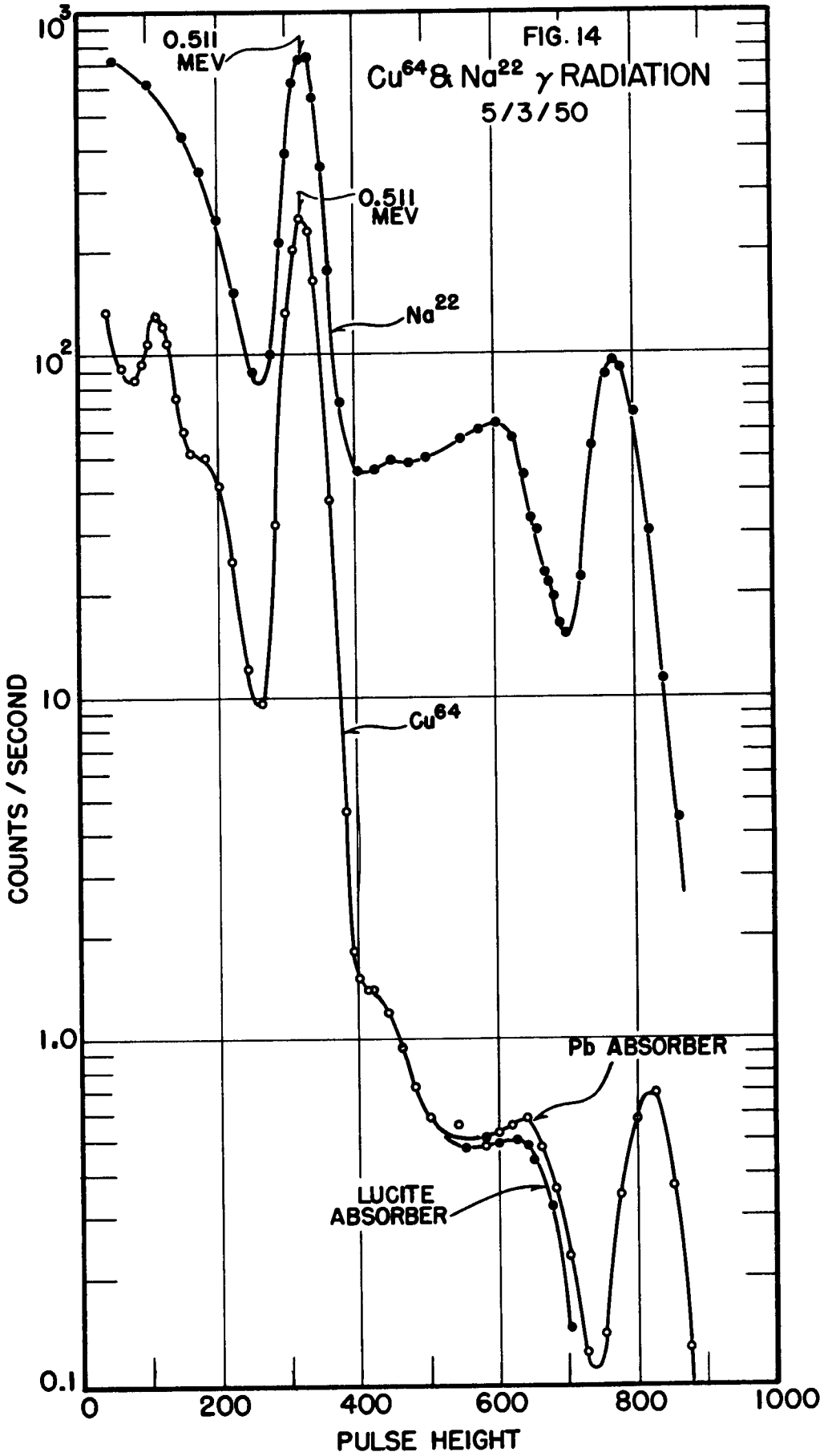

be due to a gamma ray continuum such as would be given by fast annihilation. Also shown in Fig. 14 is the spectrum given by Na^{22}. This substance emits positrons followed by a gamma ray of 1.277 Mev in cascade. The weak effect of fast annihilation cannot be seen on this curve but the shape of the gamma ray response is nearly that which should be found for the copper gamma ray if no fast annihilation were present.

The curve with the lead absorber shows a slight peak near 1.0 Mev. It is unfortunate that the peak of the Compton curve of the 1.35 Mev gamma ray is also almost at this same place, but the curves for the lead and lucite absorbers seem to be significantly different. Single quantum annihiliation of the positrons would be highly Z dependent and should give a broad peak near this energy. Further work on fast annihilation is under way with the source shielded from the detector so that the nuclear gamma ray is suppressed.

Temperature Dependence of Scintillation Pulses in Anthracene (J. E. Francis). The temperature dependence of the size of the pulses from an anthracene crystal has been investigated using a single channel analyzer. In order to eliminate any effects from the cooling of the phototube, a quartz light piper was placed between the phototube and the crystal. The crystal was cooled with liquid nitrogen and its temperature measured by a thermocouple in contact with the crystal. Figure 15 shows the results obtained with a 1P21 and a 1P28 phototube using first a Cs^{137} source then a Po α source on each tube. The pulse height which is plotted on the graph is the pulse height of the peak in the spectrum for the Po α source and the peak for the conversion of the 630 Kev β-ray for the Cs^{137}. The curves have been normalized to the pulse height for the Po α source on the 1P28 at room temperature. The pulse height is increased approximately thirty-six per cent by cooling to liquid nitrogen temperature.

Figure 16 is the curve obtained when both the 1P28 and the crystal are cooled. When the temperature is lowered rapidly the upper curve is obtained and is in agreement with the results obtained by Kelley and Goodrich. When the tube is cooled slowly the lower curve is obtained.

Figure 17 is the curve obtained when both the 1P21 and the crystal are cooled. The pulse height for the 1P21 is increased approximately 65% at liquid nitrogen temperature over its value at room temperature. Part of this increase is probably due to a change in the transmission characteristics of the envelope. Some spectrographic evidence of this change was obtained by Kelley

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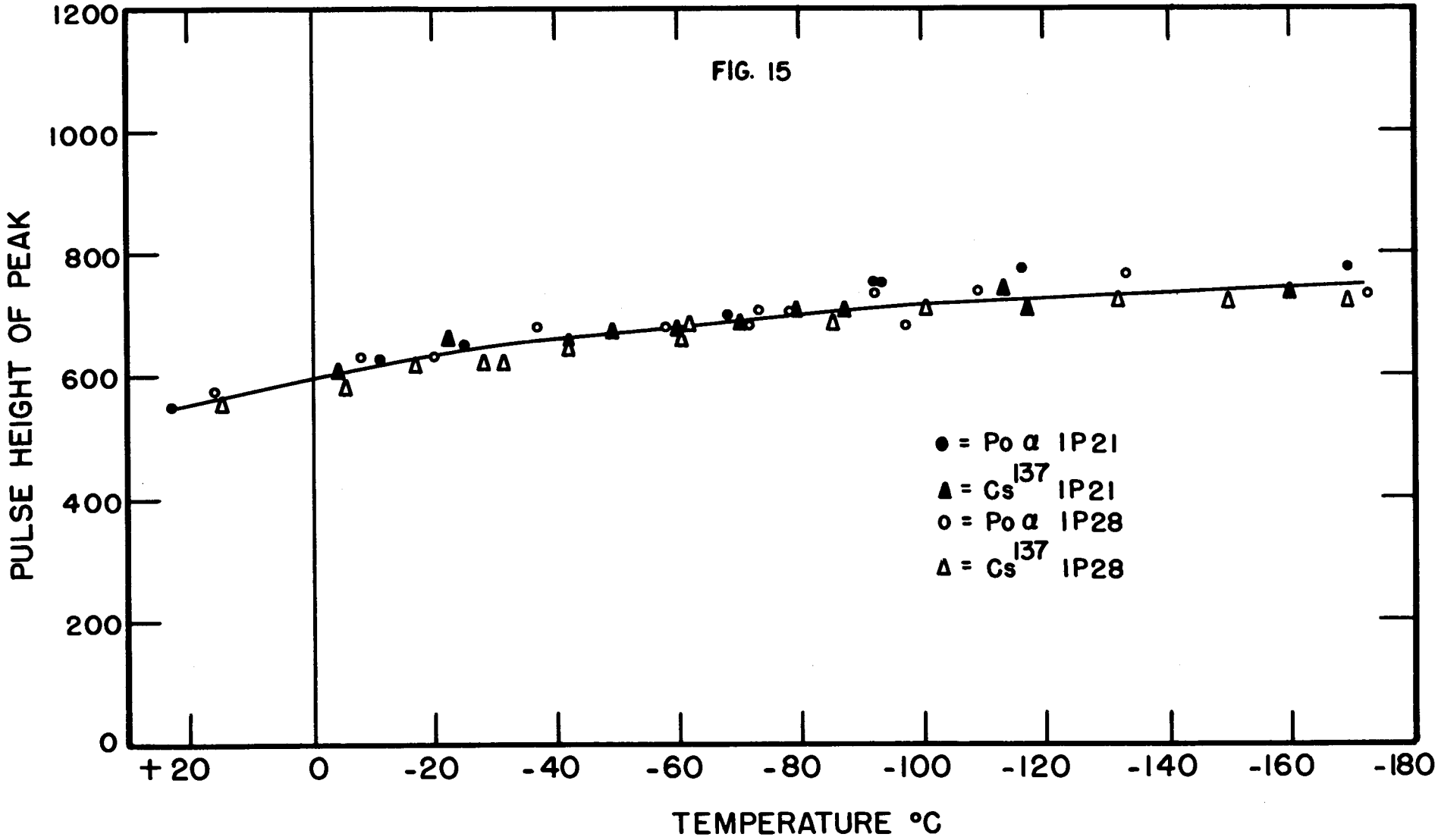

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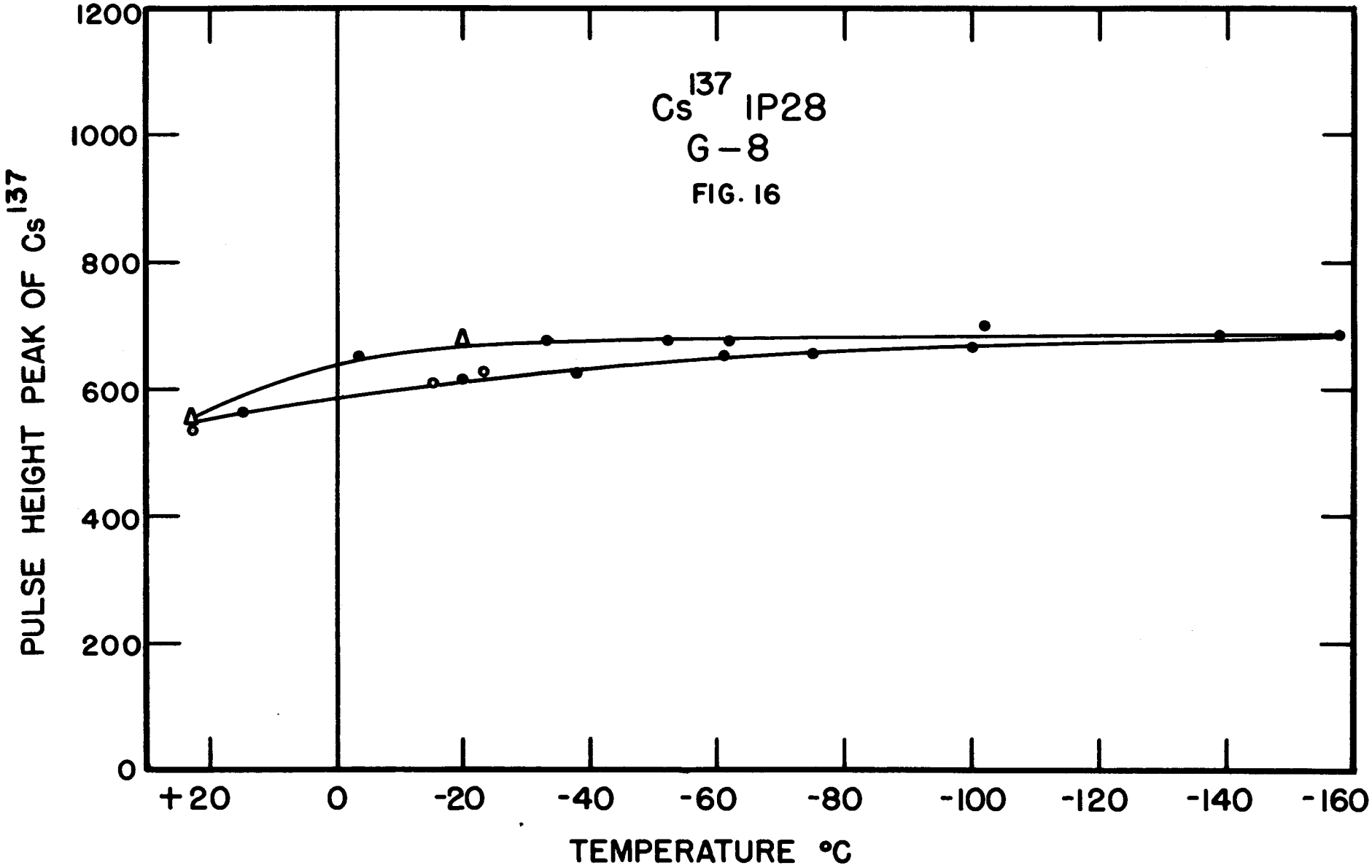

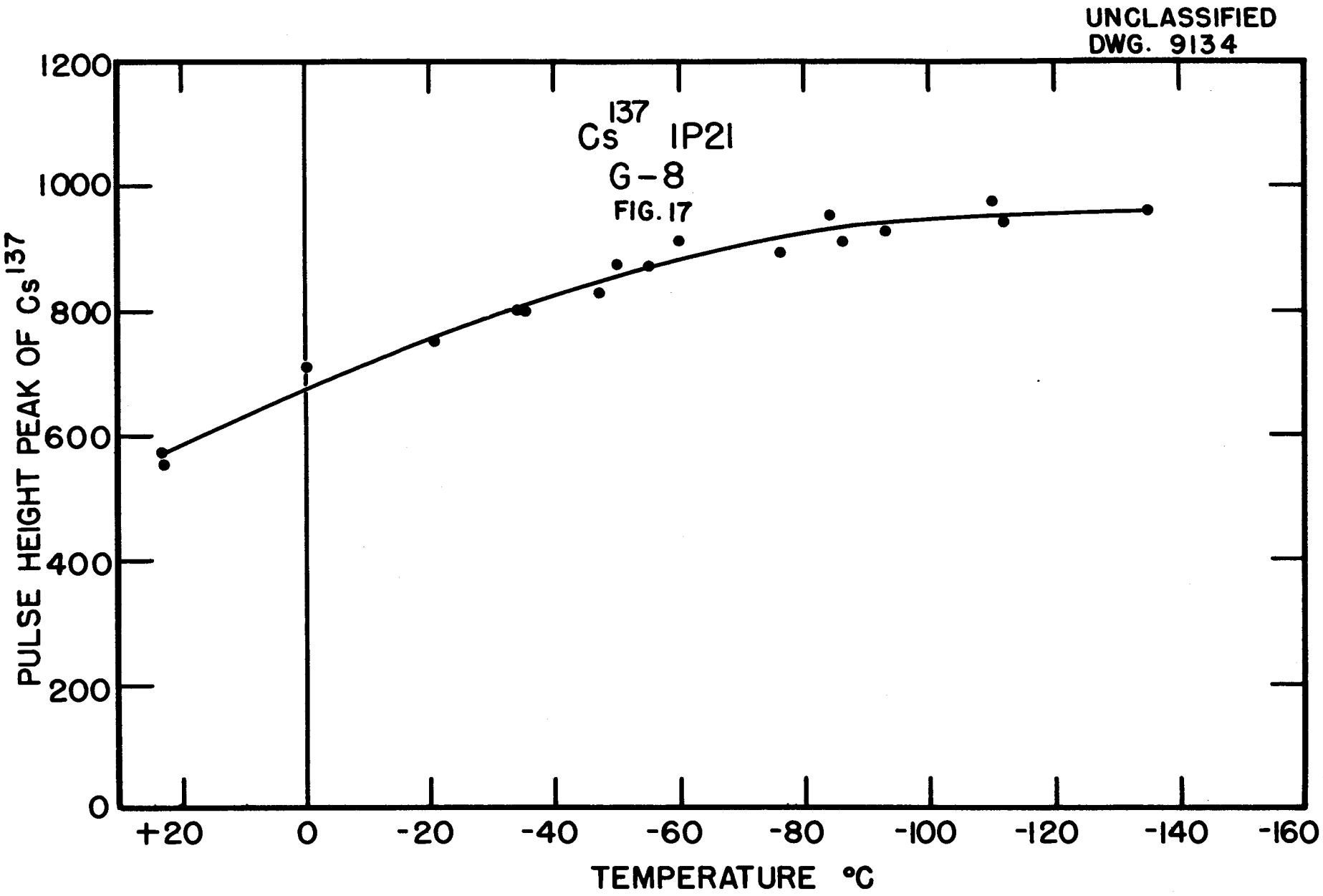
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Cs137 IP21
G-8
FIG. 17
PULSE HEIGHT PEAK OF Cs137
1200
1000
800
600
400
200
0
+20
0
-20
-40
-60
-80
-100
-120
-140
-160
TEMPERATURE °C

and Goodrich.[13] The curve for the 1P28 does not show this large increase probably because the transmission characteristics of its envelope are not changed.

SHORT-LIVED ISOMERS

F. K. McGowan

An excited state in Ir^{191} with a half-life $(5.7 \pm .5) \times 10^{-9}$ sec has been observed with a delayed coincidence scintillation spectrometer. In Fig. 18 the number of delayed coincidences is plotted as a function of delay time obtained with a source of Os^{191} (32 hr). The solid portion of the curve for delay time $T \geqslant 2.5 \times 10^{-8}$ sec represents the decay of the short-lived isomeric state which has been produced by the β^- decay of Os^{191}. Both the end point of the β^- spectrum announcing the formation of the isomeric state and the energy of the radiation emitted in the decay of the metastable state have been determined.

The delayed coincidence scintillation spectrometer consists of the usual delayed coincidence unit employing anthracene with type 5819 multiplier tubes as detectors. In addition, a small portion of the signal from either detector is fed to a linear amplifier equipped with a differential pulse height selector. This analyzer selects all pulses with amplitudes lying between E and $E + \Delta E$. The output pulses of the analyzer and the fast delayed coincidence pulses are fed into a relatively slow coincidence circuit. In this way only those pulses from the analyzer are selected that give rise to a delayed coincidence. When the detector feeding the analyzer channel is used to detect the radiation announcing the formation of the isomeric state, a measurement of the spectrum of the radiation preceding the metastable state is obtained. Similarly, when the detector is used to detect the delayed radiation, a measurement of its spectrum is obtained.

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

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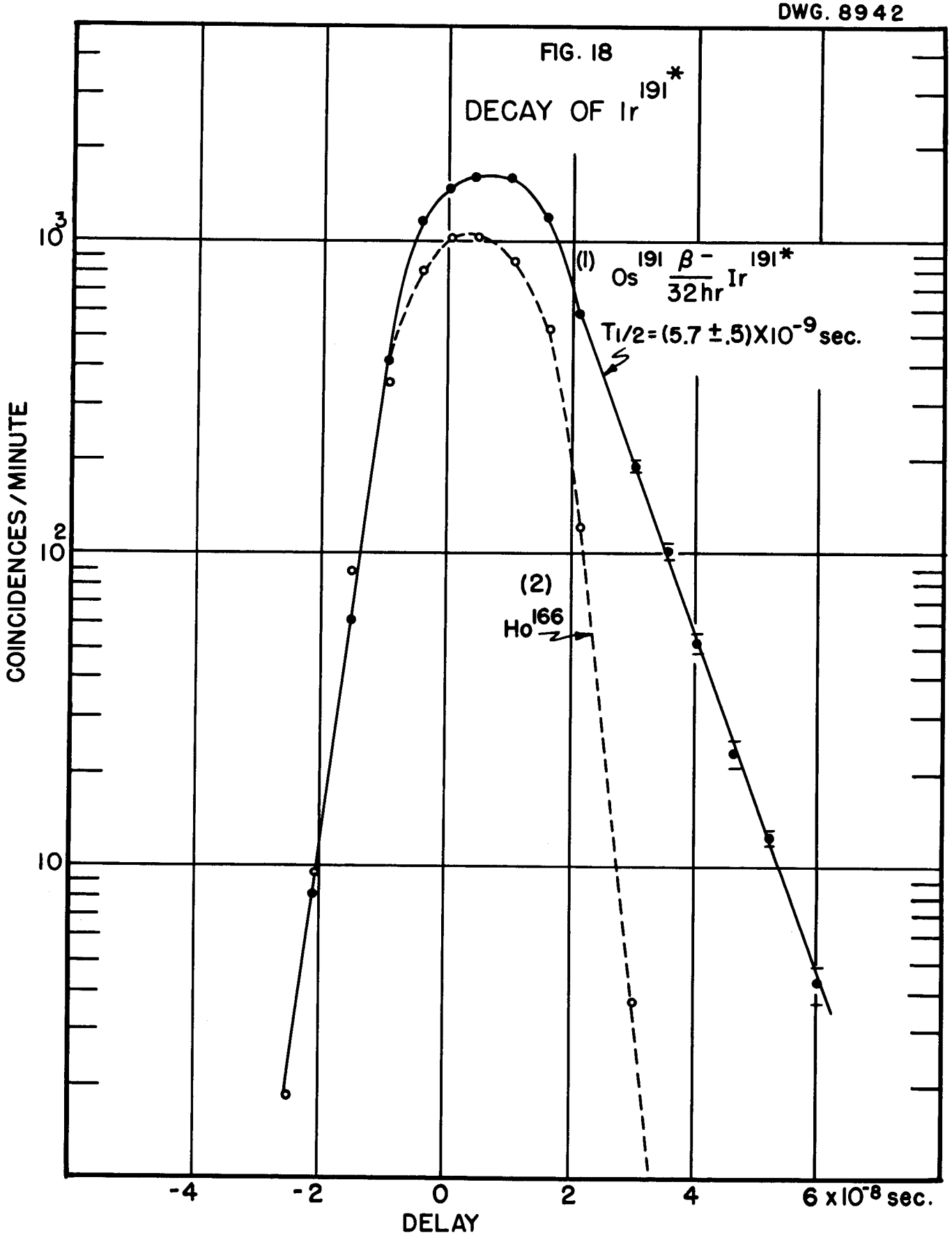

Curve (1) in Fig. 19 is the spectrum of the radiation resulting from the decay of the short-lived isomer in Ir^{191} obtained by counting delayed coincidences in a small height interval against pulse height. The internal conversion electron peak corresponds to 52 Kev. The scale of pulse height was calibrated in energy units using internal conversion electron lines of γ-rays whose energies are well known from magnetic spectrometer measurements. Curve (2) shows the internal conversion electron lines at 65 and 122 Kev of the 132 Kev transition from the decay of the 22 μ-sec metastable state of Ta^{181*} which announces the formation of the 1.1×10^{-8} sec metastable state of Ta^{181*}. In addition, L internal conversion electrons of the 85 and 80 Kev transitions following the β^- decay of Tm^{170} and Ho^{166} respectively were used for calibration.

Measurements of the radiation of other isomeric transitions with similar energy and lifetime have shown that the amount of internal conversion in the L shell is comparable to that in the K shell. Since only one internal conversion line appears in the spectrum of the decay of Ir^{191*}, the peak probably corresponds to L shell internal conversion. The energy of the transition is then (65 $\pm$ 5) Kev which is less than the K shell electron binding energy (76 Kev).

The spectrum of the radiation announcing the formation of the metastable state (not shown) appears to be a single beta ray distribution whose maximum energy determined from a Kurie plot is 1 05 ± .03 Mev.

The decay curve of Fig. 18 was obtained with the analyzer gate accepting only small pulses corresponding to the 65 Kev transition while the other channel was excited by the high energy β^--rays which gave rise to large pulses. Since the form of delayed coincidence resolution curves for originally simultaneous events depends essentially upon the distribution in amplitude of the original pulses, it is conceivable that the 65 Kev transition is not metastable with respect to the β^--ray event. In order to rule out this possible instrumental effect on the resolution curve obtained with a coincidence system using amplifiers of finite rise time, a number of other sources were tested; namely, the 1.84 Mev β^- decay of Ho^{166} followed by an 80 Kev internally converted γ-ray, the 900 Kev β^- decay of Tm^{170} followed by an 85 Kev internally converted γ-ray, and the 1.076 Mev β^- decay of Re^{186} followed by a 138 Kev internally converted γ-ray. Curve (2) in Fig. 18 shows a typical resolution curve obtained with

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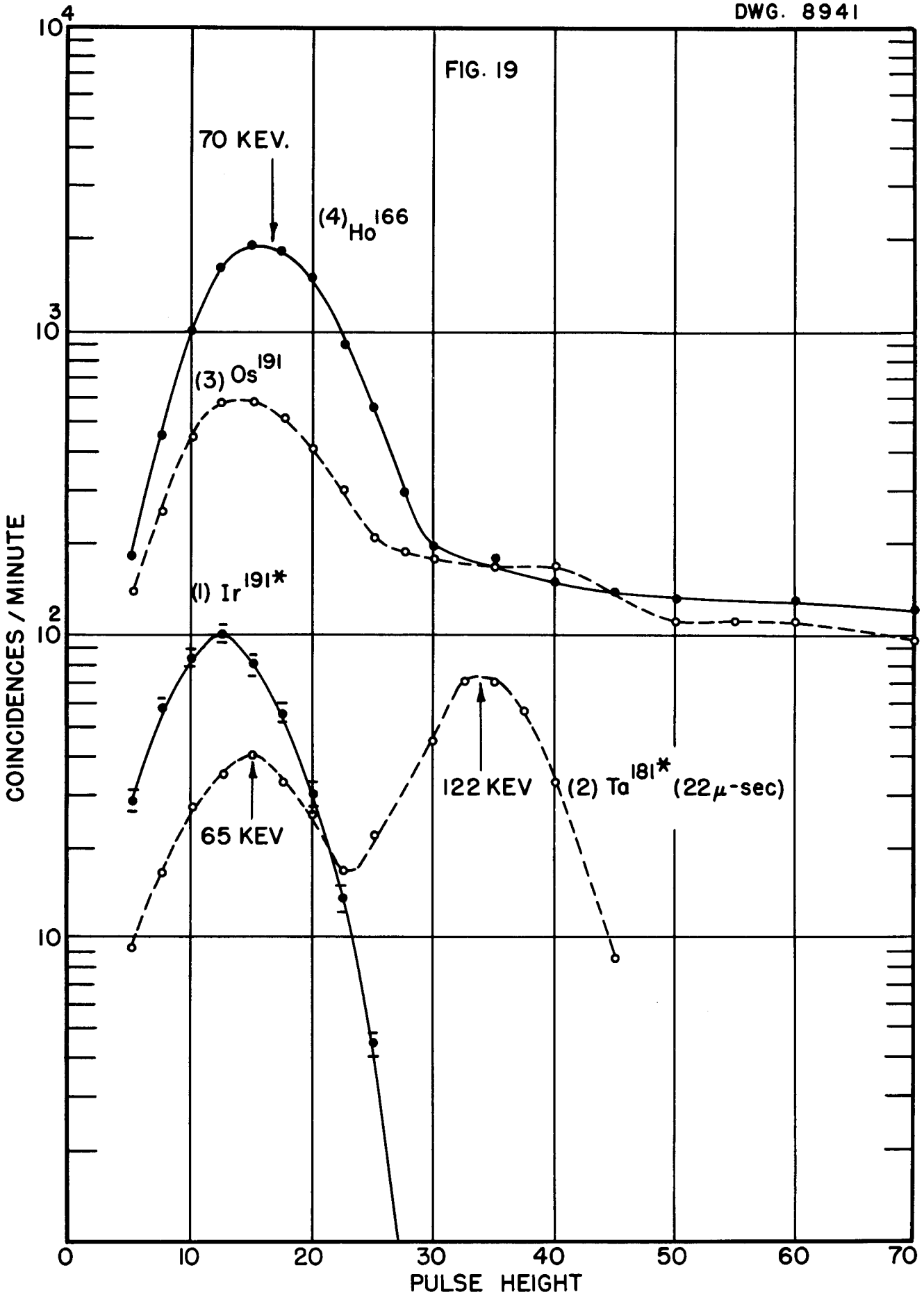

Ho^{166}. In each case the resolution curve obtained with the analyzer accepting only the low energy internally converted γ-ray was symmetrical with the leading and trailing edge being roughly exponential over three decades corresponding to a half-period 2×10^{-9} sec. In Fig. 19 curves (3) and (4), which are the low energy portion of the spectra of the simultaneous events from Os^{191} and Ho^{166} respectively, show clearly the similarity of the two distributions in amplitude of the original pulses from the scintillation detector.

As an additional check for the validity of this isomeric state in Ir^{191} the "delayed coincidence resolution curve" of Fig. 18 was analyzed by a graphical method which is analogous to a method of analysis recently reported by Newton(14) and Bay.(15) For convenience and clarity the notation used by Newton will be used in the discussion here.

In the ideal experiment, one desires to excite one channel of the apparatus by the parent radiation or the radiation announcing an excited state in a nucleus and to excite the other channels by the radiation emitted in the decay of the excited state whose lifetime is to be measured. Experimentally this is achieved by means of a delayed coincidence spectrometer. If the excited state has a lifetime much too short to be measured by the coincidence circuit, one obtains a "prompt coincidence resolution curve," $P(x)$. If there is a measurable lifetime, one obtains a "delayed coincidence resolution curve," $F(x)$.

Since the energy resolution of the scintillation spectrometer is relatively poor compared to the best magnetic beta ray spectrometer, the "delayed coincidence resolution curve" for $Os^{191} \longrightarrow Ir^{191}$ in Fig. 18 is $F(x)$ plus a "prompt curve" of simultaneous events not related to $Os^{191} \longrightarrow Ir^{191*}$ decay. "Delayed coincidence resolution curves" were calculated graphically using for $P(x)$ curve (2) of Fig. 18 and for $T_{1/2}$ values equal to or near that obtained in the usual way from the slope of curve (1) at large positive delays. The prompt curve $P(x)$ represents the response of the apparatus to simultaneous emission of particles of the same kind and energy that gave curve (1). The difference between curve (1) and $F(x)$ should yield a "prompt coincidence resolution curve" of the simultaneous events not related to $Os^{191} \longrightarrow Ir^{191*}$.

(14) Newton, T. D., "Decay Constants from Coincidence Experiments," *Phys. Rev.* 78, 490 (1950).

(15) Bay, Z., "Calculation of Decay Times from Coincidence Experiments," *Phys. Rev.* 77, 419 (1950).

The value of $T_{1/2}$ that yielded a residual prompt curve with the leading and trailing edge symmetrical about zero delay was chosen as the best value for the half-life of Ir^{191*}.

PROPORTIONAL COUNTERS

J. E. Francis and J. I. Hopkins

As a preliminary step to measuring coincidences between soft radiations and hard radiations it was desirable to study the characteristics of proportional counters. To do this two Eck-Kreb shells were filled with proportional counter fillings. One was filled with 60 cm of argon and 6 cm of methane; the other was filled with 60 cm of xenon and 6 cm of methane. They have proved satisfactory as proportional counters.

Figure 20 shows the curve obtained for the 8.6 Kev X-ray from Zn^{65}. The width at half maximum is approximately 18 percent.

MULTI-CHANNEL ANALYZER

G. G. Kelley

The multi-channel pulse height analyzer described in the last report[16] has been completed and is in operation. Circuits have been included to make the amplifier inoperative during the time a pulse is being measured. Figure 21 is a schematic diagram of the pulse sorter chassis. Window widths may be maintained to better than 2% very easily. Resolving time is between 1.5 and 7 μ-sec depending on the size of a pulse.

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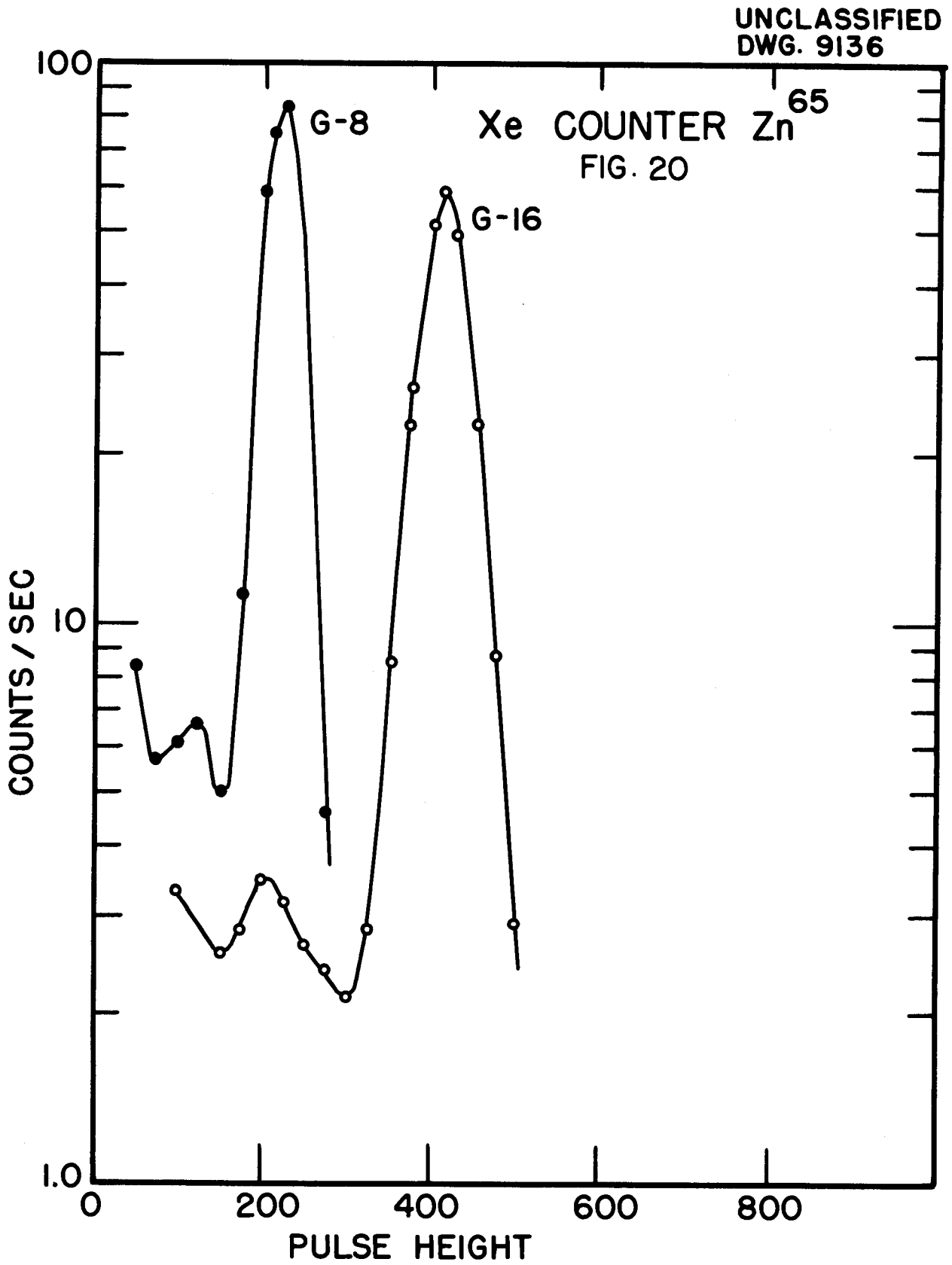
(16) Kelley, G. G., "A Multi-Channel Pulse Sorter," *Physics Division Quarterly Progress Report for Period Ending March 15, 1950*, ORNL 694, 28 (June 13, 1950).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Xe COUNTER Zn^{65}
FIG. 20
G-8
G-16
100
10
1.0
COUNTS / SEC
0
200
400
600
800
PULSE HEIGHT

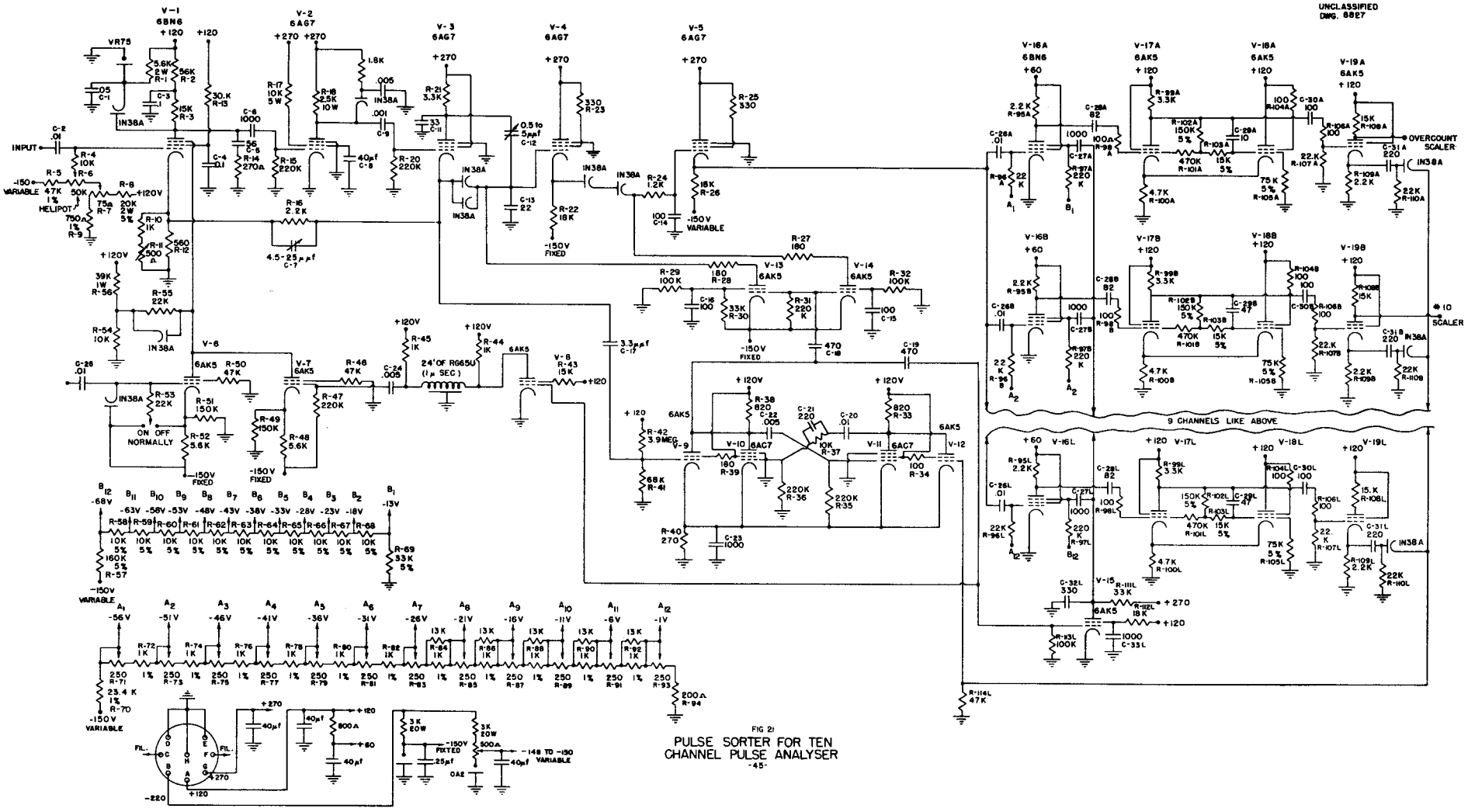

FIG 21
PULSE SORTER FOR TEN CHANNEL PULSE ANALYSER

DETECTION OF LOW ENERGY PHOTONS

E. C. Campbell - J. H. Kahn

Two proportional counters have recently been used in a preliminary investigation of low energy photon radiation occurring in elements having short half-lives. The first of the two counters was a 4 in. diameter brass counter filled to a pressure of one atmosphere with a mixture of 90% argon and 10% methane. This counter was operated with the central wire at a potential of approximately 2700 volts. The output from this was fed into an A-1-B preamplifier and then into an A-1 linear amplifier whose output is connected to a cathode ray oscilloscope. All data are collected photographically from the screen of the oscilloscope and analyzed as described in ORNL Progress Report 694.[1] Various elements were subjected to neutron bombardment inside the pile for a short period of from one to sixty seconds depending on the cross section and half-life of the element. A photograph was then taken as the sample decayed in front of the counter window. A half-inch lucite absorber stopped all beta rays. For most elements observed there appeared on the oscilloscope screen a collection of pulses whose height corresponded to an energy of 8 Kev. This line was due to the fluorescent X rays emitted from the walls of the brass counter. In many cases there was a second line of higher energy which within the limits of experimental error corresponded to the $K\alpha$ lines of the X-ray emission spectrum of the irradiated element. The resolution of the counter is not good enough to differentiate between the $K\alpha$ and $K\beta$ emission lines. Because of the large size of this counter it was difficult to shield it suitably from all stray radiations. It was suggested by Dr. C. J. Borkowski of the Chemistry Division that a commercial type Eck and Krebs glass geiger tube filled with a mixture of 60 cm krypton and 6 cm of methane would work more satisfactorily. Since this tube has a diameter of approximately 7/8 in. as compared to 4 in. for the brass counter it could be much more easily shielded. This counter has a glass wall with a silver cathode. A potential of approximately 2700 volts was applied to the central wire. In the case of many elements having an atomic number greater than krypton a double line

(1) Campbell, E. C. and Kahn, J. H., "Spectrum of 2.5 sec Erbium Isomer," *Physics Division Quarterly Progress Report for Period Ending March 15, 1950*, ORNL 694, 15 (June 13, 1950).

appears on the oscilloscope screen as an irradiated sample decays in front of the counter. The line representing the group of more energetic pulses corresponds in to the Kα X-ray emission line while the second line always appears approximately 14 Kev lower in energy. This difference corresponds to the K binding energy of the krypton. If the incoming photon ejects a K electron from a krypton atom, the subsequent rearrangement of the extra nuclear electrons may result in either emission of a K X-ray or production of Auger electrons. If Auger electrons are produced, the counter detects the total ionization caused by the ejected K-electron and the Auger electrons. This results in an output pulse approximately equal to that produced by a simple photoelectric effect in one of the outer shells. The K X-rays emitted by the krypton are weakly absorbed in the gas and most of them escape from the sensitive region of the counter. In this event only the ionization caused by the ejected K electron is detected and the output pulse is decreased by the K shell binding energy. To date we have apparently only observed characteristic X-rays from various elements, but we plan to search for possible nuclear gamma rays whose energies lie between 10 and 75 Kev. This should then give information concerning conversion coefficients in this energy range. One interesting development in our work so far was in the case of a zirconium sample that we studied. The photograph showed a collection of pulses at 55.5 Kev. This we believe to be due to a hafnium impurity in our sample since this is very close to the value of the Kα X-rays of hafnium. We may therefore have found a means of detecting certain impurities in a given sample.

THE TOTAL CROSS SECTION OF HOLMIUM

T. E. Stephenson and T. Arnette

The measurement of the total cross section of holmium as a function of neutron energy using the neutron crystal spectrometer has been completed. Preliminary results reported in the previous Quarterly Progress Report[1] are confirmed and extended.

The accompanying curve (Fig. 22) shows the cross section per holmium atom as a function of energy. The energy range has been extended so that the interval covered lies between .026 electron volts and 0.5 electron volts. The reason for extending the energy region so markedly was the interesting evidence of paramagnetic scattering. In the previous estimate of the magnitude of the paramagnetic scattering the assumption was made that this effect would be very small at 0.3 electron volts. This is even more true at 0.5 electron volts and the new estimate for the magnitude of the paramagnetic scattering at .03 electron volts is now about 16 barns as compared with 18 previously. No estimate of the effect is given for .026 electron volts since it is known that higher order reflections from the spectrometer's quartz crystal occur below .03 electron volts. Similar results have been obtained elsewhere for other paramagnetic substances[2,3] and the large magnetic moment of holmium (more than 10 Bohr magnetons) suggests that the effect should be large for holmium. It should be an interesting substance for total cross section measurements at energies lower than the bent crystal spectrometer is capable of giving and for scattering cross section measurements as a function of energy.

Evidence was also found for crystalline diffraction peaks in the energy region near 0.03 electron volts and near 0.06 electron volts. Since the magnitude of these peaks was only about three percent of the total cross section, this work was found very laborious and time consuming and no attempt was made to chart these peaks completely through the observed energy region.

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(1) Stephenson, T. E. and Arnette, T., "The Total Cross Section of Holmium," *Physics Division Quarterly Progress Report for Period Ending March 15, 1950*, ORNL 694, 32 (June 13, 1950).

(2) Ruderman, Havens, Jr., Taylor and Rainwater, "The Scattering of Slow Neutrons by Paramagnetic Crystals," *Phys. Rev. 75*, 895 (1949).

(3) Ruderman, I. W., "The Scattering of Slow Neutrons by Paramagnetic Crystals," *Phys. Rev. 76*, 1572-1584 (1949).

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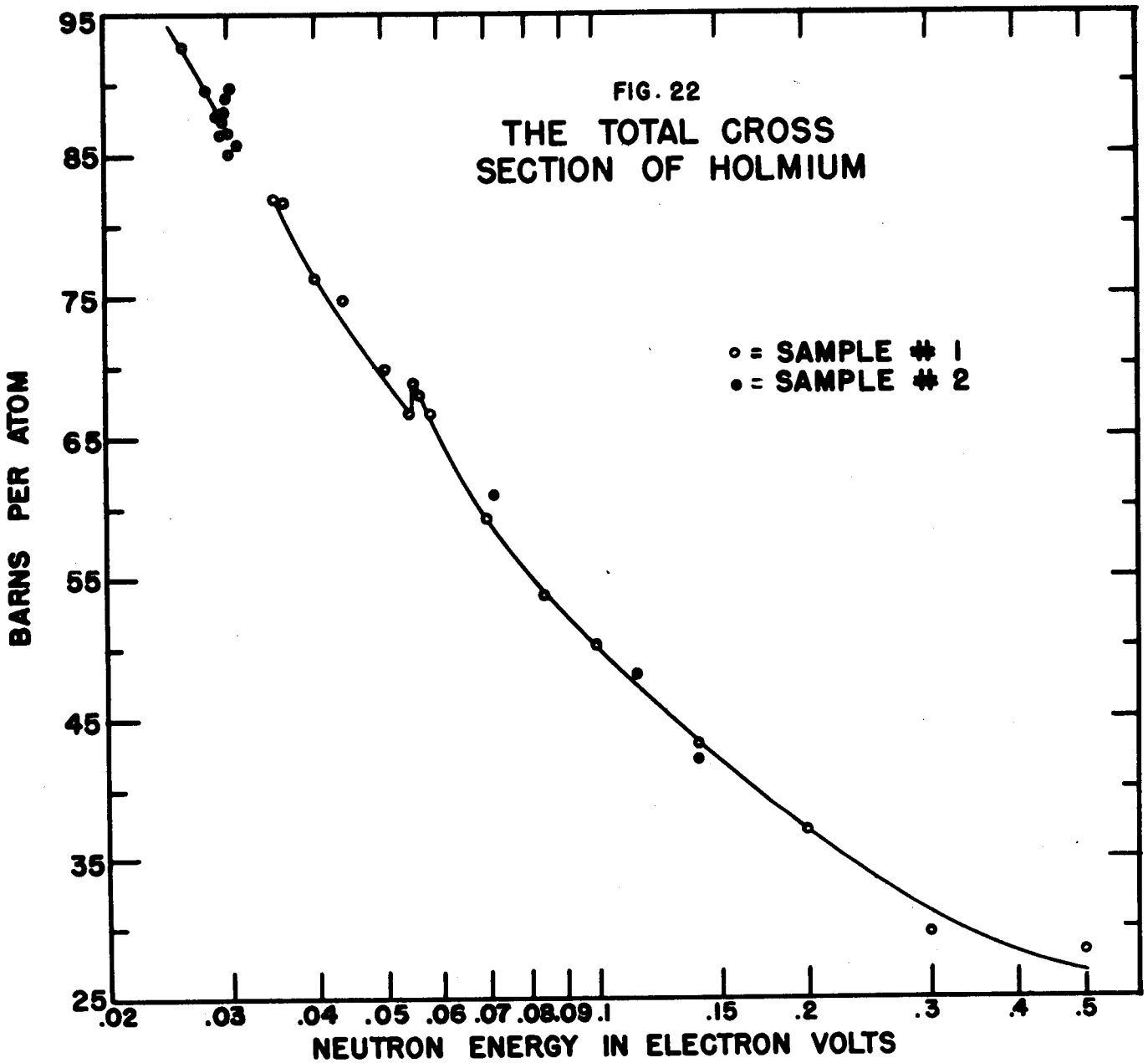

As can be seen from the curve, most of the measurements were taken on sample number one weighing 66.8 milligrams. A second anhydrous sample was prepared by Mr. Lavalle of the Chemistry Division and it was used to check the results given by the first sample. Sample number two weighed 42.0 milligrams and cross section measurements made with it are in rather good agreement with sample number one.

NEUTRON DIFFRACTION

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

BRAGG REFLECTION OF NEUTRONS BY MAGNETIZED SAMPLES

The theory of magnetic scattering of neutrons as given by Halpern and Johnson[1] predicts a relationship between intensity of scattering and the relative direction of scattering referred to the direction of alignment of the atomic magnetic moments. By using a ferromagnetic substance one can arbitrarily control the magnetic moment direction by application of external magnetic fields and hence investigate the predicted intensity effects. The directional effects of magnetic scattering are important in establishing the type of interaction existing between the neutron's magnetic moment and the atomic magnetic moment as Ekstein[2] has pointed out.

Figure 23 illustrates schematically the type of experiment to be considered. An unpolarized beam of monochromatic neutrons falls upon a polycrystalline ferromagnetic sample whose magnetic moments are all directed according to the applied magnetic field H. In a Debye ring of scattering from such a sample, the H-J theory of scattering predicts a variation of scattered intensity around the ring. For the case where $\bar{H}$ is perpendicular to $\bar{e}$ (the scattering vector) the intensity should be proportional to $(C^2 + D^2)$ whereas when $\bar{H}$ is parallel to $\bar{e}$ the intensity should be proportional to C^2 only. When the sample is unmagnetized and the magnetic moments are directed at random, the intensity is proportional to $[C^2 + (2/3)D^2]$. C is the nuclear scattering amplitude and D is the magnetic scattering amplitude. For another type of interaction originally used by Bloch and discussed by Ekstein, the intensity variation is just reversed from the above and Ekstein has introduced the possibility of an intermediate type of interaction not necessarily described by the above two limiting theories.

The initial experiments performed on the above made use of pure iron as the scattering medium. It was expected that the intensity variation around

(1) Halpern, O. and Johnson, M. H., "On the Magnetic Scattering of Neutrons," *Phys. Rev.* 55, 898 (1939).

(2) Ekstein, H., "Magnetic Intereaction Between Neutrons and Electrons," *Phys. Rev.* 76, 1328 (1949).

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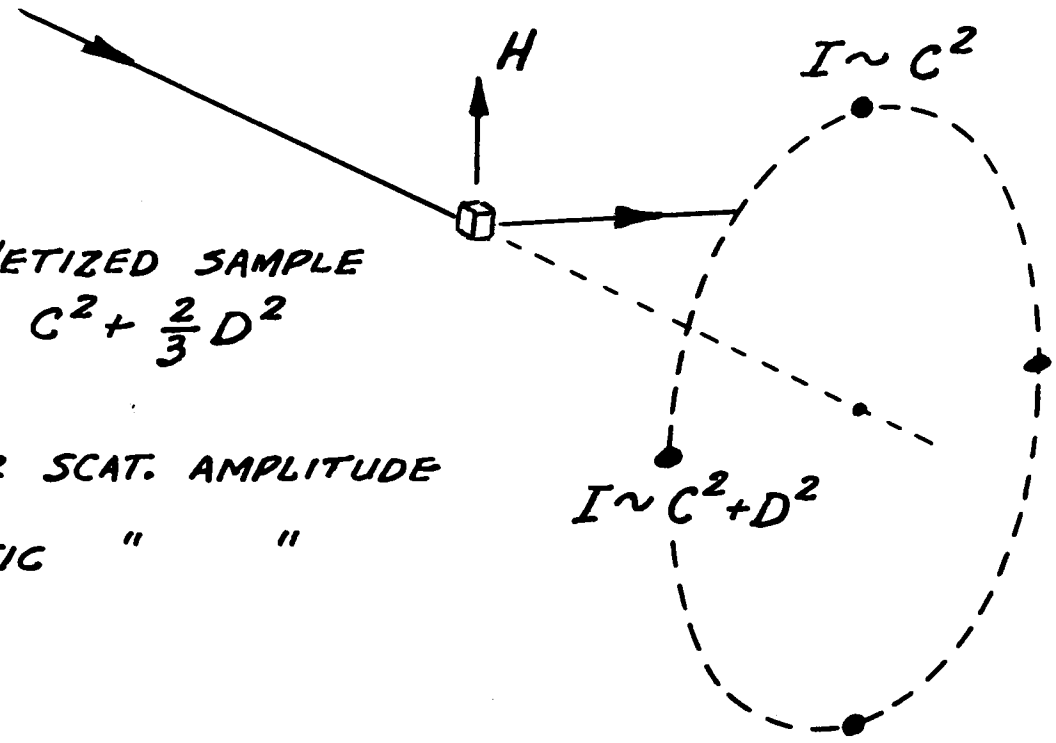
FIG. 23



FOR UNMAGNETIZED SAMPLE

$$I \sim C^2 + \frac{2}{3} D^2$$

$C \equiv$ NUCLEAR SCAT. AMPLITUDE

$D \equiv$ MAGNETIC " "

the Debye ring would be rather small (at most about 8%) for the case of iron since the relative values of C and D are not too favorable for a large effect, and this was found to be true. The use of iron is furthermore unfavorable because of the considerable polarization which is produced upon Bragg scattering when $\overline{H} \perp \overline{e}$. The polarized scattered radiation for this case suffers a different attenuation in passing through the sample than does the unpolarized scattered radiation when $\overline{H} \parallel \overline{e}$ and this influences the relative intensities.

During the period of the initial experiments it was found that one of the strong Bragg reflections from ferromagnetic Fe_3O_4 was almost wholly magnetic in nature with very small nuclear contribution. This suggested the use of this material in the directional intensity study because the intensity effects should be very large and the polarization problems mentioned above should be reduced. A sample of Fe_3O_4 powder was packed into a holder between the pole pieces of an electromagnet and the (111) powder peak was studied with the sample unmagnetized and magnetized in the two critical directions. These data are shown in Fig. 24. Variations in the scattered intensity are seen to occur, with a large intensity for $\overline{H} \perp \overline{e}$ and with a low intensity for $\overline{H} \parallel \overline{e}$ in general agreement with the Halpern-Johnson predictions. Figure 25 shows the magnetic field dependence of scattered intensity. The intensity effects are seen to saturate at reasonable field strengths and in fact it would be expected that the intensity should follow the magnetization curve of the sample attaining perhaps 95% of its saturation value at a few hundred oersteds. This is in contrast to the saturation effects which enter into polarization experiments by transmission where depolarization depends strongly upon the residual departure from saturation and hence where much higher fields are required.

Fe-Cr ALLOYS

At the suggestion of Carl H. Samans of the Standard Oil Company of Indiana we have investigated the possible existence of superlattice formation in an alloy containing 70 atom percent Fe and 30 atom percent Cr. Since the X-ray scattering amplitudes of iron and chromium are comparable, the lack of evidence for superstructure lines in the X-ray diffraction pattern of the alloy does not rule out the formation of a superlattice. On the other hand the best values available at the present time for the neutron coherent scattering amplitudes of iron and chromium make it appear that the detection of superstructure in this alloy by neutron diffraction should be feasible.

FIG. 24

(111) Fe_3O_4 MAGNETIC REFLECTION

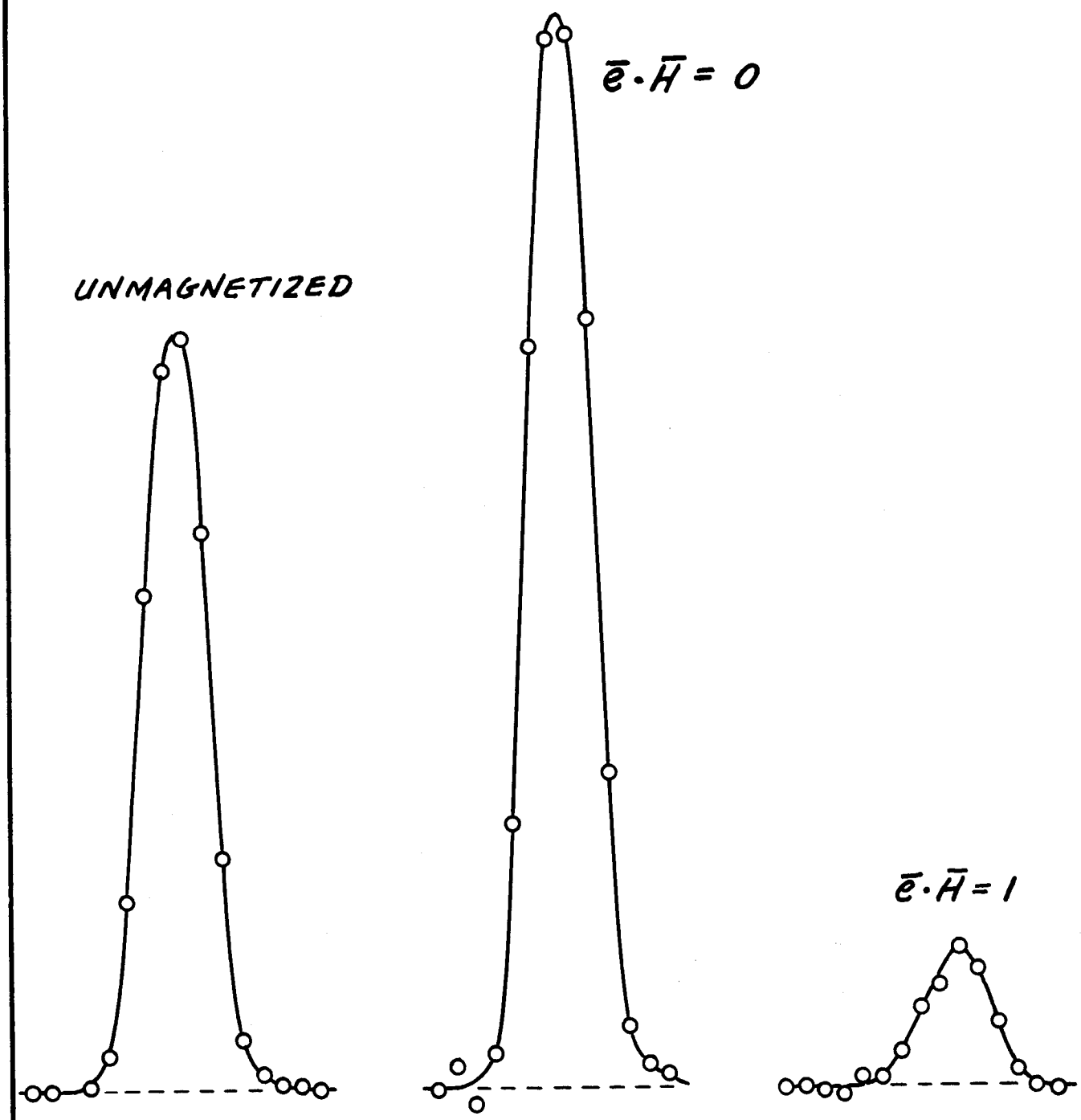


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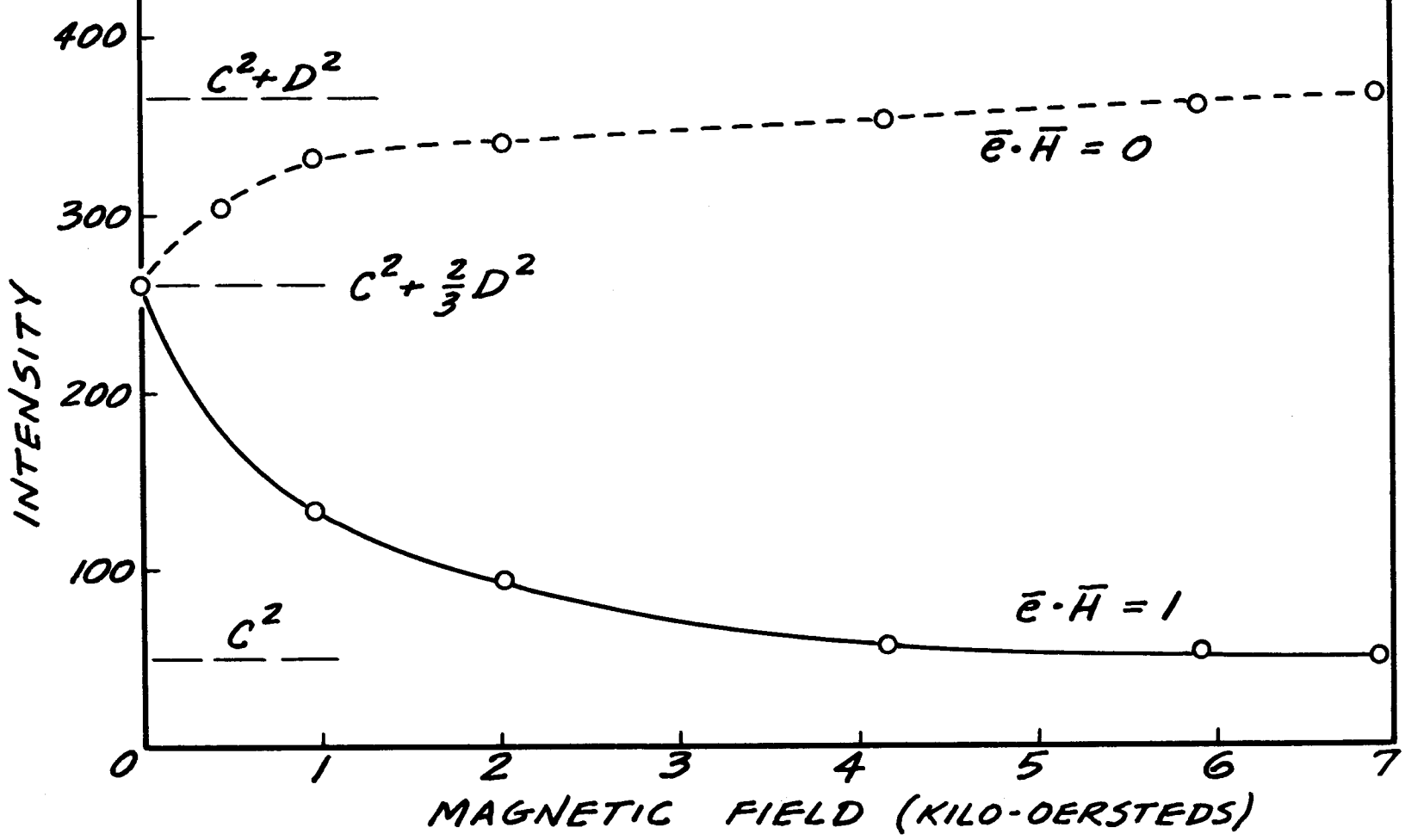
FIG. 25

MAGNETIC FIELD DEPENDENCE OF (111) Fe_3O_4 INTENSITY



In order to test the sensitivity of neutron diffraction methods we have considered two possible ordering schemes, the Fe_3Al lattice discussed by Bradley and Jay[3] and the β-brass structure. According to Bradley and Jay, aluminum atoms enter the body-centered iron lattice in a random way until at an atomic abundance of 18% an ordered lattice begins to form. To discuss this ordered lattice consider a unit cell of twice the lattice period of the iron lattice. Thus the new unit cell consists of eight of the body centered smaller units. The atoms in the larger cell lie in four sets of face centered positions:

A	0,0,0;	½,0,½;	0,½,½;	½,½,0
B	½,½,½;	½,0,0;	0,½,0;	0,0,½
C	¼,¼,¼;	¾,¼,¾;	¼,¾,¾;	¾,¾,¼
D	¾,¾,¾;	¾,¼,¼;	¼,¾,¼;	¼,¼,¾

At the 18% aluminum composition, the aluminum atoms tend to fill the *D* sites. At the composition Fe_3Al the iron atoms occupy sites *A*, *B*, and *C* and aluminum the *D* sites. As more aluminum is introduced it tends to fill the *C* sites until at the composition FeAl, the β-brass structure is formed with aluminum in sites *C* and *D* and iron in sites *A* and *B*. Since the Fe-Cr alloy is of 70-30 composition we have assumed a model in which sites *A* and *B* are occupied by iron alone, sites *D* by chromium alone, and sites *C* by iron and chromium distributed at random within the limits of the composition.

A second model is based upon the β-brass structure. Still referring the atomic coordinates to the doubled unit cell, we have assumed that sites *A* and *B* are occupied by iron, and sites *C* and *D* by a random arrangement of iron and chromium. A third model, the disordered lattice, contains a random arrangement of iron and chromium over all sites.

Structure factors based on the three models are given in Table I, and the expected intensities are compared with the observed in Table II. The best agreement is with the disordered lattice. Furthermore the intensities calculated for the superstructure lines are easily within the range of detection. We conclude that ordering of either of these two types is not present in the alloy. It is to be noted that the measured intensity of the 220

(3) Bradley, A. J. and Jay, A. H., "The Formation of Superlattices in Alloys of Iron and Aluminum," *Proc. Roy. Soc. Lond.* A136, 210 (1932).

TABLE I

Structure Factors based on the Fe_3Al, β-brass and Disordered Lattices F^2 (per unit of the doubled cell)

$h + k + l$	Fe_3Al	β-BRASS	DISORDERED
4n	$(11.2f_{Fe} + 4.8f_{Cr})^2$	$16(2.8f_{Fe} + 1.2f_{Cr})^2$	$16(2.8f_{Fe} + 1.2f_{Cr})^2$
4n + 1	$(3.2f_{Fe} - 3.2f_{Cr})^2$	0	0
4n + 2	$(4.8f_{Fe} - 4.8f_{Cr})^2$	$16(1.2f_{Fe} - 1.2f_{Cr})^2$	0
4n + 3	$(3.2f_{Fe} - 3.2f_{Cr})^2$	0	0

TABLE II

Observed Intensities and Intensities Calculated for Fe_3Al, β-brass and Disordered Lattices

INDEX	Fe_3Al	β-BRASS	DISORDERED	OBSERVED
111	18.7	0	0	< 4
200	23.8	16.5	0	< 7
220	533	533	533	625
311	16.3	0	0	Not measured
222	11.3	7.8	0	< 6
400	141	141	141	157
331	10.1	0	0	< 6
420	21.6	15.0	0	< 7
422	405	405	405	421

reflection is higher than the calculated value. Further work is needed to resolve this discrepancy.

SCATTERING CROSS SECTION OF CHROMIUM

In connection with the Fe-Cr study a separate measurement of the coherent scattering cross section of chromium was made using the body-centered modification of metallic chromium with the following results: $f_{Cr} = 0.37 \times 10^{-12}$ cm $\sigma_S = 1.7$ barns. From the allow study it may be seen that chromium scatters with positive phase.

TOTAL REFLECTION AND REFRACTION OF NEUTRONS

A. W. McReynolds R. J. Weiss
G. W. Johnson*

Several neutron reflection and refraction experiments have been initiated and partly completed in the past quarter. In Fig. 26 is shown the versatile facility for such work which has been installed at one of the pile holes. The collimator defines a 2 in. wide by 0.020 in. high neutron beam of one minute half-width. It rotates about an external horizontal axis, adjusting beam level from 30′ down to 15′ up. Mirror mount tables are adjustable in 0.1′ intervals and rotation of the BF_3 detector and monochromator crystal about a horizontal axis permits selection of a monoenergetic beam.

Small Angle Scattering in Powders. A series of measurements of spreading of a collimated beam by transmission through a powder aggregate, as a function of particle size, wave length, and neutron index of refraction were made by Brookhaven Lab personnel and will be reported in detail in the Brookhaven quarterly report.

Index of Refraction of Liquids and Gases. Reflections at 3′ angle of incidence were observed from numerous liquids, in particular ethylene glycol and triethylene glycol, $C_2H_6O_2$ and $C_6H_{14}O_4$, in which the ratio of C and O to H is such that the index of refraction is very slightly less than unity. The reflected intensity is then proportional to

$$\int_0^{E_c} E e^{-(E/kT)} \approx \frac{E_c^2}{2} \propto \lambda_c^4$$

where E_c is the critical energy below which total reflection occurs.

Reflected intensity $\propto \delta^2$, where δ = 1 - index of refraction = const × na. To determine coherent scattering amplitudes of gases, the liquid mirrors were placed in a pressure tank and relative refractive indices of the gas and liquid varied by varying gas pressure. Since the gas index is just proportional to density and therefore to pressure, the reflected intensity should be determined by

$$\frac{I}{I_0} = \left[1 - \frac{n_1 a_1^{1/2}}{n_0 a_0^{1/2}} \right]^2 = \left[1 - \frac{P}{P_0} \right]^2$$

* Guest of ORNL from Brookhaven.

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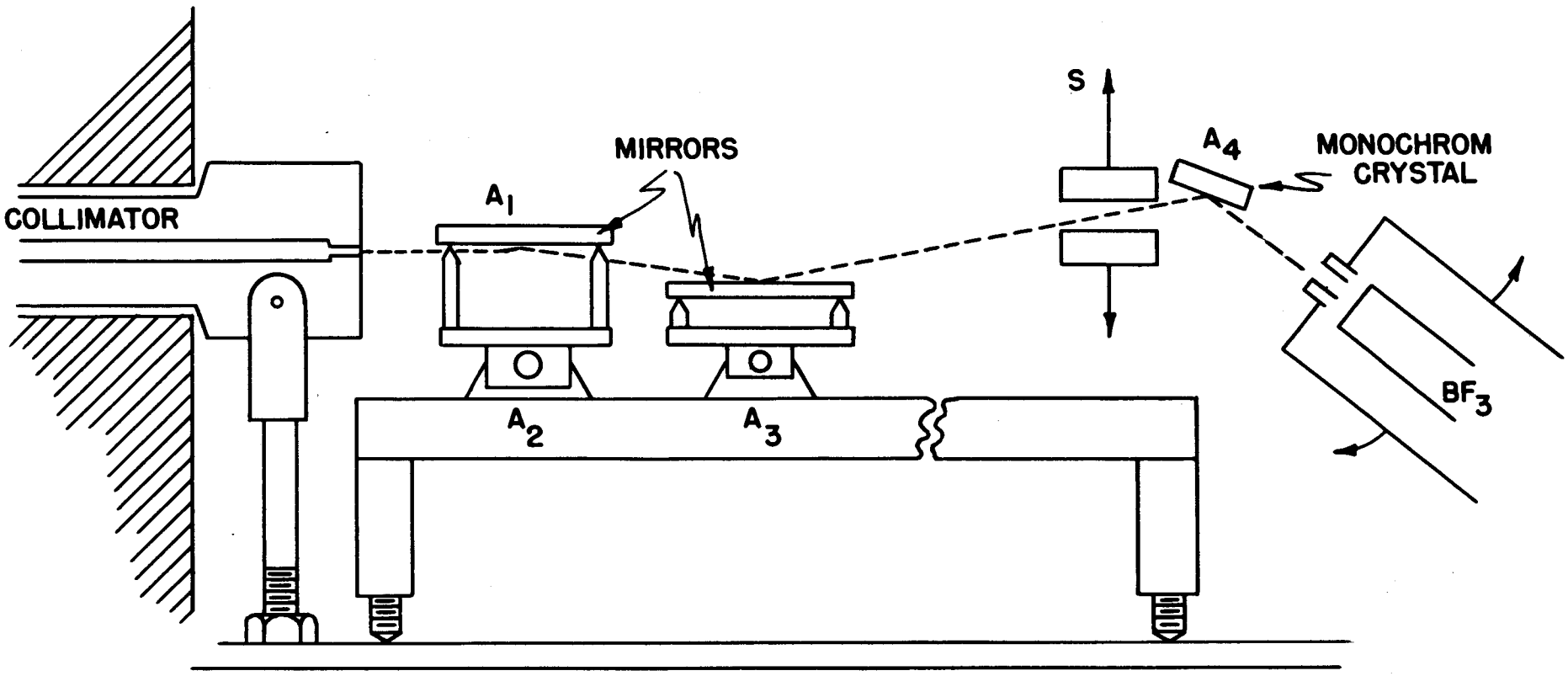

A_1 – AXIS OF COLLIMATOR
A_2 – A_3 = AXES OF FIRST AND SECOND MIRROR TABLES
A_4 = AXES OF MONOCHROMATOR CRYSTAL AND COUNTER ASSEMBLY
S – COMPARATOR SLIT

FIG. 26
NEUTRON MIRROR APPARATUS—SCHEMATIC

where n_0, n_1 = atoms/cc in liquid and gas, and

a_0, a_1 = scattering amplitudes.

P_0 = pressure at which indices of gas and liquid are equal.

In Fig. 27 are plotted preliminary curves of $(\text{intensity})^{1/2}$ vs. pressure for oxygen, nitrogen, argon, and helium, showing the straight line relation. Figure 27 illustrates the linear relationship found between $(\text{intensity})^{1/2}$ and pressure. Qualitatively these curves indicate that the scattering amplitudes for He and A are positive, and quantitatively, with more detailed corrections for diffuse scattering in the gas, the intercepts with the horizontal axis are interpretable in terms of magnitude of the scattering amplitudes.

Cadmium Mirrors. Reflection from cadmium is of particular interest as a means of studying the scattering resonance associated with the 0.18 ev, 0.7 angstrom capture resonance. Since the scattering amplitude is expected to follow a dispersion curve, being high at and above resonance and low just below resonance, it is desirable to study scattering vs. wave length. Cadmium mirrors were made by evaporation on glass and quartz, and several preliminary and qualitative results have been obtained.

a. A cadmium film deposited on the face of a single crystal quartz mirror reflects part of a beam transmitted through the quartz to the quartz-cadmium interface, indicating that δ = (1 - index of refraction) is larger for cadmium than for quartz at least in some wave length regions.

b. Reflected intensity for the Cd surfaces is lower than from glass except at small angles, indicating a low index near the thermal maximum around one angstrom.

c. Figure 28 illustrates the variation of intensity with mirror angle for a narrow range of energies selected by reflection from the (111) face of a nickel crystal. At the wave length used in Fig. 28, (about one angstrom) glass and nickel mirrors show about the expected critical angles, but cadmium gives no reflection. Further measurements will be made for various energies near the resonance range.

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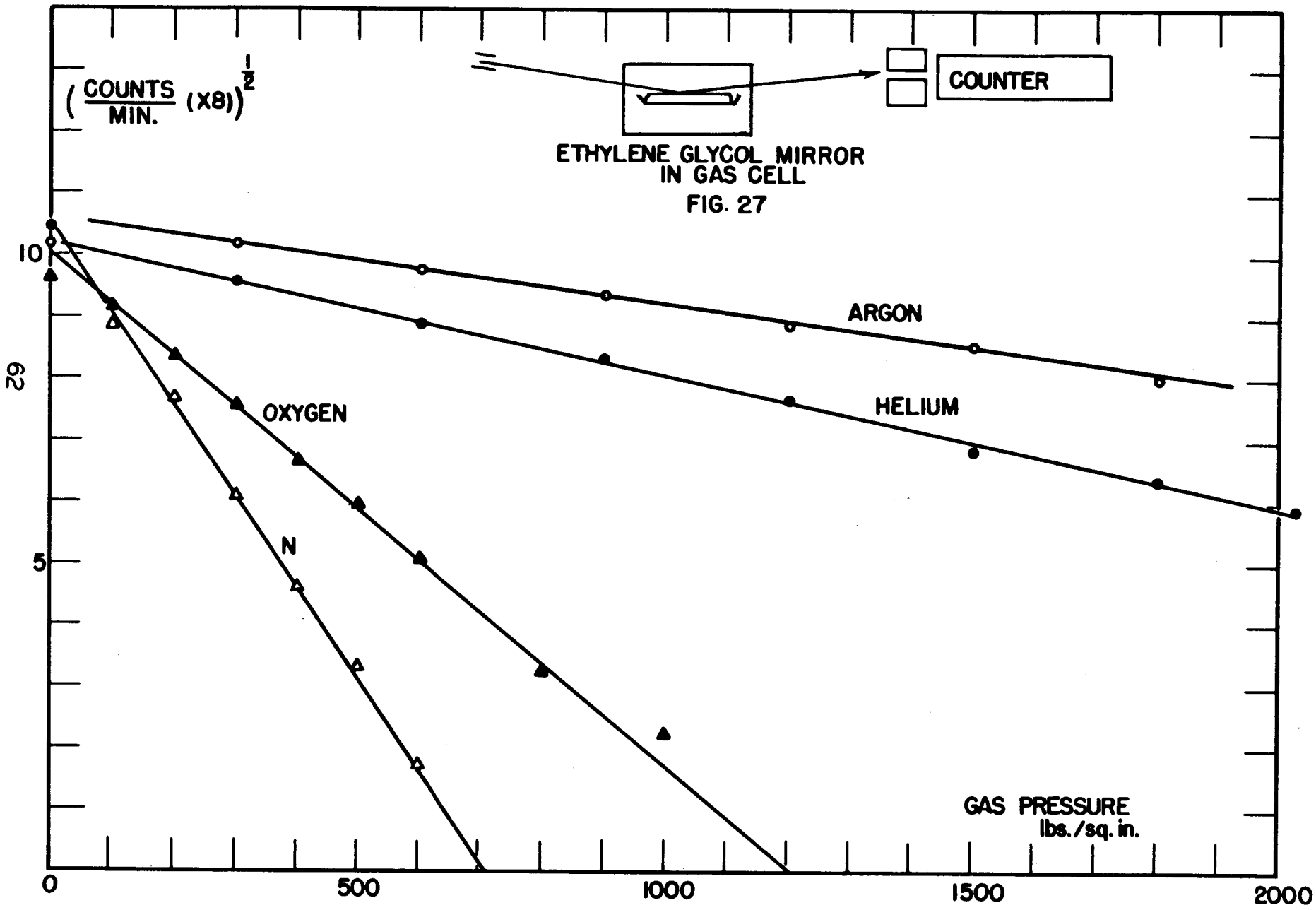

FIG. 27

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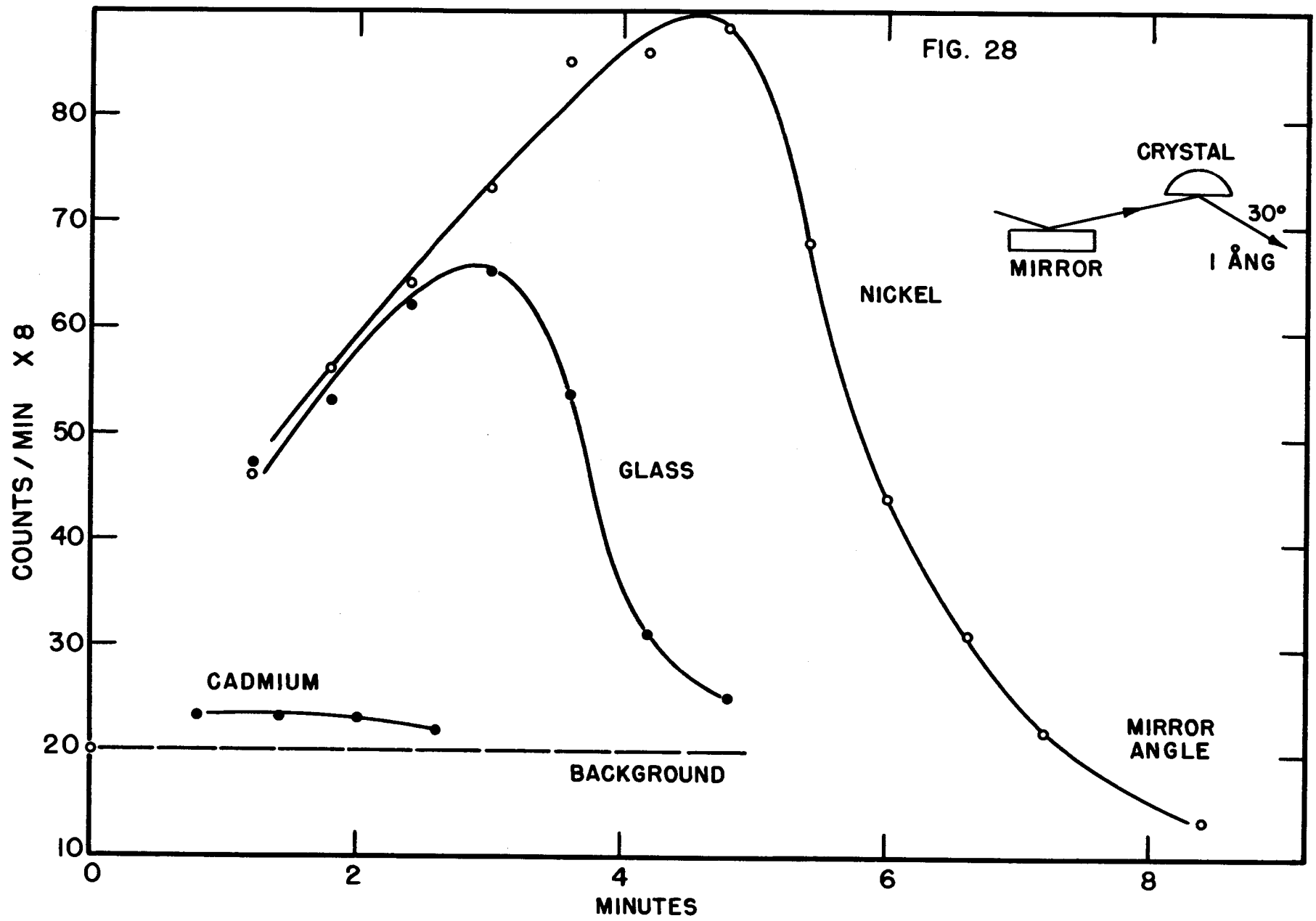

NUCLEAR PHYSICS AND LOW TEMPERATURES

ALIGNMENT OF NUCLEI

S. Bernstein
L. D. Roberts
J. W. T. Dabbs, Jr.
J. B. Capehart
T. E. Stephenson
C. P. Stanford

With the completion of the balcony construction on the south face of the pile, the neutron polarization work has been resumed. A 1 kw neutron polarizing magnet has been installed on the third level, between the large nuclear alignment magnet and the pile face. The purpose of this 1 kw magnet is to produce a beam of polarized neutrons with which to bombard the polarized nuclei. All the necessary neutron counting equipment has also been installed on the third level.

In addition a complete neutron polarization set of equipment has been put into operation on the first level of the pile. The purpose of this equipment is to furnish a means of studying the problems of neutron polarization associated with the nuclear polarization project without tying up the third level low temperature equipment.

With the installation of the complete neutron polarization and low temperature equipment, we have met directly with several minor experimental difficulties intimately associated with the main problem of demonstrating nuclear alignment. From the first it was realized that Dewar flasks of pyrex should not be used in the path of the beam, since the boron content would cut down the counting rate. However, counting rates were found to be acceptable even if the pyrex liquid-helium-containing Dewar were retained. It was soon found that the pyrex destroyed the experimental evidence for neutron polarization, that is, the single transmission effect of the iron was very much reduced when the pyrex was inserted into the beam. These results were interpreted as being due to the filtering effect of the boron. The boron selectively absorbs those (slower) neutrons which are most easily polarized. We have now assembled a complete Dewar flask system which contains no pyrex.

Our plan previously had been to procure evidence for nuclear alignment by observing the effect of the nuclear alignment on the transmitted beam of

polarized neutrons. This procedure seemed simpler experimentally than removing the bombarded sample from the depths of the Dewar flask in which it was maintained at a low temperature during bombardment, and then measuring its activity. However, the work done thus far with polarized neutrons has suggested that perhaps activation measurements should be reconsidered. The necessary sample positioning devices and β counting equipment are now being assembled for an activation experiment.

Manganous ammonium sulphate has been chosen for our first attempt at nuclear alignment because of its experimentally demonstrated large hyperfine structure. Several trial activations of this substance have been made. Counting rates achieved with the neutron beam furnished by the beam collimator which we are now using give saturated activities of about 800 counts per minute with 4 cm of neutron polarizing iron in the beam.

Our attention has been focussed also on the problem of maintaining the neutron polarization as the neutron beam leaves the neutron polarizing magnet and approaches the nuclear-alignment magnet. In order to study this problem, measurements of the following type have been taken. A piece of Fe about 4 cm thick is placed between the poles of both the small and large magnets. The magnetic field of the small magnet is kept on. The single transmission effect of the iron in the large magnet is measured for both magnetic fields parallel. A thin piece of unmagnetized iron is then placed between the two magnets in order to completely depolarize the beam while the single transmission effect of the large magnet is measured again. If the neutron beam were completely depolarized in the region of varying magnetic field between the two magnets, the two single transmission effects measured would be the same. Actually the data indicated appreciable polarization in the beam entering the large magnet. With the data available now, a quantitative value for this polarization can be calculated on the assumption that the piece of iron in the large magnet is completely saturated. We plan to continue these depolarization studies so that the proper means can be taken to maintain the neutron polarization.

As mentioned in the last quarterly report, a KB-150 diffusion pump has been installed on the third level to obtain low liquid helium temperatures by pumping. This equipment works well, giving the expected minimum temperature of 0.9°K. Without this diffusion pump, using only a 5 hp Kinney, the minimum temperature would be about 1.15°K, so the diffusion pump gives about a 25% temperature decrease. Precision oil and mercury manometer equipment has been

installed on the third level to measure temperatures from 1°K to 4°K and also magnetic susceptibility equipment for temperature measurements below 1°. The 300 kw MG set which is to supply power to the large magnet to be used for nuclear polarization is now installed and has performed well in preliminary tests. It will be connected to the large electromagnet, replacing the present 30 kw supply, as soon as convenient.

A possible experimental technique for obtaining nuclear alignment in the presence of a large hyperfine structure would be as follows. One would apply a large magnetic field, $H_0 \sim 20$ KG to the sample at a temperature $T_0 \sim 1$°K isothermally, and then do a partial adiabatic demagnetization. For suitable paramagnetic salts, and for a sufficiently large magnetic field, H, the temperature, T, will be proportional to H. Thus

$$T \cong \frac{T_0}{H_0} H.$$

Also, in the (T, H) region in which this relation holds, the adiabatic magnetic susceptibility will be quite close to zero, *i.e.*, the magnetic moment will be very nearly constant, independent of H and T. According to Dr. M. E. Rose, the fraction of the nuclei aligned, F_n, will be given by

$$F_n = \frac{a}{T} f_e,$$

where f_e is the fraction of the electrons aligned, and a is the constant containing the Boltzman constant, a spin factor, and the hyperfine splitting. At one degree K and 20 KG, f_e is essentially unity for manganous ammonium sulphate. By performing the partial demagnetization described above, one obtains a temperature lowering proportional to H, but with f_e constant. Clearly there is some critical field H_k below which T is no longer proportional to H and it is of interest to determine H_k. Then to obtain the largest possible nuclear alignment in a partial adiabatic demagnetization as described above, one would demagnetize approximately to the field H_k. This would give the maximum nuclear alignment F_n, since f_e would still have its maximum value of unity (approximately), and the temperature T would have the lowest possible value consistent with this.

We have set up equipment to measure the adiabatic susceptibility as a function of H for manganous ammonium sulphate. The field H_k would be that at

which this susceptibility was essentially zero. The following table gives preliminary results from our first run. D_s is a galvonometer swing proportional to this adiabatic susceptibility. H is the external magnetic field, uncorrected for demagnetization effects. The T^* value is so corrected however. The length to diameter ratio of the sample was 2.33 with an equivalent temperature correction $\Delta = 0.046°K$.

Demagnetization from $H_0/T_0 = 6440$ gauss/deg to a T^* (sphere) of 0.12° at $H = 0$.

H (gauss)	D_s (observed)
0	857
203	343
469	262
799	169
1000	117
968	128
1391	66
1720	44

Demagnetization from $H_0/T_0 = 4010$ gauss/deg to a T^* (sphere) of 0.26°K at $H = 0$.

H (gauss)	D_s (observed)	D_s (calculated)
0	288	288
445	206	207
1166	66	65
1710	24	29

Demagnetization from $H_0/T_0 = 1470$ gauss/deg to a T^* (sphere) of 0.59°K at $H = 0$.

H (gauss)	D_s (observed)
0	115
290	78
825	46
1152	30
1564	18

The first of these curves corresponding to demagnetization from H_0/T_0 = 6440 gauss/deg is of most interest. It is seen that in going from $H = 0$ to $H = 1720$, the susceptibility has fallen by a factor of about 20 but is still fairly large. It is estimated that H_k, which we define as the field necessary to decrease D_s by a factor of 50, will fall in the region of 3000 G. This is based on a thermodynamic calculation first given by Casimir assuming Curie's law and a specific heat going as A/T^2, discussed below. Because the above experiment leads only to an estimate of H_k we are considering checking this estimate by extending these measurements from the present maximum value of $H = 1720$ gauss to an H in excess of 3000 gauss. Assuming $H_k = 3000$ gauss, upon partial demagnetization from an initial field of ~ 20,000 gauss to H_k, one would obtain a final temperature in the region of 0.15° - 0.2°K with f_e still close to its maximum value of unity. The aim of this experiment was to obtain information about this important temperature region. However, one can obtain more information from this experiment, *i.e.*, the value of the specific heat constant, A.

According to Casimir (see above)

$$D_s = D_T{}^0 \frac{(1 + \frac{a}{A} H_0{}^2)^{1/2}}{(1 + \frac{a}{A} H^2)^{3/2}}$$

where D_s is the galvanometer deflection proportional to the adiabatic susceptibility of the sample in the magnetic field H, $D_T{}^0$ is the galvanometer deflection proportional to the isothermal susceptibility at the initial temperature and zero magnetic field, H_0 is the initial magnetic field in gauss, H, the final magnetic field, a is the Curie constant per mol = 4.34°K, and A is the specific heat constant (above) in erg deg. We have fitted this function to our data for the curve corresponding to H_0/T_0 = 4010 gauss/deg. With $a/A = 1.25 \times 10^{-6}$, the only adjustable parameter involved, we obtain D_s (calculated) in the above table.

The poor agreement at the point of largest $H = 1710$ gauss was due to a very poor signal to noise ratio there. The otherwise good agreement of theory and experiment is somewhat fortuitous for two reasons: (1) the thermodynamic theory is based on Curie's law, whereas it is the Weiss modification which is correct in this case, and (2) the values of H listed should be corrected for demagnetization effects. The effect of these corrections on the value of a/A

has not yet been accurately estimated, but it is in the neighborhood of 20%. Our value of $a/A = 1.25 \times 10^{-6}$ may be compared to the two values of Gorter, 1.33×10^{-6} and 1.56×10^{-6}, to that of Volger, 2.17×10^{-6}, and that of Benzie and Cooke, 1.56×10^{-6} where these measurements were made in the temperature region, 1° - 70°K, while ours was made in the temperature region 0.26° - 0.4°K. The fact that our value lies lower than previous measurements may in part be due to the different temperature region, but in any case it must not be taken seriously until the above mentioned corrections have been made. A spread of the order of 30% seems to be typical of this type of measurement.

We have fitted the thermodynamic function to our data for $H_0/T_0 = 4010$ gauss/deg only because it is only in the corresponding temperature region, 0.26° - 0.4°K, that the fundamental assumptions underlying this function even approximately hold. At higher temperatures, $H_0/T_0 = 147$ gauss/deg, there is a T^3 contribution to the specific heat which the theory neglects, and at lower temperatures, $H_0/T_0 = 6440$ gauss/deg, both the Curie law and the specific heat approximation, A/T^2, are completely invalid.

It may be added that the approximate agreement of our value of a/A in the low temperature region with other measurements made at higher temperatures indicates that there is no serious increase of the nuclear spin-electron-lattice relaxation time in the vicinity of 0.3°K relative to this value at 1°K and above.

INVESTIGATION OF NUCLEAR PHENOMENA IN PARAMAGNETIC SALTS

S. F. Malaker

A Hartshorn mutual inductance bridge, using a recently fabricated astatically wound mutual inductance, has been set up and preliminary measurements give about 1.98 μ henries per turn for the astatic mutual inductance. Decades down to 0.1 turn are operating satisfactorily, but more shielding will be necessary for the 0.01 turn inductor. Single crystals of cobalt ammonium sulphate, and this Tutton salt diluted with various diamagnetic ions, have been grown. Crystallographic studies of the various crystals are being made to ascertain the structure of the salt, with a view toward obtaining the size and shape of the water "octahedra" surrounding the paramagnetic ions. Dr. Max Bredig and Mr. B. Borie are making Fourier analyses of the salt. The large magnet is being wound and will be ready in a few weeks.

Appreciation is expressed to Dr. M. E. Rose for assistance in theoretical calculations and Dr. Max Bredig and Mr. Bernard Borie for assistance and information on crystallographic analysis.

PHYSICS OF SOLIDS

SEMICONDUCTOR BOMBARDMENT RESEARCH

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

Cuprous Oxide Rectifiers and Plates. Several commercial copper oxide rectifiers were exposed in the pile in a high fast flux region in order to determine the effect of pile irradiation on their characteristics. All but two of the units became very erratic after about one day of bombardment. The two good units, however, gave interesting results. The conductance in the back direction was affected very slightly while in the forward direction the conductance decreased very rapidly during the first several hours of bombardment. After the initial period this decrease, though less rapid, was definite and the forward conductance approached that of the back direction. These data are shown in Fig. 29.

Before continuing experiments on rectifiers it was considered advisable to investigate more thoroughly the effects of pile irradiation on the bulk properties of Cu_2O. Over a year ago several Cu_2O samples were bombarded, but due to lack of temperature control the results are not very significant. Two Cu_2O plates were prepared by heating in air at 950°C for 1-1/2 hours and the Hall coefficient and resistivity were measured as a function of temperature before bombardment. The samples were bombarded in a water cooled hole in a high fast flux region. The water cooling gave very uniform temperatures during the period of bombardment with temperature fluctuations of not more than three degrees. The conductance was measured periodically during the bombardment. The results are shown in Fig. 30.

The conductance decreases linearly with bombardment during the initial part of the exposure, passes through a minimum, and then increases with further bombardment.

In view of the similarity of this behavior to that of Ge, one might suspect a change of type. However, since the original material was P-type due to excess oxygen, the change, if it occurred, would be from P to N in contrast with a change from N to P in Ge.

A change in type in Cu_2O is theoretically feasible on the basis of oxygen removal. Ionic semiconductors usually owe their electrical properties to a

* Consultant from Purdue University.

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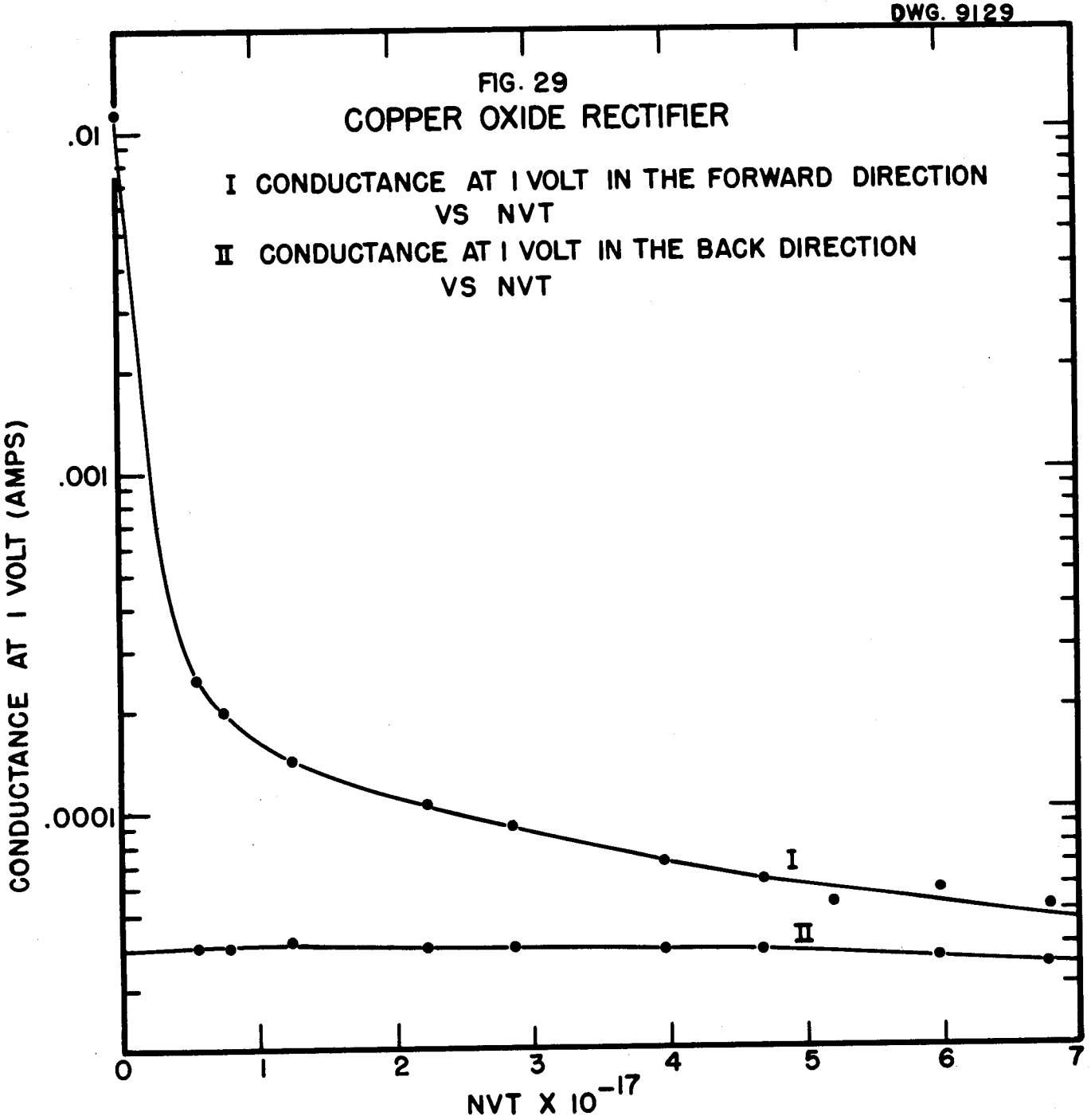

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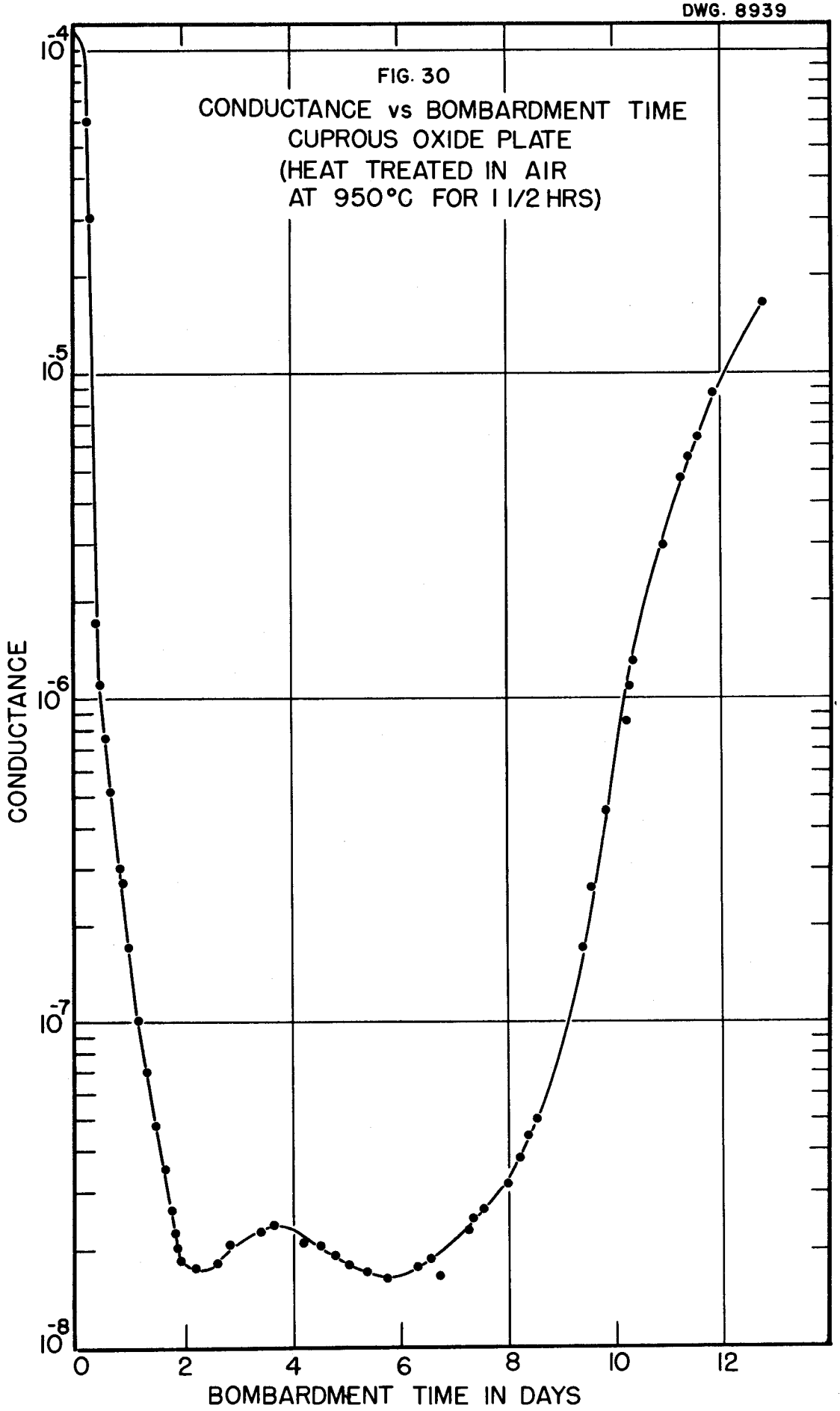

stoichiometric excess of one of their constituents. If the excess is metallic, the material is N-type while a nonmetallic excess leads to P-type conduction. Engelhard[1] has attempted to prepare N-type Cu_2O by prolonged annealing in a vacuum at high temperatures. These experiments however, always yielded P-type material even though copper metal was visible on the surface of the oxide. The reason that conversion to N-type was not possible is probably due to the fact that the copper separated out as a different phase instead of remaining atomically dispersed throughout the lattice. During fast neutron bombardment it may be that the excess oxygen is removed or made ineffective either by a differential knock-on process, the oxygen atom being four times lighter than the copper atom, or by being boiled out of the lattice by localized heating or a so-called "Thermal spike" associated with the terminus of the range of a fast neutron. If such is the case, one would expect any resulting excess of copper to remain atomically dispersed.

Due to the very high level of activity associated with the exposed samples (> 250 mr/hr after one month) we were unable to substantiate by Hall effect measurements whether or not a change of type had occurred. Such experiments are now under way.

In addition to these results a zero field emf was observed between the resistivity probes on both samples. At times during bombardment the value of this emf was as large as 0.1 volt. The origin of this potential difference is not known. It may be due to a photo-voltaic effect sensitive to γ and β radiation which is associated with a barrier layer produced during bombardment, since decay of this emf is observed when the pile is down. This effect is also being examined more thoroughly.

The Cu_2O plates used in these experiments were shaped from polycrystalline Cu_2O prepared by S. J. Angello of Westinghouse. They were prepared by suspending strips of high purity Chilean copper in air at 1000°C for periods of 16 hours. Even though the copper used was polycrystalline Cu_2O grains of 1 to 2 mm on edge were produced on oxidation. Whenever possible it is advantageous to work with single crystal semiconductors, since any effects due to grain boundaries and those due to inhomogeneities between grains are thus eliminated. Engelhard[2] was able to prepare single crystal plates of about 1 cm^2 area

(1) Engelhard, E.; "Elektrisches und optisches Verhalten von Halbleitern 9.;" *Ann. Physik*, *17*, 501 (1933).

(2) *Ibid.*

from copper strips by allowing the temperature to oscillate slowly between 950° to 1000°C during an oxidation period of over 24 hours. For future Cu_2O studies attempts will be made to prepare single crystals. Strain-free single crystal plates of electrolytic copper[3] have been prepared and will be oxidized in air at elevated temperatures. In view of Engelhard's success with polycrystalline copper, we hope to be able to prepare even larger single crystals by this method.

Quasi-Intrinsic Germanium Produced by Transmutations. K. Lark-Horovitz has suggested the possibility of preparing Ge with near intrinsic properties from N-type material by introducing a sufficient concentration of Ga impurity by thermal neutron capture to just neutralize the concentration of N-type impurity. Any effects due to lattice damage can be annealed out by holding for a sufficient period of time at an elevated temperature. Material prepared in this manner would be expected to have a higher resistivity then pure, intrinsic Ge because of a relatively high concentration of charged scattering centers which would be absent in the pure Ge.

Consequently, several high resistivity N-type Ge single crystals have been bombarded in the pneumatic tube, the thermal neutron dosage being determined from the initial donor concentration as estimated from Hall effect measurements and the effective capture cross section for Ge due to H. Pomerance.[4] In order not to introduce too much Ga impurity, *i.e.*, in order not to convert the material completely to P-type in one exposure, only about 80% of the calculated dosage was given in a single bombardment. Thus several exposures were necessary before complete neutralization of the N-type impurities was effected.

After each bombardment the effect of lattice damage was removed by annealing the samples for 24 hours at 450°C in a vacuum furnace at a pressure of about 5×10^{-5} mm Hg. The Hall coefficient and resistivity were then measured as a function of temperature. These are shown in Figs. 31 and 32 for one sample. The sudden break in both the Hall constant and resistivity curves is due to a change from intrinsic conduction at higher temperatures to impurity conduction at lower temperatures. After each bombardment the transition point moves to lower temperatures. When the material becomes intrinsic (the concentration of conduction electrons equal to the concentration of holes) there should be no break in the curve.

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(3) We are indebted to F. A. Sherrill, and to the Metallurgy Division, for preparation of these specimens.

(4) Pomerance, H., "Capture Cross Section of the Elements as Determined with Pile Oscillator" *Physics Division Quarterly Progress Report for the Period Ending December 15, 1949)*, ORNL 577, 25 (Feb. 8, 1950). See also, Cleland, J. W., Lark-Horovitz, K., and Pigg, J. C., "Transmutation-Produced Germanium Semiconductors," *Physics Division Quarterly Progress Report for Period Ending March 15, 1950*, ORNL 694, 56 (June 13, 1950).

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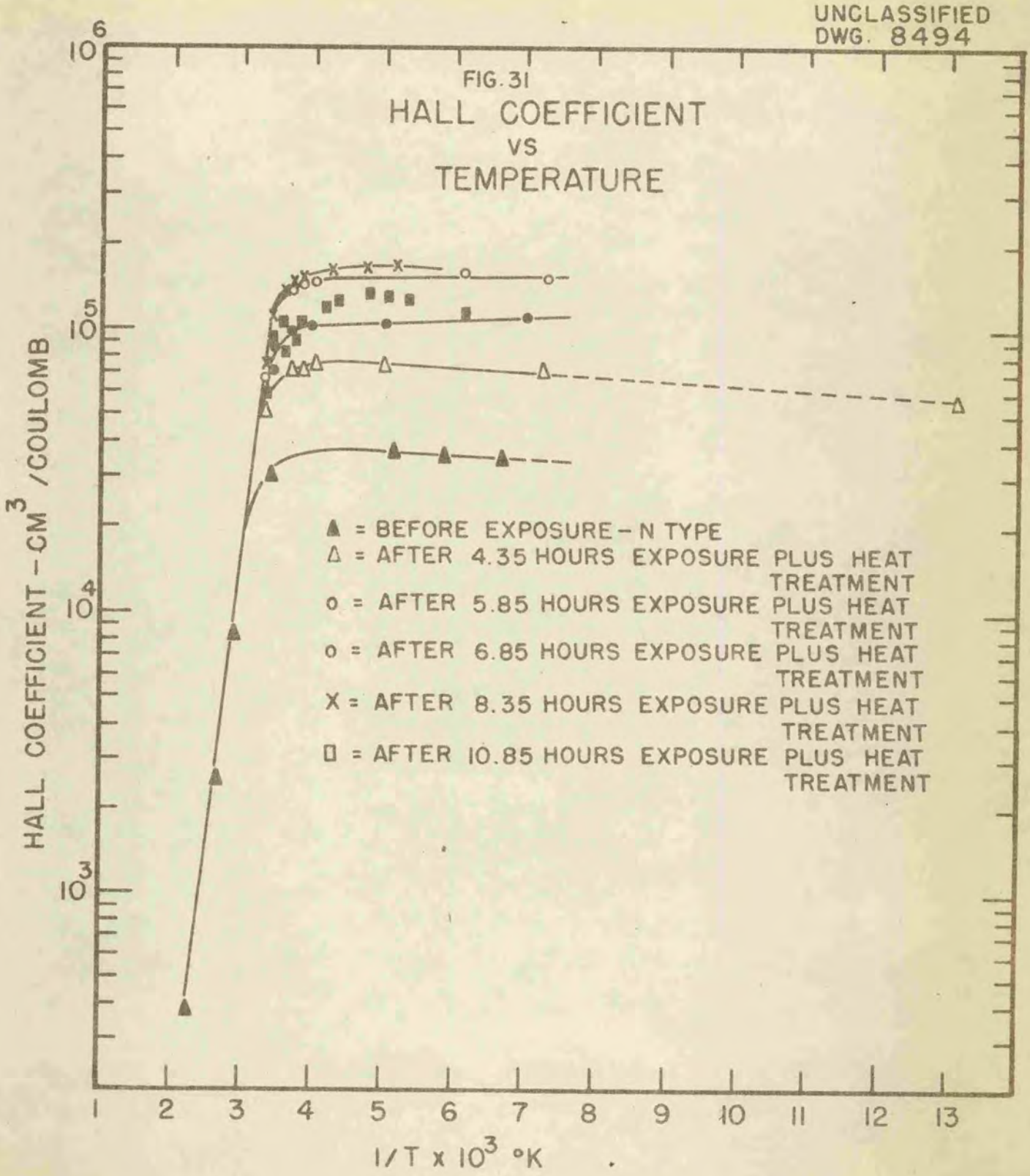

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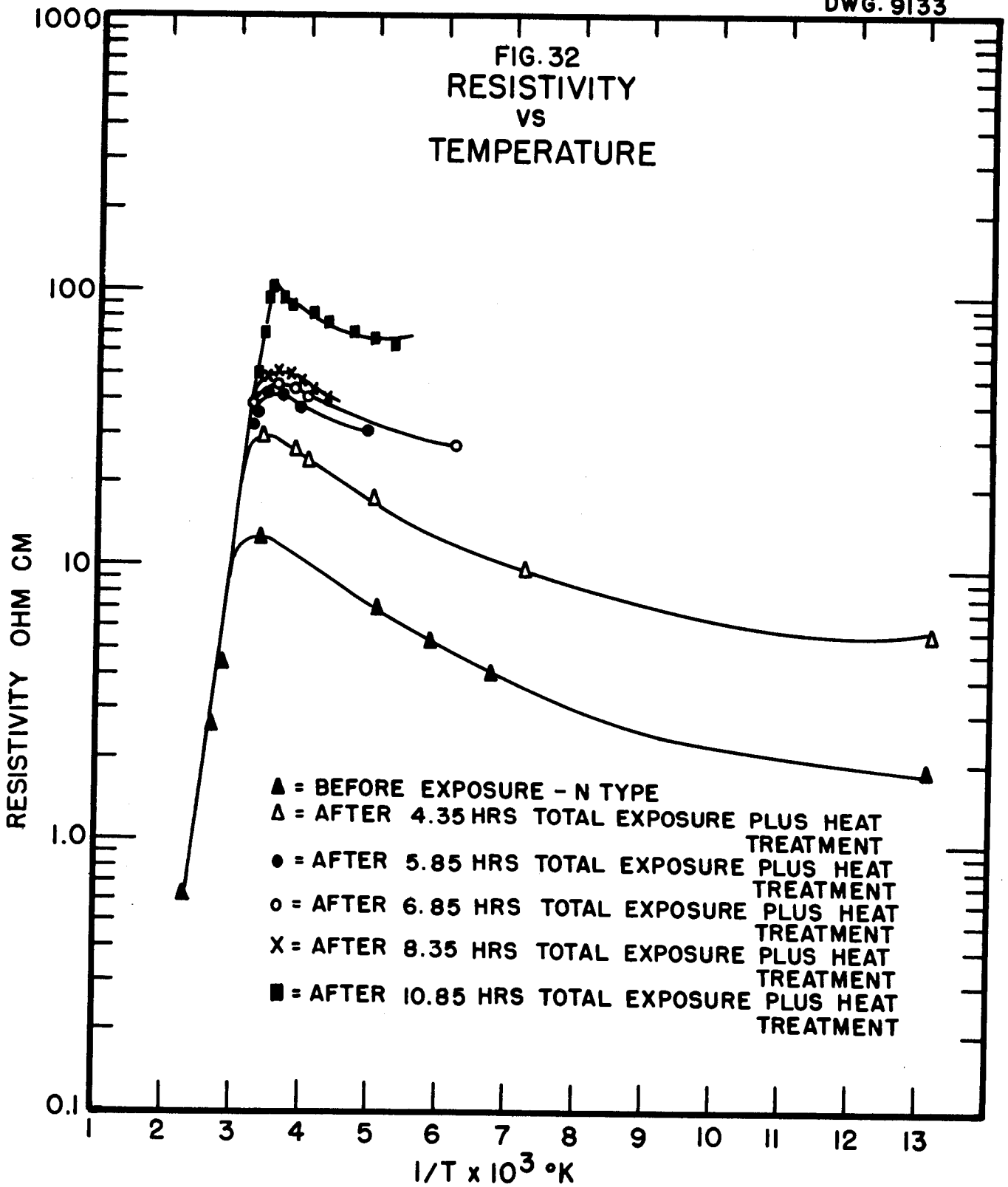

Effect of Fast Neutron Damage on Germanium Conductivity. In the last Quarterly Report[5] the results of analyses of conductivity vs. bombardment curves for N-type samples were reported. This work has been continued with emphasis on P-type samples. Three P-type and N-type samples were investigated. The change in carrier concentration per incident neutron was calculated from the initial linear slope of the conductivity vs. bombardment curve by means of the following relation:

$$\frac{dn_i}{d(\mathrm{nvt})_{fast}} = \frac{d\sigma_i}{d(\mathrm{nvt})_{fast}} \cdot \frac{1}{e\mu_i^0} \qquad (1)$$

where n_i is the carrier concentration, σ_i is the conductivity and μ_i^0 is the carrier mobility. The results are tabulated below in Table I.

TABLE I

SAMPLE	TEMPERATURE OF EXPOSURE	CHANGE IN CARRIER CONCENTRATION PER INCIDENT FAST NEUTRON
1 (N-type)	~ 30°C	- 3.9
2 (P-type)	0°C	+ 0.61
3 (P-type)	~ 20°C	+ 0.70
4 (P-type)	~ 30°C	+ 0.77

The results obtained on the N-type sample are in good agreement with those reported earlier. Also the agreement between the three P-type samples is very good.

If each acceptor introduced in P-type material due to bombardment were available for conduction, the initial change in carrier concentration per incident neutron for P-type material would be expected to have the same magnitude but opposite sign as that for N-type. This would essentially mean that the

(5) Crawford, J. H., Jr. and Lark-Horowitz, K., "Fast Neutron Bombardment Effects in Germanium," *op. cit.* ORNL 694, 50 (June 13, 1950).

activation energy necessary for the ionization of the acceptors be much less than kT. This is not the case. Thus one is led to the conclusion that there is an activation energy which is somewhat larger than kT. That the acceptor ionization process is activated is borne out by the temperature dependence of $d\ n_h/d\ (\text{nvt})_{fast}$. Experiments are being planned to study this point more accurately and to determine this activation energy.

Quasi-Intrinsic Germanium Produced by Lattice Damage. A preliminary report on this work was made in the last Quarterly Report.[6] The experiment described was repeated with greater care. The same sample was used, a high resistivity N-type single crystal of Ge, which was bombarded at dry ice temperature until the minimum conductivity was reached. The sample was then immediately pulled and stored in dry ice to minimize annealing until radioactively "cool" enough to handle. Hall coefficient and resistivity measurements were then carried out as a function of temperature, first at -78°C and then from room temperature to -78°C. Due to the extremely high resistance of the sample at low temperatures it was not feasible to make measurements at lower temperatures with the equipment on hand. These results together with those of the previous experiment are shown in Figs. 33 and 34.

Due to the fact that the conductivity minimum cannot be recognized until just after it is passed and due to the finite time required to remove the sample from the pile, the sample was converted to P-type as was evidenced by the sign of the initial value of the Hall coefficient. On heating to room temperature, however, sufficient annealing took place to cause the sample to change back to N-type.

When the sample is at the intrinsic point the Fermi level must lie at the center of the forbidden band giving an intrinsic slope to the log R_H vs. $1/T$ curve which corresponds to ½ the energy gap between bands (.75 ev for Ge). That the sample is not at the intrinsic point is indicated by the change in slope near room temperature to a lower value. However, comparison with previous results indicates that a closer approach to intrinsic was made than previously since the activation energy in the low temperature range is ~.31 ev as compared to ~.11 ev for the previous experiment.

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(6) Cleland, J. W., Crawford, J. H., Lark-Horovitz, K., and Pigg, J. C., "Preparation of Intrinsic Semi-Conductors," *op. cit.*, ORNL 694, 62 (June 13, 1950).

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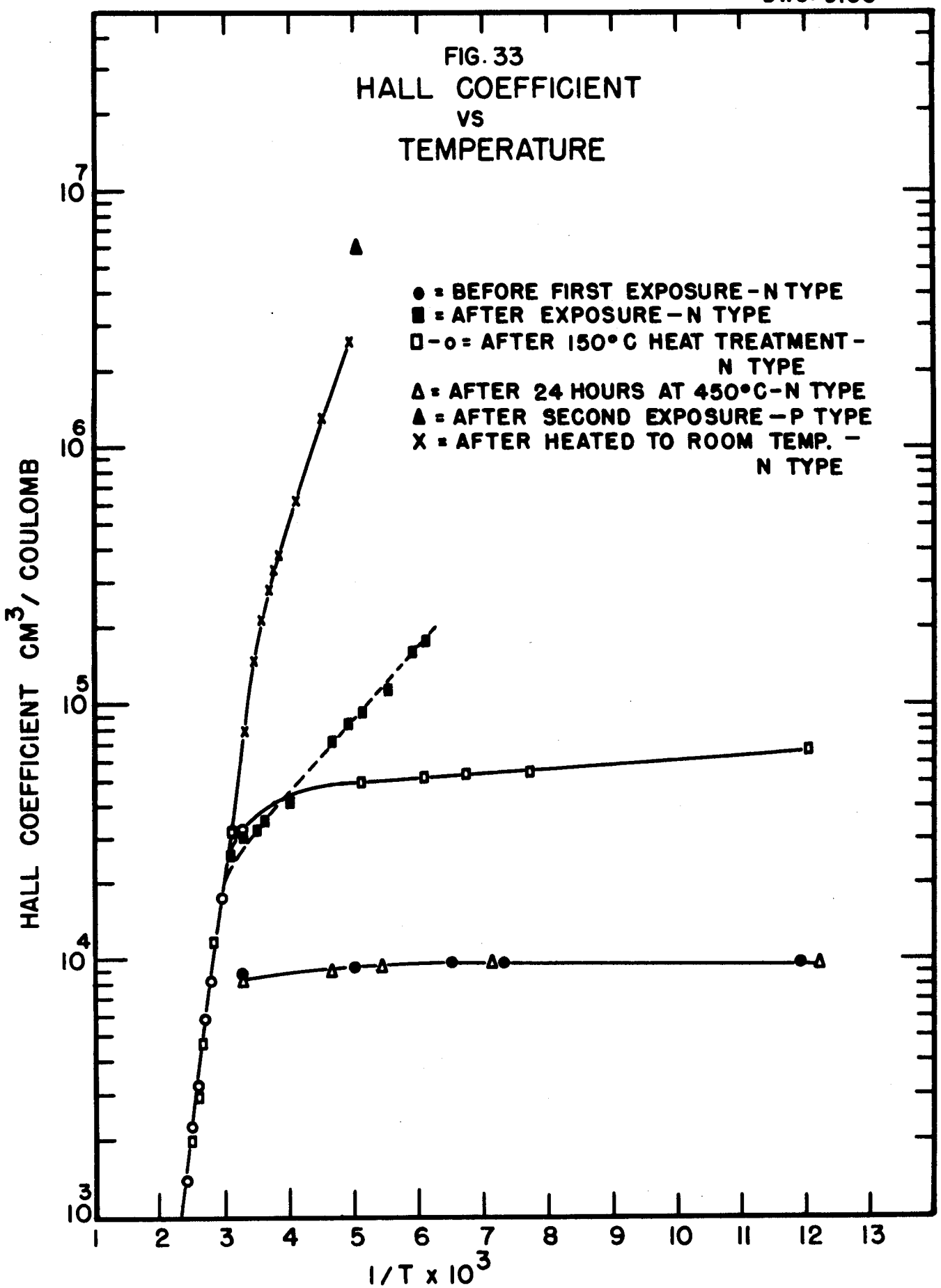

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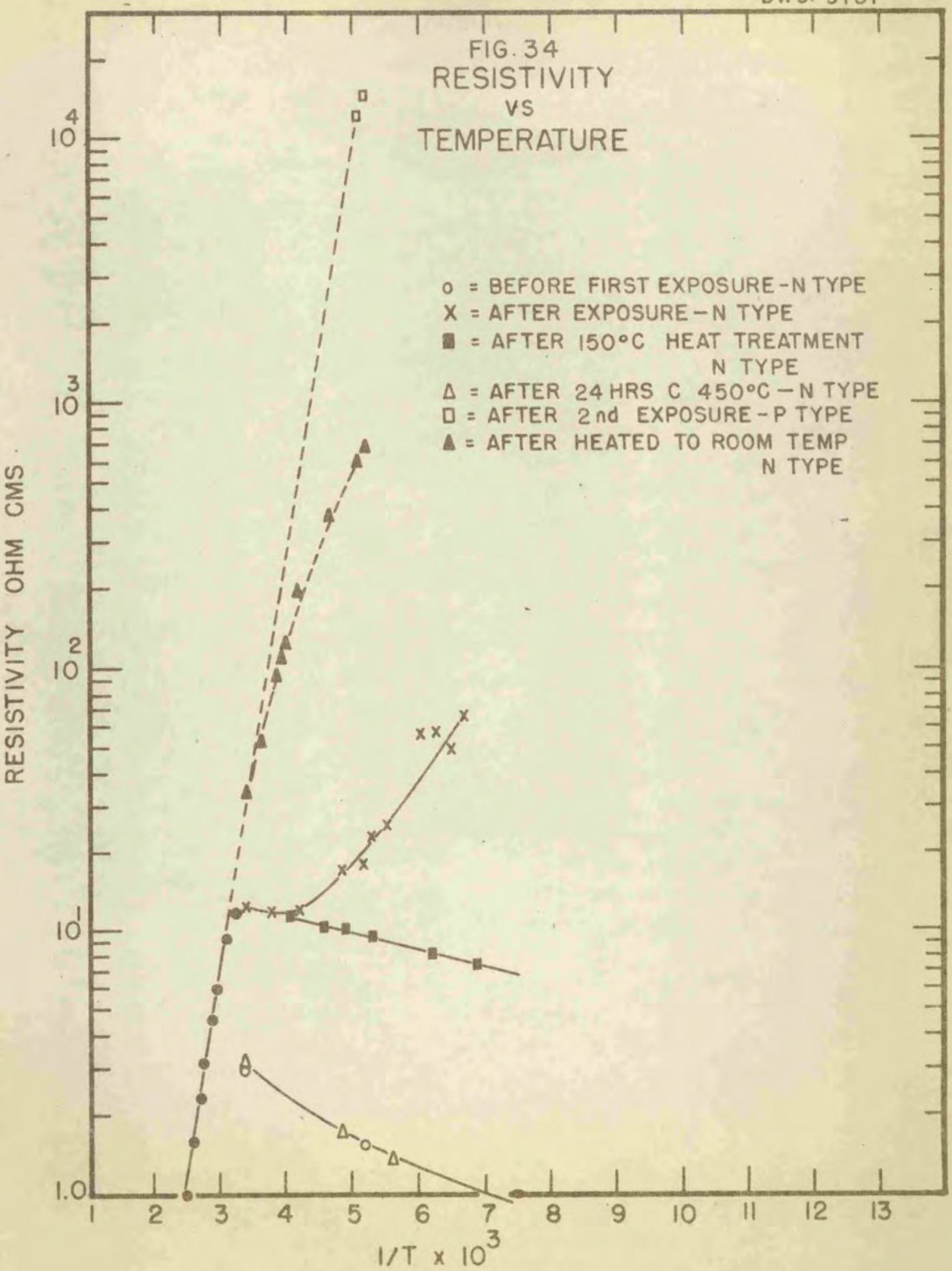

In view of the appreciable rate of annealing of lattice damage at room temperature, it is doubtful whether the intrinsic point can ever be experimentally observed by this experimental method. However, it is believed that these experiments are of value since the temperature dependence of the Hall effect and resistivity near the intrinsic point have been determined.

Another point of interest was observed. After being stored in dry ice for over a month the properties of the sample were essentially unchanged. Thus no measurable recombinations of lattice defects took place at this temperature. This sample will be used to study the rate of annealing of lattice damage by the time dependence of conductivity at various temperatures.

Neutron Bombardment of PbS and PbSe Photo-cells. Preliminary experiments have been carried out on PbS and PbSe photo-conductive films deposited on glass which were prepared at Purdue University. Although the results of these experiments are not very conclusive, they may still be worth reporting. An untreated low resistance PbS film which had extremely poor photo-conductive properties increased in resistance by two orders of magnitude almost immediately on being exposed in the reactor. Such an increase in resistance usually accompanies so-called photo-activation (treatment producing enhanced photo-conductivity). Thus it is possible, though not conclusive, that pile exposure activates PbS films. This effect will be studied more thoroughly.

The resistance of all cells studied increased initially during bombardment with this change seeming to saturate or even reverse after several weeks' bombardment. Due to the very large temperature coefficient of resistance and to temperature fluctuations in the pile these data are uncertain. Also contact to the films was made with a layer of aquadag. Since the electrical behavior of aquadag under bombardment is unknown, additional uncertainties are introduced. These experiments will be repeated with better temperature control and plated platinum contacts.

Germanium Rectifier Bombardment Experiments. Due to both the lack of available information necessary for a complete analysis of experimental results and the unsatisfactory theory of high back voltage Ge rectifiers, experiments on commercial rectifier units have been discontinued temporarily. Instead experiments are being carried out on rhodium plated rectifiers prepared by R. Bray at Purdue University. These units are much better suited for bombardment work. Their characteristics are easily analyzed in the light of existing

rectifier theory and there is no spreading resistance. Also the important properties such as bulk resistivity and Hall effect, contact area and other sample dimensions are readily measured.

Preliminary experiments have been carried out on two of these units and the results seem to be very promising. A more complete report on this work will be made in the next Quarterly Report.

NEW PHYSICS OF SOLIDS "HOT" LABORATORY AND EQUIPMENT

S. E. Dismuke, D. S. Billington

With the steel framework of the new building completed, the design of those additional cells which will be constructed after completion of the building (Nov. 1), and in which use will be made of the Chicago "Master Slave" manipulator is in progress. The design and construction of the two electrically operated Tell Manipulators, for use in the original three cells, is 75% complete.

The shielding and darkening characteristics of a high-density lead glass, received from the Pemberthy Instrument Company, is being investigated.

Engineering drawings for the "hot" machine shop lathe have been released for construction. The design of the milling machine is proceeding.

The optical system for indirect sample illumination of the Tukon hardness tester is under construction.

The work on liquid metals indicates the need for "dry boxes" to be located within a "hot" cell. This problem is being studied at the present.

Argonne National Laboratory and Knolls Atomic Power Laboratory were visited for conferences on design problems common to the three laboratories, with members of the Special Equipment Design group (Frank Ring, H. Dugan, A. Schlanger) participating.

HEAVY POSITIVE ION BOMBARDMENT STUDIES

G. E. Evans

Work has been started on the design and construction of a positive ion source, capable of producing beams of heavy ions (Z greater than two), for use

in the Cockroft-Walton and Van de Graff accelerators. Preliminary designs are also being studied for target assemblies to be used in range-energy and scattering experiments.

BONDED WIRE RESISTANCE STRAIN GAGES

M. R. Goodman

A summary of recent work has appeared in unclassified report ORNL 706, entitled *Characteristics and Behavior of Bonded Wire Resistance Strain Gages in Thermal Coefficient of Expansion Measurements - Part I. SR-4 Paper Bonded A-7 and Bakelite Bonded AB-19 Gages.*

Unclassified report ORNL 707 has also been issued. It is entitled *Characteristics and Behavior of Bonded Wire Resistance Strain Gages in Thermal Coefficient of Expansion Measurements - Part II. SR-4 Bakelite Bonded Dual Lead Gages.* The abstract of this report is quoted below.

"Dual lead type bonded wire strain gages appear to have no significant advantage over other types of bonded wire strain gages except less inherent gage creep. The literature indicates that ceramic bonded wire strain gages have been used at temperatures as high as 800°C. These gages exhibit properties similar to paper and bakelite bonded strain gages. Bonded wire resistance strain gages of any type are appropriate for application to very many problems. Where extreme accuracy is desirable, it is important to be thoroughly familiar with the characteristics and behavior of these gages."

The identical specimens and mounted gages described in ORNL 707 were inserted in the pile to determine radiation damage effects and dimensional changes. The specimens consist of annealed copper, 2S aluminum and Nilvar (coefficient of expansion 1×10^{-6}) upon which are mounted two SR-4 bakelite-bonded dual-lead gages. Pile operating temperature is about 34°C. Previous history of these mounted gages, under no load, had indicated a gage creep of $+5 \times 10^{-6}$ in./in. in over a period of four months.

Preliminary results during pile irradiation (still in process) indicate an average change of -145×10^{-6} in./in. strain for an nvt of 1.3×10^{18} fast neutrons per square centimeter. The curves of strain against nvt appear to be of two types: (a) a straight line for the copper specimen, and (b) an exponential curve for the 2S aluminum and Nilvar specimens. Interpretation of the results will have to be deferred until more data accumulate. It will probably be necessary to perform auxiliary experiments in order to properly evaluate the meaning of the data now being obtained.

CRYOSTAT FOR PILE IRRADIATIONS

R. P. Metcalf

During the past quarter, rather extensive beach tests have been run on the new cryostat built last fall. Although a leak in the vacuum jacket prevented satisfactory insulation of the cryostat, the tests showed rather definitely that the general design is good.

These tests also served to try out the helium refrigerator received last fall from Arthur D. Little, Inc.

The cryostat is now back in the shop for repair if possible, or rebuilding if necessary. While this is being done, some repairs and adjustments will be made to the helium refrigerator.

NEW STORAGE FACILITIES FOR HOT LAB

R. M. Carroll and S. E. Dismuke

Hitherto the storage facilities in the Hot Lab have consisted of a lead box with a removeable lid. In order to obtain a specimen it was necessary to place the storage box behind the barrier by means of a crane, then to remove the lid, also by means of a crane, and attempt to grasp the specimen with a manipulator. Since it was impossible to obtain a clear view of the bottom of the container by use of the periscope it was very difficult to use any system of filing. Also after a number of specimens of high level of radiation were

placed into the box, the intensity of radiation was such that when the lid was lifted from the box there was a field of several R/hr outside of the barrier, due to air scattering. This reduced the working time of the lab personnel considerably, especially as there generally had to be a search for the desired specimen.

In view of this situation it was desired to design and construct a storage device that would expose only the desired specimen and from which a specimen could be obtained with a minimum of time and effort. Since the storage device would be difficult to repair when filled with hot specimens, it also had to be designed with the most rugged and simple methods possible.

The design employed consists of a horizontally rotating disk with sixteen evenly spaced slots cut along the edge (Fig. 35). Small aluminum pans are set directly above the slots and wooden sample holders placed into the pans. The disk can be rotated so that any of the pans can move to the doorway in the lead brick shielding. The position of the disk is indicated by a pointer attached to the center shaft of the disk, the disk and shaft being rotated by a reversible electric motor. The doorway itself is closed by a moveable lead shield, mounted on ball bearings that run in grooved tracks, and designed to interlock with the wall shielding.

The pick-up is mounted onto the moveable shield. It consists of a hinged parallelogram that can be collapsed to a small height or raised into a rectangle; a spring placed within serves to keep the pickup in a normally erect rectangular form. Cables, mounted on pulleys, serve to move the doorway shield, with the pick-up, in and out of the holder. One end of the cable is attached to the edge of the pick-up so that a sharp tug upon the cable collapses it; when the pressure is released the pick-up springs back into the erect position. A small alnico magnet in the doorway shield serves to lock the pick-up in place in the erect position.

In operation, the disk is rotated to the position desired, the motor driven cable is released and the pick-up lifted through the slot cut into the disk, raising the pan with the samples. As the cable continues its movement, the door shield and the pick-up supporting the sample pan roll along the grooved track away from the holder. In the open, the sample can easily be removed from the numbered slot in the sample holder by means of the manipulator, in clear

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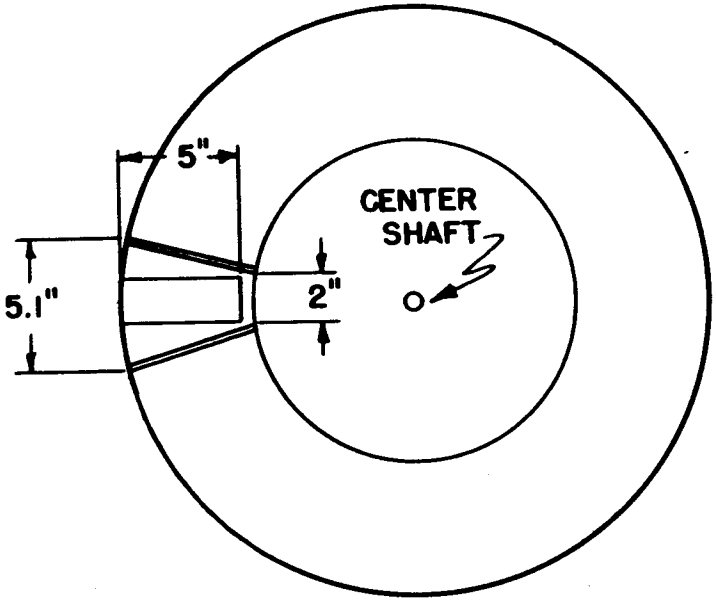
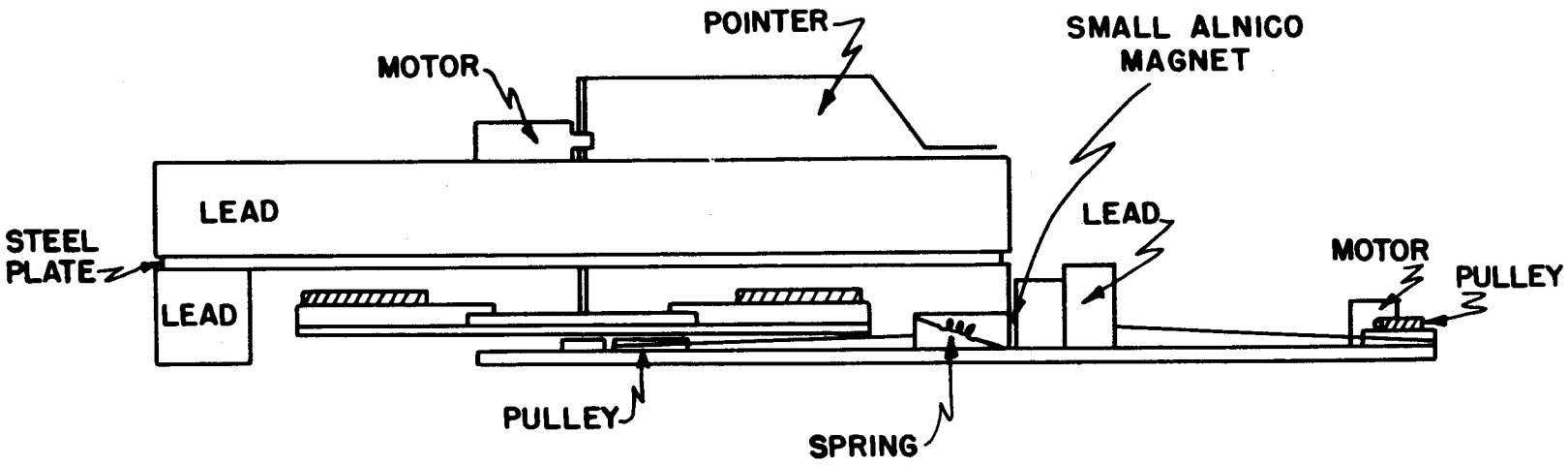
FIG. 35



INNER DISK HAS DIA. OF 1'-2"
PROJECTING LEAFS FROM THE
INNER DISK ARE OF 1/4"
MATERIAL, AND REACH TO
OUTER EDGE OF LARGE DISK

OUTER DISK, DIA. OF 2", HAS
16 EQUALLY SPACED
SERRATIONS



view through the periscope. To return the sample pan, the cable drive is reversed and the pan-door assembly moved back into the storage apparatus. As the door shield is returned completely into place it encounters stops set into the grooved track, and as the cable continues to pull it collapses the pick-up, setting the sample pan back into position.

In the event of any failure, all of the cable system, track, moving doorway and pick-up can be removed, repaired, and replaced without disturbing the specimens in the holder, or exposing personnel to radiation. All motors and wiring are on the outside of the holder and the specimen pans are locked into position above the slots.

The complete operation of obtaining a specimen requires only a fraction of the time formerly used, and the rise in radiation level while removing specimens is negligible.

X-RAY DIFFRACTION

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

X-ray Diffraction Spectrometer for High-Level Radioactive Specimens (M. A. Bredig, B. S. Borie, Jr.*). Plans, reported previously, of using a pulsed X-ray tube have been abandoned at least for the present. Considerable advances in the design of highly discriminating proportional counters were reported by C. Borkowski. After consultations with him, Professor R. Pepinsky, the Instrument Department and P. R. Bell, it was concluded that with the use of a proportional counter of the new design a high-power (50 milliampere) commercial X-ray diffraction tube such as the one built by the Machlett Company might provide for a sufficiently strong signal-to-noise ratio in most cases. The further design is therefore development under this assumption.

Other plans had been concerned with the use, instead of the focussing principle of our present Norelco spectrometers, of so-called Soller slits for producing parallel X-ray beams from an unusually large X-ray focus of a high-power X-ray tube to be specially designed. There would have been at least one

* Metallurgy Division

considerable advantage. It would have been possible by deflecting on a flat or curved monochromator crystal the X-ray beam out of the plane of the goniometer circle to avoid having to move, on scanning for X-ray reflections, either a very heavy load of lead shielding or the X-ray tube itself. Instead only an arm carrying the monochromator crystal and X-ray detector (small proportional counter) would have to be moved through a slot in a stationary shielding. It was found, however, experimentally, that in order to produce with Soller slits a resolution equal to that obtainable with focussing, a forbidding loss of intensity would result. Also, the gain in increasing the X-ray tube focus is largely offset by the loss in specific current load per unit focus area as a function of its shape, a line focus affording by far the most efficient cooling. It was therefore decided to purchase the new General Electric X-ray Spectro-goniometer which is based on the Bragg-Brentano focussing principle. This sturdy instrument will permit being modified in such a way that, instead of moving a heavy lead shield together with the monochromator crystal and X-ray detector, all these parts will be kept stationary with respect to the axis of the goniometer. Rather, the X-ray tube will be carried around the specimen on the arm now bearing the X-ray detector.

A number of tests have been conducted with curved crystals of lithium fluoride and metallic copper. Under the conditions of these tests improvements by a factor of only 3 to 6, when compared with a flat crystal, have been obtained thus far. A much larger factor is hoped for with the final arrangement where the X-ray line focus will be parallel to the axis of the crystal curvature, rather than perpendicular to it as is unfortunately the case in our present commercial (Norelco) spectrometer.

Determination of the Crystal Structure of Tutton Salts (M. A. Bredig, B. S. Borie, Jr.*). In connection with the study of the low-temperature specific heat of nuclei (S. Malaker) a refinement of the crystal structure determination, found in the literature, of cobaltous ammonium sulphate hexahydrate, $Co(NH_4)SO_4 \cdot 6\ H_2O$, appears very desirable. The present knowledge of the atomic positions, particularly of the oxygen atoms of the water octahedra and sulphate tetrahedra, seems unsatisfactory, especially when one attempts to correlate crystallographic and magnetic data. Weissenberg patterns have been made and X-ray intensity data are being collected. It is planned to employ R. Pepinsky's electronic computer of Pennsylvania State College for

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* Metallurgy Division.

their evaluation in terms of electron density charts.

Miscellaneous X-Ray Diffraction Work (R. M. Steele, B. S. Borie, Jr.,* M. A. Bredig). A large number of samples were examined for identification of reaction products in connection with the liquid metal corrosion work of the Metallurgy Division. Other work performed was concerned with isotope separation and neutron diffraction problems of the Chemistry Division. Results will be incorporated in the reports of the various investigators concerned with those problems.

Growing Single Crystals (F. A. Sherrill). Usable single crystals of lead and copper, tapering up to an inch in diameter, three or four inches long have been grown in a graphite crucible placed in a resistance-type vacuum furnace, by melting and slowly cooling. To cool, a small Bodine motor cranks down the furnace variac. One of these lead crystals is now being used by Dr. C. Shull as a monochromator in a neutron spectrometer. Many of the copper crystals have been sliced up into wafers having the (100) plane parallel to the surface. One such wafer has been found suitable for use as bent monochromator crystal in the hot-laboratory X-ray spectrometer. For other purposes, some of the copper crystals have been sliced without reference to orientation, and polished to remove cold work.

In connection with C. G. Shull's interest in single crystals of ferromagnetic material, a few substances of this type have been used in an attempt to get single crystals. So far, no pure cobalt crystals have been obtained, only small grains, produced by the inversion from cubic to hexagonal, were found. The addition of 7 percent iron is expected to permit the production of usable single crystals of cubic structure. Also, single crystals of an alloy of 96% iron and 4% silicon have been made. These have been sliced into wafers of known orientation, 7/8 in. in diameter, and 1/8 in. in thickness. Work on nickel is in progress.

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THEORETICAL PHYSICS

M. E. Rose

Work on the effect of the finite size of the nucleus in beta-decay has continued and only the numerical work remains to be carried out. The most important immediate application of this work is the possibility of accounting for the RaE spectrum which has hitherto been unexplained. The following conclusions can be drawn: (a) The effect of the finite size of the nucleus is very large for all forbidden transitions except those with favorable parity change on Gamow-Teller selection rules. (b) For a first forbidden transition the ft value or the predicted decay rate would change, but for higher forbidden transitions the shape would also change in the direction that the relative probability of low energy electrons is suppressed. (c) The effect goes down with increasing electron angular momentum. (d) The effect is important mainly for $Z \gtrsim 60$. In those cases where experiment and previous theoretical predictions checked no important changes are caused by the finite nuclear size.

Work on orbital electron capture has been well started and will be continued. The work on finite nuclear size is also useful in connection with the problem of forbidden (nuclear spin 0 to 0) transitions which is now being studied by S. D. Drell.

In addition, the rather extensive computation program for calculating nuclear field factors for forbidden beta transitions has been organized in all details with the collaboration of P. R. Bell and members of the computing panel. The results should be very useful to workers in the field.

The interpolation for the K-shell internal conversion coefficients is being repeated since it was felt that some improvement in accuracy could be obtained using methods somewhat different from those used before.

VAN DE GRAAFF PROGRAM

W. M. Good C. D. Moak
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THE TWO MEV VAN DE GRAAFF

Design work on the 2 Mev conversion is largely completed, and progress is mostly a matter of procurement and fabrication. Components for the tube have been completed, but assembly of the tube will await completion of other items of the conversion.

In the meantime, some improvements are being made in the diaphragms particularly in their precision and degree of polish. The proofing system is scheduled for completion in early August. The spray-on system for positive or negative terminal potential and biased corona point for voltage control are partially installed. The telemetering system for transmitting information from the terminal has been designed and a proto-type found to perform satisfactorily. Very considerable progress has been made on the ion source and system for initial focusing. An ion source that can be relied upon to deliver 50 μa of separated protons has been studied in the Cockcroft-Walton generator. This is a radio-frequency ion source, and some version of this particular source and corresponding lens system will be the first source employed in the 2 Mev machine. At the same time a development program is under way to adapt the calutron as an ion source.

Such a source would have the advantage of high efficiency and mass separation before the beam enters the accelerating tube proper.

THE 300 KILO-VOLT GENERATOR

The 300 Kev tube has been re-assembled with electrodes of re-entrant design to permit greater pumping speeds. Simultaneously a vacuum valve has been added to permit opening to air without shutting down the diffusion pumps thus permitting operation of the machine within an hour after a let down to air. A non-focusing magnetic analyzer with ports for mass one and mass two has been installed. The machine as a whole delivers a steady beam of well focused particles, under very satisfactory control. Total currents are about 100 μa with up to 60 μa of separated protons.

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The magnetic analyzer deflects the beam 15 degrees from the vertical. An electrostatic analyzer to render the beam horizontal is nearing completion.

The gamma rays from protons on Boron have been observed and a scintillation spectrometer is presently being used to study these gamma rays as to angular distribution.