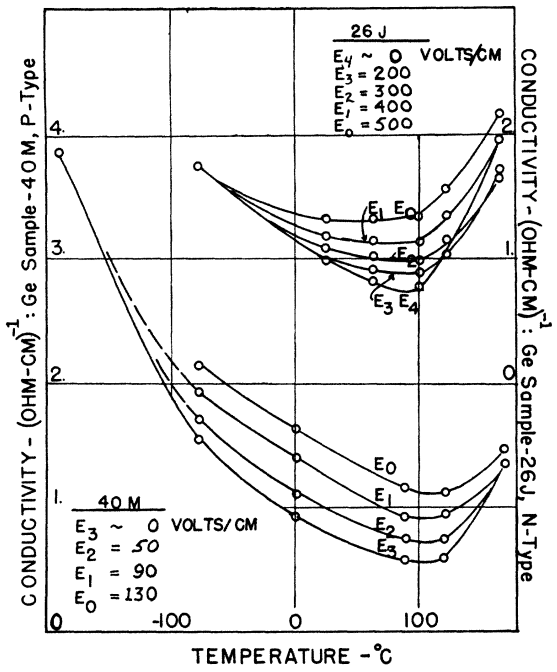

FIG. 2. Dependence of the conductivity of an N- and a P-type germanium sample on the temperature, at various electric fields across the sample. The samples are impurity semiconductors for temperatures below about 100°C; above that temperature, there is a transition to intrinsic conduction. The N-type sample (26J) is 0.21 cm long with a cross-sectional area of 0.011 cm². The corresponding dimensions on the P-type sample (40M) are 0.45 cm and 0.028 cm².

the *injection of electrons from the negative metal contact* accounts for the effects in *P-type germanium*. The latter results will be presented in a subsequent communication.

* Work supported by the Signal Corps.

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[3] J. Bardeen and W. H. Brattain, Phys. Rev. **74**, 230 (1948); E. J. Ryder and W. Shockley, Phys. Rev. **75**, 310 (1949).
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Cathode Sputtering in the Abnormal Glow Discharge

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TO continue the study[1] of intensities of spectral lines from a He low voltage arc, an intense He glow discharge (Geissler tube) was constructed. Some properties of this glow discharge are discussed.

Intensities as a function of pressure (see Fig. 1) agreed qualitatively with results found[1] for the low voltage arc. Since the pressure for maximum intensity was well within the abnormal glow discharge region (<15-mm Hg), cathode sputtering was expected to be high.[2]

To decrease sputtering Al electrodes are useful.[3-6] Our comparison of Al alloy electrodes (4 percent Cu, 0.5 percent Mg, 0.5 percent Mn) with pure Al (99.99 percent Al, 0.003 percent Fe, trace Ca, Cu, Mg, Si) showed markedly reduced sputtering for the latter. If the relatively higher sputtering rate of alloy Al were due to the higher sputtering rate of most of the alloy materials (in pure form),[7] the deposit should be richer in alloy materials. Spectrographic analysis of deposits from pure and alloy electrodes failed to show this enriching effect except for two or three doubtful cases.

The sputtered material appeared to be deposited in two forms. The localized form was characterized by fairly well-defined bands on the glass coaxial with the cylindrical tube and cylindrical hollow electrodes. With the tube axis vertical, the top of the upper band, for example, was in the same plane as the bottom of the upper electrode. Considerations of electrode and tube diameters, and band width and position, imply, for rectilinear motion, that the sputtered material reaching the tube wall came from the inside lower $\frac{1}{4}$ of the electrodes within a certain maximum angle with the normal (*ca.* 45°). The general form was deposited evenly throughout the bulbs and to a lesser extent within the capillary. The rate of deposit of the general form relative to that of the localized form increased with decreasing pressure. These two forms, also observed by Hulbert,[6] may represent different methods of deposition, the localized due to ion bombardment and ejection of solid particles, the general due to high temperatures and subsequent evaporation.

Measurements, with pure Al electrodes, showed that sputtering rate increases with decreasing gas pressure, agreeing with previous results.[7] In our case the region of maximum line intensity (*ca.* 2-mm Hg) was also a region where the sputtering rate changed markedly, increasingly by a factor of 20 as the pressure decreased from 2.70-mm Hg to 1.30-mm Hg. This large difference in sputtering rate results in a correspondingly large difference in the useful life of tubes sealed off at different pressures. Moreover, small changes in gas pressure have a marked effect on spectral intensities in this region. These two effects make it desirable that the sealing-off pressure for high intensity long-life tubes be determined with some certainty.

Investigation showed a region of large current change for small change in pressure (Fig. 2). The curves must have a steep slope at about 1.7-mm Hg since in no case is there an experimental point on neither the upper nor lower curves. The curves, representing data from the same tube, were taken at different times after starting the discharge (causing shift along current axis) and at different gauge temperatures (causing shift along pressure axis).

As gas pressure was decreased across this critical region (near 1.7-mm Hg) the discharge became suddenly and considerably

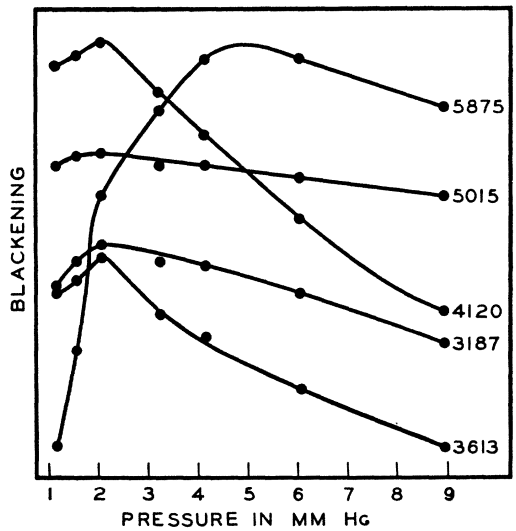

FIG. 1. Photographic blackening as a function of gas pressure. On the blackening axis the origin for each curve is different; the units are arbitrary, but the same for all curves. Four curves (5015, 4120, 3187, and 3613A) are typical. Of 17 lines measured, 16 are similar, showing a maximum intensity at 2.2-mm Hg; line 5875A, however, is anomalous.

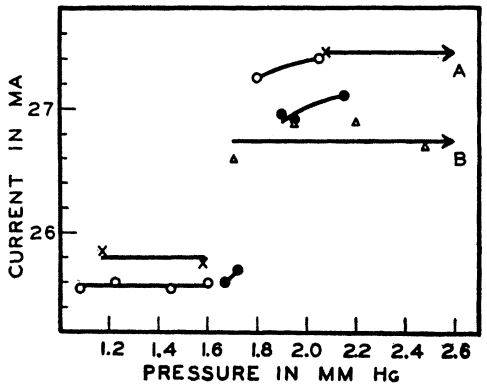

FIG. 2. Tube current as a function of gas pressure. Other data (not shown) indicate that curves *A* and *B* extend, at constant current, to 9-mm Hg and 4-mm Hg, respectively.

whiter. This abrupt change occurred in addition to the gradual change to a whiter discharge (as pressure is decreased) which takes place at higher gas pressures. The latter is probably due to the relatively late saturation of the intensity-pressure curve for the strong yellow line at 5875A. The abrupt change may likewise be connected with this line since the blackening-pressure curve has a large slope in this region (Fig. 1).

The large current change at about 1.7-mm Hg may account for the large change in sputtering rate, since sputtering increases with voltage.[7] The voltage increase, corresponding to the current decrease (negative linear current-voltage characteristic), was observed to be as abrupt as the latter. The determination of this critical gas pressure can be used to ascertain both operating and sealing-off pressures of high intensity, low pressure discharges where the sputtering rate must be small.

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On the Measurement of the Energy of Fast Neutrons by Photographic Emulsions Loaded with Enriched Li^6

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IN the literature[1] it is suggested that Li^6 disintegrations in photographic emulsions be used to measure the energy of fast neutrons. In commercial lithium loaded plates the disintegrations are masked by a high background of proton tracks. To overcome this Roberts[2] suggested the use of emulsions heavily loaded with enriched Li^6. This isotope with an enrichment factor of about 98 percent was supplied to the Los Alamos Scientific Laboratory by the Carbide and Carbon Chemical Corporation of Oak Ridge, Tennessee. The Eastman Kodak Company impregnated the enriched Li^6 into NTA type emulsions.

Some of these plates have been bombarded with neutrons from a mixed Po+Be source at the Argonne National Laboratory. Figure 1 shows a disintegration produced by a neutron from this source.

About 225 tracks produced by thermal neutrons from the thermal column of the heavy water pile at the Argonne National Laboratory were measured giving $R_\alpha = 6.8 \pm 0.6\mu$ and $R_T = 38.2 \pm 1.1\mu$. An analysis of the method indicates that it can be used to measure neutrons of energy less than one Mev to a precision of at least ± 0.1 Mev; preliminary measurements with monoenergetic neutrons confirm this. Such resolution is obtained as follows:

For a given neutron energy and angle θ between the alpha-particle and triton there are in each disintegration two possible triton energies. Select those disintegrations for which the triton has the greater energy. The disintegrations so selected must now be considered individually according to the value of the angle θ. As θ decreases from 180° to its limiting value, the neutron energy becomes an increasingly sensitive function of θ. Thus for tracks with θ greater than say 170° the neutron energy can be determined from an accurate measurement of the sum of ranges of the two particles and a rough determination of the angle. For tracks with successively smaller θ values it is necessary to determine θ with increased accuracy in order to obtain the neutron energy with the same precision. The method is being tested at Northwestern to measure the energy of neutrons from a thin beryllium target bombarded with polonium alpha-particles.

The Li^6 technique will extend the photographic method to neutron energies below one Mev. It is particularly suited to the measurement of the energy distribution of fast neutrons inside a material medium since collimation of the neutrons is not required and perturbations introduced by the detector are minimized.

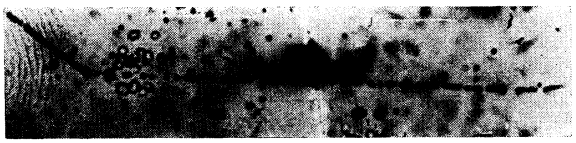

FIG. 1. Li^6 disintegration by a neutron from a mixed Po+Be source. $R_\alpha = 17.5\mu$, $R_T = 86.2\mu$, and $\theta = 149°$. Approximate range energy curves and $Q = 4.64$ Mev give a neutron energy of 4.6 Mev.

The results of this study of the method together with some specific applications will be published in detail at a later date.

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The Effect of Alpha-particles on a Superconductor*

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May 9, 1949

SUPERCONDUCTING bolometers have been bombarded with alpha-particles from a polonium source, and it is found that countable electrical pulses are produced, one for each particle impact. The bolometer used in the experiment reported here was made of a strip of columbium nitride, approximately $3.5 \times 0.4 \times 0.006$ mm, mounted with bakelite lacquer on a copper base, and maintained at the operating temperature of 15.5°K in a cryostat, as previously described;[1] its time constant was about 10^{-3} sec.

To provide a mounting for the polonium source, a glass tube *ca.* 30 cm long and 3 cm diameter was sealed to the cryostat nose facing the bolometer. The source could be slid back and forth in this tube, placing it at distances from the bolometer ranging from 2 cm to 20 cm.

The source consisted of polonium on a nickel disk 1 cm diameter, attached to the face of a steel cylinder. A vacuum of better than 10^{-6} cm was maintained in the source tube and around the bolometer by a charcoal trap at liquid nitrogen temperature aided by the many contiguous surfaces at 15°K, so that the α-particles traveled from the source to the bolometer with no significant loss