

annealed specimen again approximates that for pure aluminum.

The experimentally determined critical fields have been plotted as a function of the square of the temperature in Fig. 2. Data for the alloy specimens in the quenched, fully hardened, and annealed conditions are shown together with data for pure, single crystalline aluminum. Besides the relatively large magnitude of the displacement produced by hardening, it is noteworthy that analysis of the slopes of the alloy transition curves indicates that the electronic specific heat in the normal state is not affected by the hardening process. The observed changes in the superconducting properties are attributed to the internal strain in the aluminum lattice which develops as the Mg_2Si begins to precipitate. It is hoped that work still in progress on the superconducting properties in intermediate conditions of hardness will yield further information on the way in which the stress fields in these specimens develop.

From the viewpoint of the atomic theories recently advanced by Fröhlich² and by Bardeen,³ the substantial displacement of the critical field curve can be interpreted as due to a change in the vibration spectrum of the lattice. The validity of this interpretation can be examined by experiments on the effect of precipitation hardening upon the Debye temperature. From a simple argument based on the Fröhlich-Bardeen concept it can be shown that the Debye temperature for a superconductor should vary inversely with its critical temperature when the changes are induced by lattice strains. The magnitude of the changes in critical temperature observed in the present work are believed to be sufficiently large to correspond to measurable changes in the Debye temperature of this alloy if the above proportionality is correct. An investigation of this possibility is now being carried out.

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† On leave from Preston Laboratories, Butler, Pennsylvania.

¹ Kindly supplied to us by the Aluminum Company of America.

² H. Fröhlich, *Phys. Rev.* **79**, 845 (1950).

³ J. Bardeen, *Revs. Modern Phys.* **23**, 261 (1951).

Distribution of Trapping Levels in Cadmium Selenide

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TRAP distributions in phosphors have been investigated with the glow curve technique by many workers including Randall and Wilkins,¹ Klasens,² Bude,³ Gillson,⁴ and Johnson and Williams.⁵ The technique involves cooling the phosphor in the dark, irradiating, and then warming again in the dark after the original phosphorescence has decayed to equilibrium. During the warming process the phosphor glows as

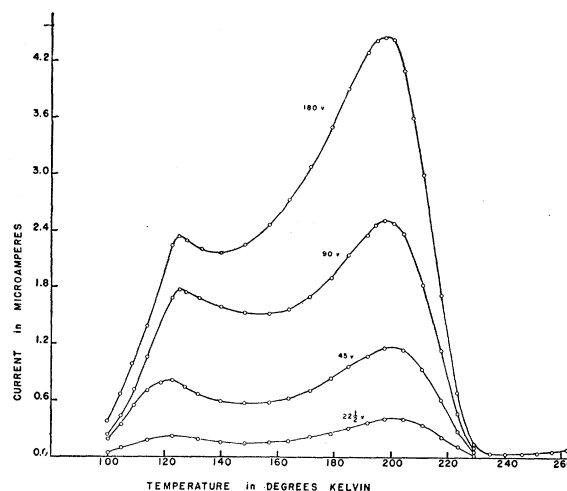


FIG. 1. "Electrical glow curves" taken in CdSe with various bias potential differences.

traps are emptied by thermal activation and the intensity of glow is measured as a function of the temperature. The temperature at which the glow peak occurs is proportional to the energy depth of the traps and the height of the peak is proportional to the number of traps at that temperature.¹

An analogous procedure for the investigation of trap distributions in photoconductors is suggested by the work of Herman and Hofstadter⁶ with willemite reported in 1940 and that of Frerichs⁷ with cadmium sulfide in 1949 where current pulses, instead of light pulses, occur during the warming of photoconducting materials, in the dark. Measurements of this nature were made by Dutton and Maurer⁸ in 1953 on KCl and KBr who also measured absorption after irradiation, but both before and after warming, that gave definite correlation between absorption peaks and current peaks. Herman and Hofstadter used ultraviolet, Frerichs gamma rays, and Dutton and Maurer x-rays.

Figure 1 exhibits "electrical glow curves" for a crystal of cadmium selenide (4 mm long by 1-mm² cross section) for each of four different bias potential differences and shows peaks at 125°K and 200°K for warming rates of about 2 degrees per minute. The slow increase of conductance above 235°K, as shown on the 180-volt curve, is presumed to be the normal semiconductor increase of conductance with temperature. No further peaks were observed when the temperature was raised to 360°K. Furthermore, if the cycle of cooling and warming is performed without irradiation at the low temperature, no current is observed during the warming. The sample was kept in vacuum of about 10⁻⁶ mm of Hg to prevent condensation at the low temperatures. The excitation was produced with a small tungsten lamp operated at its normal power rating of six watts.

Although the curves in Fig. 1 were all taken from the same sample of CdSe, other samples were investi-

gated and they also showed current peaks differing only in detail. It is to be noted that the currents involved here are many orders of magnitude larger than those mentioned by other workers. Frerichs reports a total charge of 10^{-7} coulomb in CdS and Dutton and Maurer report only 10^{-11} coulomb, while the charge involved in the $22\frac{1}{2}$ volt curves for CdSe was 10^{-3} coulomb. The large currents and charges reported here may be attributed to several factors: (1) higher original excitation, (2) high photosensitivity of CdSe to light in the visible portion of the spectrum, (3) larger bias potential differences used in this work, and (4) a possibility of higher trap densities in CdSe.

The photosensitivity and the time required for photocurrent decay in cadmium selenide are both very much greater at the low temperatures where the traps are active than at room temperatures where they cannot be active. Work involving this aspect of photoconductivity in cadmium selenide is in progress and will be reported later.

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¹ J. T. Randall and M. H. F. Wilkins, Proc. Roy. Soc. (London) **A184**, 365 (1945).

² H. A. Klasens, J. Electrochem. Soc. **100**, 72 (1953).

³ R. H. Bude, J. Phys. Chem. **57**, 785 (1953).

⁴ J. L. Gillson, J. Opt. Soc. Am. **44**, 341 (1954).

⁵ J. S. Johnson and F. E. Williams, J. Opt. Soc. Am. **39**, 709 (1949).

⁶ R. C. Herman and R. Hofstadter, Phys. Rev. **57**, 936 (1940).

⁷ Rudolf Frerichs, Phys. Rev. **76**, 1873 (1949).

⁸ D. Dutton and R. J. Maurer, Phys. Rev. **90**, 126 (1953).

⁹ Rudolf Frerichs, Naturwiss. **33**, 281 (1946).

Voltage Dependence of Electroluminescent Brightness

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THE voltage dependence of electroluminescent brightness is of considerable interest since it may provide valuable indications of the processes involved, and also since any theory which is proposed to explain the phenomena must be able to account for this dependence.

Destriau¹ has proposed the relationship,

$$L = aV^n \exp(-b/V), \quad (1)$$

where a and b are constants and n , in general, lies between 1 and 3. Weymouth and Bitter² have stated, for a single phosphor particle, that the relationship be-

TABLE I. Fit of Eq. (2) to several representative electroluminescent phosphors.

Material	Refer- ence	Fre- quency (cps)	a (arb. units)	b (volts)	V_0 (volts)	b/V_0
ZnS:Ag(WL.132)	a	1000	7.0×10^{-10}	1200	67	18
ZnS:Cu(WL.100)	a	1000	1.0×10^{-6}	1050	39	26
ZnS:Cu(WL.168)	a	1000	2.1×10^{-7}	970	30	32
ZnO:Zn(WH.200)	a	1000	6.0×10^{-9}	1150	82	14
ZnS: ?	b	60	2.0×10^{-7}	600	27	22
ZnS: ?	c	60	9.5×10^{-7}	2500	113	22

^a These phosphors were made in this laboratory.

^b E. Lowry, Physics Today **6**, No. 7, 4 (1953).

^c Weymouth, Jerome, and Gungler, Sylvania Technologist (July, 1952).

tween brightness and voltage is linear with a "voltage threshold." Thorington³ has also reported a relationship of this type for phosphors in vacuum. Halsted and Koller,⁴ using transparent thin films of ZnS, report that the brightness is related to voltage by a simple power law. Also, Piper and Williams⁵ have explained the form of the voltage dependence by a rather complex equation involving the distribution of electron traps in the phosphor. However, since they used an experimental arrangement in which a ZnS single crystal was in contact with metallic electrodes, their data are not, strictly, applicable to the case which we are considering, namely that of a conventional plaque cell, in which the phosphor is embedded in a dielectric medium between two planar electrodes.

However, none of these relationships provides good fit to all of the available experimental data over a large voltage range. Thus, we have tried to find an equation which, although having no more constants than that proposed by Destriau, could be universally applied. As a result, we have found that an equation of the form

$$L = aV \exp[-b/(V+V_0)] \quad (2)$$

satisfactorily fits the voltage dependence of the electroluminescent output from a conventional plaque cell.

The general form of Eq. (2) is similar to that of Eq. (1) in that it gives zero brightness at zero voltage and

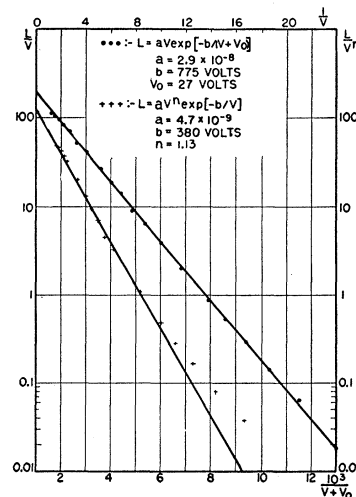


FIG. 1. Comparison between the fit for Eqs. (1) and (2) for a typical electroluminescent phosphor (ZnS:Cu).