

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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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 Gungle, 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

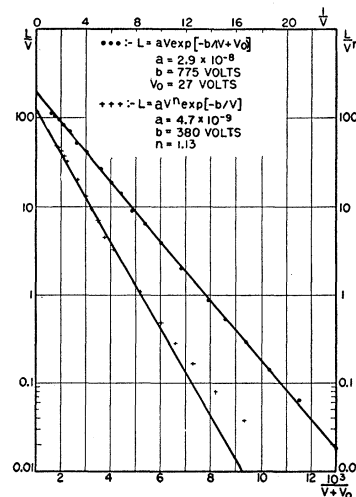


FIG. 1. Comparison between the fit for Eqs. (1) and (2) for a typical electroluminescent phosphor (ZnS:Cu).

infinite brightness at infinite voltage. However, Eq. (1) predicts a point of inflection under certain conditions while Eq. (2) does not. Also, Eq. (1) predicts a power-law dependence at high voltages while Eq. (2) gives a linear dependence.

This equation has been tested on results reported from several published sources and we have also carried out more exhaustive comparisons with experimental results obtained in this laboratory. The results are shown in summarized form in Table I. In all cases the fit of the curve, given by Eq. (2), to the experimental results was as good as, or better than, that of the other relationships proposed. A typical example is shown in Fig. 1 for a ZnS:Cu phosphor prepared in this laboratory. It can be seen that, while the Destriau relationship gives considerable deviation at low voltages, Eq. (2) provides good agreement over the whole voltage range. The deviation at very high voltages, shown in this figure, has been observed in only a few cases and gen-

$$V_0 = V_0' f^n, \quad (4)$$

where the exponent n is the same in both cases. This results from the fact that the ratio b/V_0 remains constant over the whole frequency range, as we have shown in the diagram. The frequency dependence of the constant a , also shown in Fig. 2, appears to be somewhat more complex; this is not too surprising since it would appear that this constant is the most sensitive to external influences.

No attempt has been made, in this Letter, to interpret the implications of Eq. (2) but a more complete account of this work will be published at a later date.

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² J. Waymouth and F. Bitter, *Phys. Rev.* **95**, 941 (1954).

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⁴ R. Halsted and L. Koller, *Phys. Rev.* **93**, 349 (1954).

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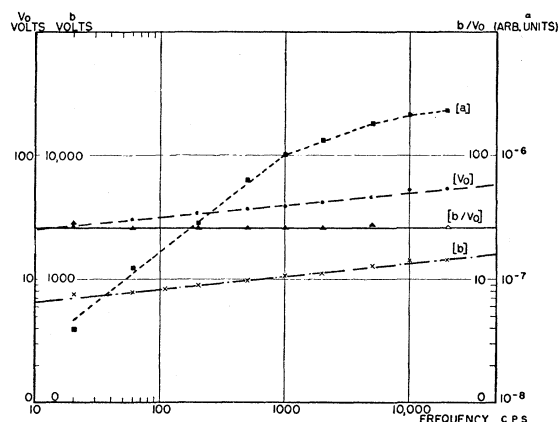


FIG. 2. Variation of the constants a , b , and V_0 of Eq. (2) with frequency of applied electric field (ZnS:Cu).

erally lies within the limits of experimental accuracy. Nevertheless, this apparent inconsistency is being investigated more fully.

It can be seen from Table I that, although there is considerable variation in the constant a due to the different arbitrary units of brightness which have been used, the values of the constants b and V_0 are restricted to comparatively small ranges, b being of the order of 1000 volts and V_0 of the order of 50 volts. Further, the dimensionless quantity b/V_0 , which is independent of cell thickness, shows even more constancy and seems to depend upon the activator used in the phosphor.

We have also studied the frequency dependence of the constants b and V_0 ; the results are shown in Fig. 2. It appears that both b and V_0 have a slight dependence upon frequency which can be expressed by the relationship,

$$b = b' f^n, \quad (3)$$

Magnetic Anisotropy Constants of Ferromagnetic Spinel

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IN calculations involving magnetization processes, it is necessary to know the magnetic anisotropy constant of the material in question. Unfortunately, this information is lacking for most ferromagnetic spinels. Single crystals of NiFe_2O_4 and CoFe_2O_4 made by the flame-fusion method apparently always have some ferrous iron present¹ and are, therefore, in reality mixed crystals with magnetite, Fe_3O_4 . Magnetite, however, has been made in single crystals of good purity² and K_1 , the first order magnetic anisotropy constant, measured^{3,4} as -1.1×10^5 ergs/cm³.

One can calculate anisotropy constants for the ferromagnetic spinels as follows. Went and Wijn⁵ have presented strong evidence that, unlike metals, the *initial permeability*, μ_0 , of sintered, polycrystalline ferromagnetic spinels is predominantly due to spin rotation. We then have

$$\mu_0 - 1 = k M_s^2 / K_1,$$

where M_s is the saturation magnetization and k is a constant variously given⁶⁻⁸ as π , $4\pi/3$, and $8\pi/3$. From the known data for magnetite ($\mu_0 = 45$ for sintered material and $M_s = 480$, both at room temperature) we find $k = 21$. Now taking this value for k we find K_1 for the other ferromagnetic spinels. Initial permeability of dense, polycrystalline materials was obtained by the author for carefully prepared samples. These were