On the high-field "reverse" half-cycle, ionization of the luminescent centers occurs; the electrons are transported sufficiently far by the field that no luminescence can occur until the field is removed or reversed, permitting them to return to and recombine with their parent centers. The typical waveform of light output from many-particle lamps, showing two major peaks per cycle, occurs because these rectifying junctions can be oriented in either direction. Excitation will occur in some on one half-cycle and in others on the other half-cycle.

We quite agree with Thornton's computation of 10^{14} ionized luminescent centers per cubic centimeter as an average concentration which would correspond to about one-half lumen radiated per cubic centimeter. However, in view of item (A) we believe these to be localized in approximately one percent of the volume, making the local concentration 10^{16} per cubic centimeter. This is about the same as the 10^{16} thermally-ionized coactivators Thornton assumes to determine the potential distribution.

In view of items (B) and (C), we cannot believe that an assumption such as Thornton's second, which ignores the transport of free electrons by the field away from and back to the ionized luminescent centers, can be correct. We cannot explain our observations on the application and removal of dc fields without considering this transport.

In addition, in setting up boundary conditions, Thornton assumes that the response of the phosphor to both half-cycles of the ac electric field is the same. Figure 16 of our paper[2] shows that the response of the ultimate radiating spot to both half-cycles of the ac field is most certainly not the same.

While we agree completely that trapping of electrons does occur and that it has effects upon the shape of the brightness waveform, we do not agree that the entire dependence of light output on time during the cycle can be accounted for on this basis alone. Our observation (C) above indicates that the removal of the electric field shortly after its application suffices to release electrons and produce light, whereas the original application of the field produced no detrapping and no light.

[1] W. A. Thornton, Phys. Rev. **102**, 38 (1956).
[2] J. F. Waymouth and F. Bitter, Phys. Rev. **95**, 941 (1954).

Electroluminescence in Zinc Sulfide

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OF the considerations objected to by Waymouth and Bitter,[1] the first is not a basic assumption but an incidental remark at the end of a section of paper I[2]; the second is not at all inconsistent with the experimental observations (A) through (C) pointed out in the preceding Letter.

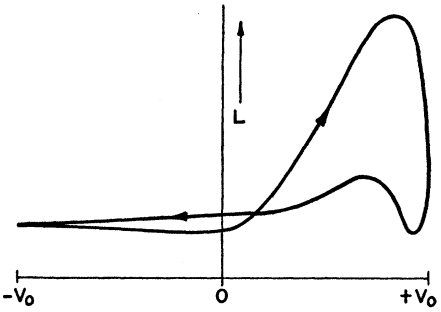

FIG. 1. Expected light output wave form of electroluminescence from a single crystallite or small crystal volume.

The point concerning localization of light emission is feasible. It is also likely, however, that all of the trapping states or donors, at depths near 0.2–0.3 ev, become ionized at least in the localized region of maximum field. Since neither the density of the ionized luminescence centers nor that of the ionized traps or donors is apparently known within a factor of 100, it seems of little value to compare them. What is more to the point is that the theory of paper I considers an average (not constant) field proportional to applied voltage; the distribution of this field, and whether it is dominated by ionized luminescence centers or traps, is irrelevant.

The following remarks refer to the second question: (a) The dependence on field of effective trap depth is considered to govern only the shape and phase of the primary peak. Processes contributing to the secondary peak are not considered, and the dc light level upon which the peaks are superposed is considered due to thermal release and recombination in crystal regions not dominated by the field. (b) The importance of potential barriers in electroluminescence is assumed in paper I; their presence, plus the assumed strong field dependence of the ionization process, leads to strongly localized regions of light emission. Electron transport is implicit in these ideas, also, both in setting up the potential barriers and in motion back and forth between traps and luminescence centers. This latter transport is very likely involved also in observation (C); there being initially no ionized centers, the sequence must be: ionization, trapping, thermal release, and recombination. This sequence is identical to that considered in paper I except that the rate of the third process is enhanced and controlled by the onset of the applied sinusoidal voltage. (c) It can be noted that the theoretical curves on wave form, in paper I, cover a range of the argument from zero to π radians; that is, light output is considered from zero voltage through the primary peak until it falls toward zero due to depletion, and this occurs within the first half-cycle of voltage. It is not suggested that the same crystal region responds to both half-cycles; rather it is believed that this is not

the case. In fact, Fig. 1 (which was deleted from the original manuscript for the sake of brevity, together with the associated reference[3]) represents the envisioned wave form from a single crystallite, or small crystal volume, and is completely consistent with Fig. 16(a) of reference 3.

[1] J. F. Waymouth and F. Bitter, Phys. Rev. **103**, 1584 (1956), preceding letter.
[2] W. A. Thornton, Phys. Rev. **102**, 38 (1956).
[3] J. F. Waymouth and F. Bitter, Phys. Rev. **95**, 941 (1954).

Cyclotron Resonance Effects in Graphite

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We have observed cyclotron resonance effects[1] in crystalline flakes of graphite at 77°K, 4.2°K, 1.3°K, and 1.1°K, at a frequency of 24 000 Mc/sec. Our experiments are similar in concept to cyclotron resonance experiments done by others on semiconductors,[2] but different in certain important respects. Similar effects have previously been observed in bismuth by some of us[3] and by Dexter and Lax.[4]

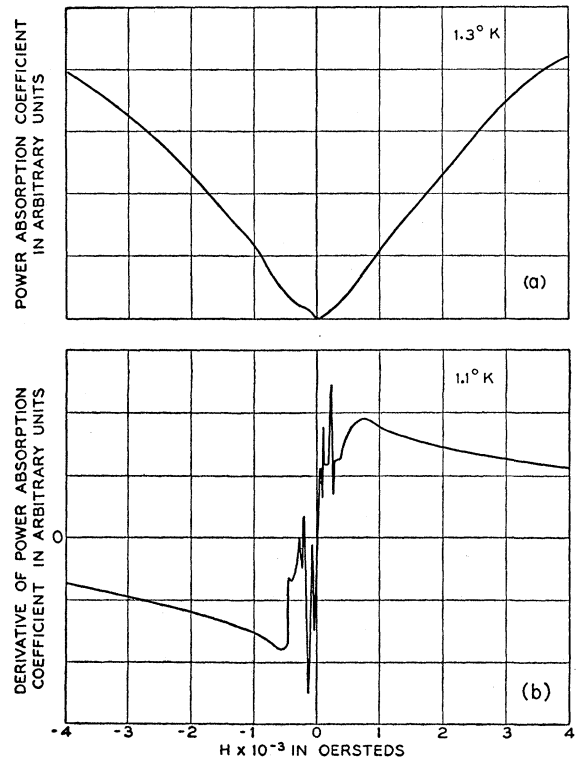

FIG. 1. (a) Plot of power absorption coefficient *vs* dc magnetic field for circularly polarized radiation at 24 000 Mc/sec at normal incidence on the (00.1) plane of graphite at 1.3°K. The magnetic field is normal to the (00.1) plane. The vertical scale is only approximately linear. Zero absorption is somewhere below the axis of abscissas. Cyclotron resonance for electrons will occur on the negative side of $H=0$, that for holes on the positive side. (b) Plot of derivative of curve shown in (a) as observed experimentally in an independent experiment done at 1.1°K with a field modulation method. The modulation method is more sensitive than the direct measurement of signal level used to obtain the data shown in Fig. 1(a).

Our samples are flakes of graphite almost a centimeter in diameter and approximately 0.025 cm thick, kindly supplied by Dr. G. R. Hennig of Argonne National Laboratory. They are not perfect, but x-ray observations of the best one suggest that it is a quite good single crystal containing impurities which have precipitated out to form separate phases, and which therefore affect our results relatively little. The amount of the impurity content has not yet been established, but we are informed that other graphite contained about 500 parts per million of relevant impurities after comparable purification procedure.

The method of the present experiment is substantially the same as that described previously by us.[3] Circularly polarized radiation is incident on the sample; the ratio of the two circular polarizations in the radiation was maintained at 15 to 1 or higher during our experiments.

Data taken on several samples were very similar. Our best results are shown in Figs. 1 and 2 with the noise level removed for the sake of clarity. The noise level was comparable with some of the features shown in the figures but, nevertheless, they were quite reproducible from run to run and for the most part from sample to sample. Figure 1(a) illustrates the field dependence of the absorption coefficient at 1.3°K while Fig. 1(b) shows the derivative of the absorption curve at 1.1°K as obtained by conventional magnetic field modulation technique. The structure observed at low fields is shown in more detail in Fig. 2.

The broad variations in power absorption coefficient have the general shape expected from the behavior of majority carriers as discussed theoretically by Anderson[5] and by others.[6] We have not made a detailed fit of these data to a theoretical curve, but crude efforts to do so lead us to believe that the masses of the majority carriers are less than that of the free electron, m_0, and that their relaxation times are of the order of 10^{-11} sec. It is not clear from our data, however, whether the majority carriers include both holes and electrons, or whether they are all of one type but have highly eccentric constant energy surfaces[7,8] so that our circularly polarized radiation fails to discriminate against them on either side. More detailed information awaits attempts to change the Fermi level of our samples.

At 4.2°K, we find substantially the same results, with each singularity slightly broadened. At 77°K, most of the low-field structure cannot be seen, and the points of inflection of the broad variations on both sides of $H=0$ are at higher fields. We looked for power saturation effects and did *not* see them. When we rotated the steady applied magnetic field to be more nearly parallel to the plane of the disk, the singularities at low fields moved to larger H roughly as $1/\cos\theta$, where