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]

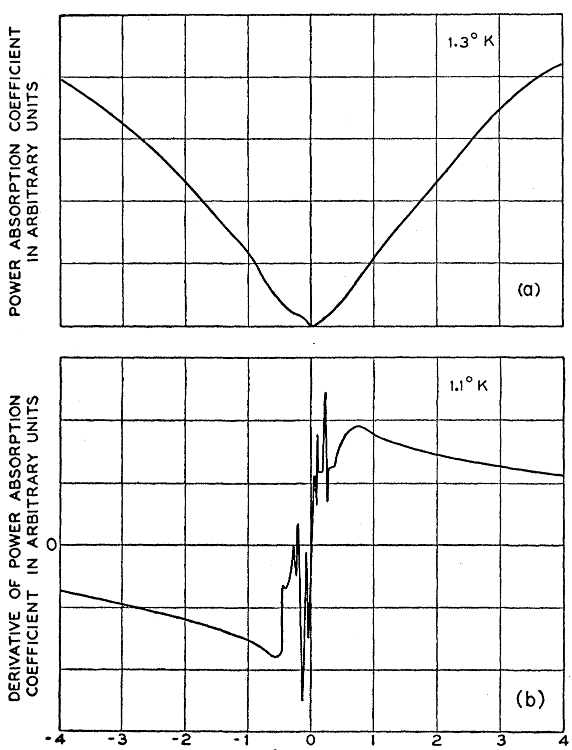

Fig. 1. (a) Plot of power absorption coefficient *vs* dc magnetic field for circularly polarized radiation at 24 000 Mc/sec at normal incidence on the (00.1) plane of graphite at 1.3°K. The magnetic field is normal to the (00.1) plane. The vertical scale is only approximately linear. Zero absorption 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

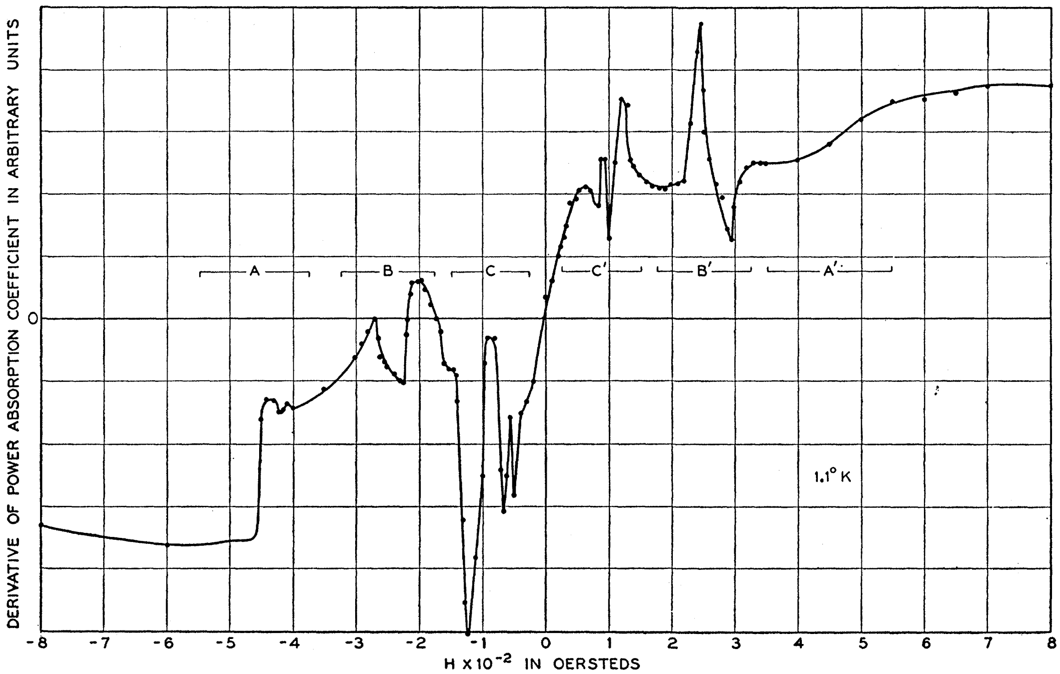

FIG. 2. Expanded plot of the low-field data in Fig. 1(b). The points are taken from the original data, which were taken as a continuous plot.

θ is the angle between H and the normal to the plane of the disk.

We do not feel qualified to make a definitive interpretation of the data in Fig. 2. We do suggest, however, that the structure in these data consists essentially of singularities which arise from the resonance behavior of minority carriers as suggested by Anderson.[5] We associate one of these singularities with each of the field ranges labeled A, A', B, B', C, C'. The two singularities labeled with the same letter occur in each case at roughly the same magnetic field but on opposite sides of $H=0$. As a result, we cannot say with confidence whether each pair corresponds to a hole and an electron or to one type of carrier for which the constant energy surfaces are highly eccentric.[7,8] The fields at which singularities occur lead from the cyclotron resonance condition to a mass of about 0.05 m_0 for those marked A and A', about 0.03 m_0 for those marked B and B', and to a mass of less than 0.02 m_0 for those marked C and C'. These numbers are very approximate, of course.

We do not exclude the possibility that there are other carriers which are not resolved at our frequency, but our data lead us to expect a minimum of four and a maximum of eight types of charge carriers.

One other effect, not shown in Figs. 1 and 2, became apparent at fields above about $H=2500$ oersteds. This is an oscillation in the absorption coefficient *vs* H curve with period proportional to $1/H$. Anderson[7] has suggested that the carrier mean free path and, therefore, the conductivity should show oscillatory behavior under the conditions of our experiment, as energy levels emerge from the Fermi sea, and this may be the reason for these oscillations. More work will be necessary, however, to show conclusively that this effect does not arise simply because at higher fields our skin depth may be comparable to the thickness of our samples.

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Structure of Neutron-Disordered Silica*

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IT is known[1–3] that under prolonged irradiation by fast neutrons crystalline quartz and vitreous silica become converted to a new amorphous modification.