appreciably heating the lattice. Experiments on germanium are in progress.

A temperature difference between T_R and T_S may also be obtained in systems in which the free carriers relax via spin-orbit coupling.[8] In this case the spin relaxation time may be several orders of magnitude longer than the electron-lattice collision time. As a result T_S will lag behind T_R. If the electrons are accelerated in an electric field gradient, a difference between T_R and T_S will be produced. The sign of the nuclear polarization will then depend on the sign of the electric field gradient.

Another possible application of the saturation of the electron spin resonance signal in the presence of hot electrons seems worth mentioning. If the hot electrons could preferentially saturate the outer levels of a three-level system, a maser would be realized which would not require the high pumping frequency that is presently used.[9]

It is a pleasure to acknowledge many helpful discussions with P. W. Anderson and H. Suhl which provided the stimulus for the above work, and to thank E. A. Gere for his assistance in the experiments and I. M. Mackintosh for the preparation of the n^+ contacts.

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[3]This discussion, as well as the Overhauser effect, is of course not limited to electron-nuclear systems but is applicable to any two interacting spin systems (e.g., conduction electrons interacting with bound electrons).

[4]G. Feher and E. A. Gere, Phys. Rev. (to be published).

[5]The n^+ contacts were prepared by I. M. Mackintosh. 5×10^{20} P/cm^2 were diffused to a depth of ~0.0003 in. and a 500A gold layer evaporated on top of it.

[6]Such a breakdown in silicon was observed at 20°K by W. Kaiser and G. H. Wheatley (to be published). It is in contradiction with the conclusions of Lampert et al. [Lampert, Herman, and Steele, Phys. Rev. Letters 2, 394 (1959)].

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CYCLOTRON RESONANCE IN ALUMINUM*

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We have observed cyclotron resonance in a single-crystal sample of aluminum at 24 kMc/sec and 4.2°K. The results indicate the presence of two distinct groups of carriers with properties consistent with the theoretical analysis of Heine.[1]

Changes in power absorption in the sample were observed using a standard microwave reflection spectrometer. Both absorption and absorption-derivative measurements were made, the latter using magnetic field modulation.

The sample was cut from a single crystal of zone-refined aluminum using a string saw wetted with $CuCl_2$ solution. The resulting plane surface was then smoothed and electropolished. This surface was a {110} plane and formed part of the end wall of a TE_{011} cylindrical cavity which was mounted with the magnetic field parallel to the sample surface. The cavity together with the sample could be rotated about their common axis.

Figure 1 shows experimental curves of absorption and absorption-derivative *versus* magnetic field taken with the magnetic field 10° from a ⟨110⟩ crystal axis. At fields above 2 kilo-oersteds the absorption curve shows a component periodic in $1/H$ superimposed on a monotonically decreasing component, a behavior similar to that previously reported in copper.[2] The variation is (not surprisingly) somewhat different from that predicted by Azbel' and Kaner[3] for a free-electron gas. The absorption-derivative curve shows the oscillations more clearly. These oscillations correspond to a cyclotron mass of $1.5m_0$ and an $\omega\tau$ of about 10.

For some sample orientations the hump which appears at 2 kilo-oersteds on the absorption curve in Fig. 1 is resolved into distinct peaks. Experimental curves for such an orientation are shown in Fig. 2. These curves were taken with the magnetic field parallel to a ⟨111⟩ crystal axis. The peaks correspond to a cyclotron mass

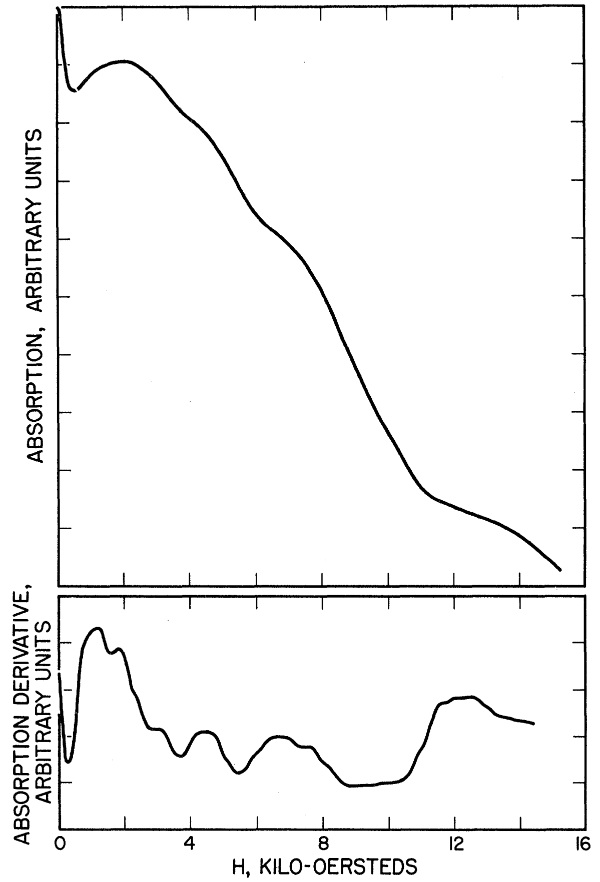

FIG. 1. Absorption and absorption-derivative curves for aluminum with magnetic field 10° from a ⟨110⟩ axis in a {110} plane. $\vec{J}_{rf}$ in {110} plane and 65° from $\vec{H}$. $f = 23.54$ kMc/sec.

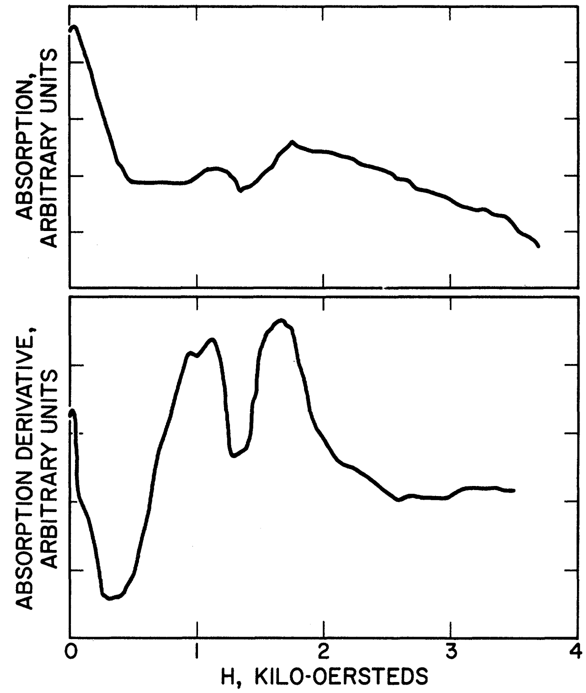

FIG. 2. Absorption and absorption-derivative curves for aluminum with magnetic field parallel to a ⟨111⟩ axis. $\vec{J}_{rf}$ in {110} plane and 90° from $\vec{H}$. $f = 23.54$ kMc/sec.

of $0.18m_0$. For this orientation the oscillations corresponding to the higher mass were not well resolved.

The dependence of the resonances on sample orientation with respect to the magnetic field has been explored. The present data do not permit a detailed analysis, but some general statements can be made. Some trace of the high-mass resonance appears for most orientations of the sample. This resonance is most clearly resolved in a region perhaps forty-five degrees wide centered on a ⟨110⟩ direction. Over the range of orientations for which some estimate of cyclotron mass could be made, the mass was quite isotropic; the variation was of the order of 10 % or less. The anisotropy in the low masses was of the order of 50 %.

We believe that the low masses are associated with the holes (~4×10^{-3} hole/atom) located, according to Heine, at the corners of the first Brillouin zone and observed by Gunnersen[4] using the de Haas–van Alphen effect, and that the high-mass resonances are associated with the major part of the Fermi surface which is located in the second zone. No de Haas–van Alphen effect attributable to this part of the surface has been observed. The electron pockets (~10^{-5} electron/atom) observed by Gunnersen and located at the corners of the third zone by Heine probably do not contribute to the resonances observed in the present work and it is doubtful that they can be detected with the present cyclotron resonance methods.

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