The explanation of the premature loss in fringe visibility probably depends on some other physical process. One possibility is that since our photomultiplier response is not fast enough to record amplitude variations within the 0.56-μsec amplitude pulses, we could be missing some finer structure of these pulses. If t_1 was reduced by an order of magnitude, our model would predict a loss of fringe visibility as observed. Another possibility is that spatial coherence associated with two regions across the beam and separated by a time delay τ is degraded with increasing delay length.

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OSCILLATORY MAGNETIC BREAKDOWN IN ZINC*

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Previous experimental data on the galvanomagnetic properties of zinc single crystals have shown that very large amplitude Shubnikov–de Haas oscillations are found for magnetic field directions near the c axis of this hexagonal close-packed metal.[1] These oscillations are associated with a very small, needle-shaped portion of the Fermi surface which contains approximately 10^{-6} of the conduction electrons in zinc. The amplitude of these oscillations appears to be many orders of magnitude larger than any existing theory would predict. We have found that these oscillations are not of the normal Shubnikov–de Haas type as previously thought, but are caused by a perturbation of magnetic breakdown by the position, relative to the Fermi energy, of the Landau levels of the needle-shaped portion of the Fermi surface. This magnetic breakdown produces a giant orbit like that previously found in magnesium.[2-4]

The de Haas–van Alphen measurements of Joseph and Gordon[5] and the magnetoacoustic measurements of Gibbons and Falicov[6] indicate that the Fermi surface of zinc is nearly identical to Harrison's single orthogonalized plane-wave model[7] as modified by Cohen and Falicov[8] to take into account the effects of spin-orbit coupling. The second band hole surface (the "monster") of this model is multiply connected and will support open trajectories parallel to the hexagonal axis.

A thorough investigation of the transverse magnetoresistance of several single-crystal specimens of zinc has been completed using magnetic field strengths as high as 23 000 gauss. The results of this investigation indicate that the topological features of the Fermi surface of zinc are identical to those of magnesium[4] with the exception that the Fermi surface of zinc is open parallel to the sixfold hexagonal axis. This openness was not observed in magnesium presumably because of magnetic breakdown of the spin-orbit energy gap which is much smaller in magnesium than in zinc.

Figure 1 is a stereographic projection in reciprocal space of those directions of H which were found to produce open trajectories in zinc. Directions of H are given by the coordinates θ, the angle between H and the polar axis $\vec{b}_3$, and ϕ, the angle between the plane of H and $\vec{b}_3$ and the plane of $\vec{b}_1$ and $\vec{b}_3$. The periphery of the stereogram corresponds to H in the basal plane. These directions of H produce open trajectories parallel to $\vec{b}_3$. The radial lines which emanate from the pole of the stereogram are directions of H which produce open trajectories parallel to the basal plane. These open trajectories are of the same type as those observed earlier in magnesium[4] and are produced by magnetic breakdown of the energy gap which separates the second band hole surface, the monster, and the needle portions of the third band electron surface. The longer radial lines are directions of H which produce the ee type open trajectories, while the shorter radial lines give rise to the ff open trajectories, both of which are shown in

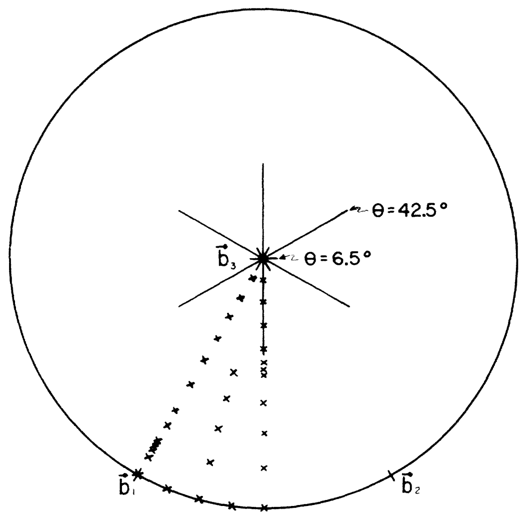

FIG. 1. Stereogram of the magnetic field directions which produce open trajectories in zinc. $\vec{b}_1$, $\vec{b}_2$, and $\vec{b}_3$ are the basis vectors of the hexagonal reciprocal lattice. The pole of the stereogram is along the sixfold $\vec{b}_3$ axis. The crosses show the current directions of the specimens investigated.

Fig. 2 of reference 4. In addition, there is a small two-dimensional region of magnetic field directions ($\theta \leq 1.3°$) about $\vec{b}_3$ which give rise to open trajectories in the basal plane. This is also the region in which a giant orbit is produced.

Figure 2 shows the variation of the transverse magnetoresistance as a function of the magnitude of H for H parallel to $\vec{b}_3$ for three different crystal purities. All of these curves contain a large oscillatory component which is periodic in H^{-1}. The period of these oscillations is identical to the de Haas–van Alphen period of the needle-shaped portion of the Fermi surface. The magnetoresistance saturates for this particular direction of H, because the presence of the giant orbit which is produced by magnetic breakdown destroys the hole and electron volume compensation. Any fluctuation in the transition probability (i.e., any fluctuation in the number of giant orbits produced) will be seen as a fluctuation in the magnetoresistance.

The standard method of treating magnetic breakdown is to assume that the energy difference between the two bands involved is independent of the magnitude of H. However, to be completely correct, we must consider that the transition takes place between the quantized Landau levels of each band. We should thus express the energy difference between the two bands as the sum of the energy difference in zero magnetic field, $E_g^{\,0}$, plus the difference between the energy of the highest populated Landau level of the respective band and the Fermi energy, $\Delta\epsilon(H)$, for a particular value of H. The maximum value of $\Delta\epsilon(H)$ for any value of H will be limited by the energy separation of the Landau levels and is given by

$$\Delta\epsilon(H)_{\max} = \hbar\omega = \hbar eH/m^*c.$$

The de Haas–van Alphen data of Joseph and Gordon[5] give a value of $m^* \simeq 0.01\,m_0$ for the needles, while the effective mass of the particles on the monster is about m_0, where m_0 is the

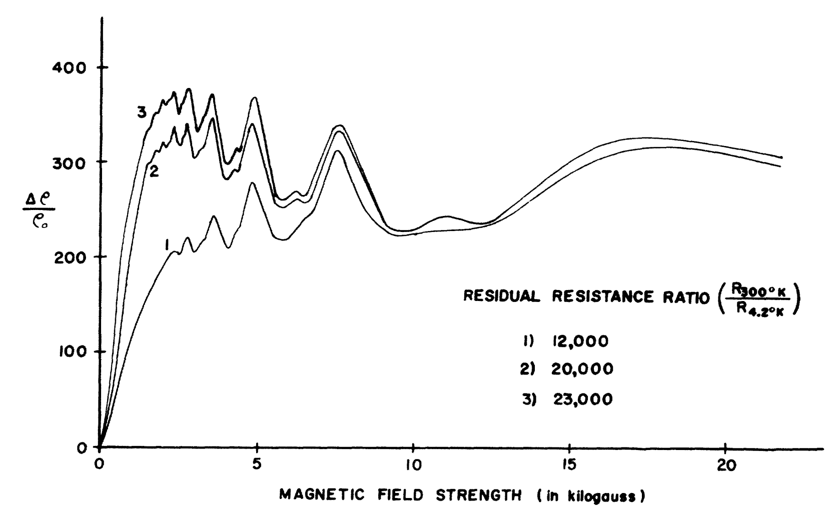

FIG. 2. Transverse magnetoresistance saturation curves for H parallel to $\vec{b}_3$ for three different specimen purities. The quantum oscillations in the magnetoresistance are the result of an oscillating magnetic breakdown.

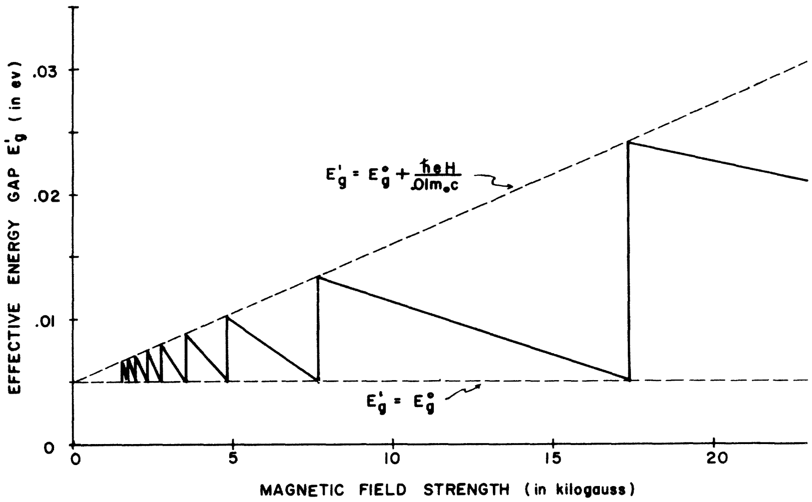

FIG. 3. The effective energy gap E_g' as a function of the magnetic field strength. The oscillations have the periodicity of the needle portions of the Fermi surface.

free electron mass. Thus, $\Delta\epsilon(H)_{\max}(\text{needles}) \simeq 100\,\Delta\epsilon(H)_{\max}(\text{monster})$, and we can neglect the perturbation due to the monster levels compared with that due to the needle levels and express the effective energy gap as

$$E_g' = E_g^0 + \Delta\epsilon(H;\ \text{needles}).$$

The curves shown in Fig. 2 indicate that the magnetic breakdown is nearly complete by the time the magnetic field has reached 2500 gauss. From this we estimate a zero magnetic-field energy gap E_g^0 of about 0.005 eV. The separation of the Landau levels of the needles is about 0.006 eV for $H = 5000$ gauss. Figure 3 shows the variation of the effective energy gap, E_g', as a function of magnetic field strength in the limit of $T = 0°\mathrm{K}$. It is evident that the periodic fluctuations of E_g' will cause periodic fluctuations in the transition probability and hence a periodic fluctuation in the magnetoresistance, and that the periodicity of these fluctuations will be identical to the de Haas–van Alphen period of the needles. Note that the fluctuations in E_g' are contained between a lower envelope of $E_g' = E_g^0$ and an upper envelope of $E_g' = E_g^0 + \hbar eH/0.01\,m_0c$. These correspond to the lower and upper envelopes, respectively, of the oscillations in the magnetoresistance.

If we look at the curves in Fig. 2 we see that there is a pronounced hump in the magnetoresistance for $H \simeq 2500$ gauss for the higher purity curves. This hump is especially pronounced if we look only at the lower envelope of the oscillations which is associated with the breakdown of the zero field gap E_g^0. Before magnetic breakdown becomes significant ($H \lesssim 1500$ gauss) the magnetoresistance varies as H^2. After magnetic breakdown is relatively complete the magnetoresistance saturates. The hump is the result of a transition from the H^2 behavior to the saturation behavior. The absence of a hump in the lower curve is due to the relatively low purity of the specimen, which prevented the initial H^2 rise of the magnetoresistance from becoming larger than the final saturation value.

Using the simple two-band model for the magnetoresistance we obtained expressions for the upper and lower envelopes of the oscillations. The result of the calculation indicated an amplitude of oscillation of about 30% of the saturation value of the magnetoresistance. This is in quite good agreement with the experimental value.

Figure 4 shows an enlarged view of the oscilla-

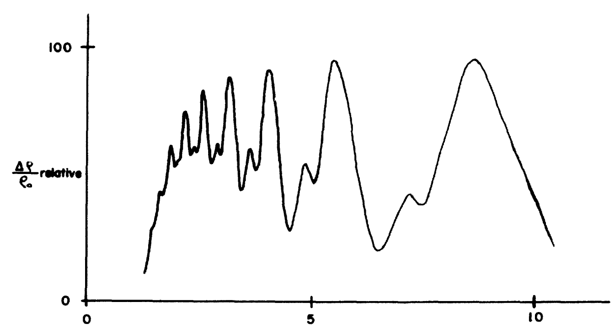

FIG. 4. The oscillatory component of the transverse magnetoresistance for H parallel to $\vec{b}_3$. The small oscillations are the result of spin splitting of the Landau levels.

tory component of the transverse magnetoresistance for H parallel to $\vec{b}_3$. Note the presence of the small secondary oscillations which occur on the left-hand slope of each of the major oscillations. These small oscillations have a constant phase relationship with the major ones. According to the foregoing treatment each minimum in the magnetoresistance must correspond to a maximum in the transmission probability. Thus each of the minima on either side of the small oscillation must correspond to a quantum level being at the Fermi energy. Hence the small oscillations must result from spin splitting of the original Landau levels. If each of the Landau levels is split into two levels by magnetic interactions, the effective energy gap E_g' will contain a secondary oscillation associated with the spin splitting which will be exhibited in the transverse magnetoresistance as a secondary oscillation of the type seen in Fig. 4. We estimated the effective g factor for the electrons on the needle from the separation of the two subsidiary minima and obtained a value of $g = 34$. While effective g values of this magnitude have been observed previously in semiconductors and semimetals, none have been observed, to our knowledge, which differed appreciably from a value of 2 in any metal with a large number of conduction electrons. It is of interest to note that the effective g value of the needle portion of the Fermi surface cannot be measured by a normal spin-resonance technique, since the needle contains only a very minor portion of the conduction electrons in zinc, while the spin-resonance technique measures the effective g values of the predominant carriers.

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SOME OBSERVATIONS OF GROWING OSCILLATIONS IN ELECTRON-HOLE PLASMA

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Highly reproducible growing oscillations have been observed in electron-hole plasma. The plasma is produced by injection[1] from current contacts into single-crystal p-type indium antimonide at 77°K. The circuit consists simply of an essentially constant-current source (pulsed) and a 10-ohm resistor in series with the sample to allow determination of the current through it. Since the pulse lengths are short (~10^{-6} sec) and the repetition rate low (<1 sec^{-1}), the temperature of the sample increases by less than 10^{-1} °K. Side contacts on the crystal are used to observe voltage behavior. The sample dimensions are $(0.75 \pm 0.03) \times (0.75 \pm 0.03) \times 12$ mm with contacts soldered as shown in Fig. 1.

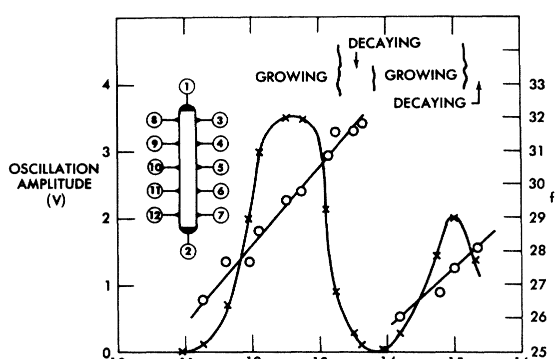

FIG. 1. The full amplitude of oscillation at maximum and the frequency plotted as functions of the current. The currents at which growing oscillations occur are indicated. Basic properties of this sample (No. A) are $p_0 = 5.5 \times 10^{15}$ cm^{-3}, $\sigma = 4.5$ (ohm-cm)$^{-1}$, and $\mu_p = 6300$ cm^2/V-sec.

Two types of growing oscillations have been observed: For one type, observed in sample No. A, the frequency is current controlled and for the