THE INFLUENCE OF PRESSURE ON THE MAGNETIC PROPERTIES OF ZINC SINGLE CRYSTALS AT LOW TEMPERATURES

I. M. DMITRENKO, B. I. VERKIN, and B. G. LAZAREV

Physico-Technical Institute, Academy of Sciences, Ukranian S.S.R.

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AN investigation of the magnetic properties of metals at low temperatures and under pressure if of interest in connection with the possible effect of the pressure on the structure of the electron energy spectrum in the metal. For metals in which the de Haas-van Alphen effect is observed, such an investigation is of particular interest in connection with the presence of different types of binding forces between the atoms of the lattice. It is possible that this may explain one of the fundamental magnetic properties of this group of metals, namely the presence of anomalously small groups of electrons.[1]

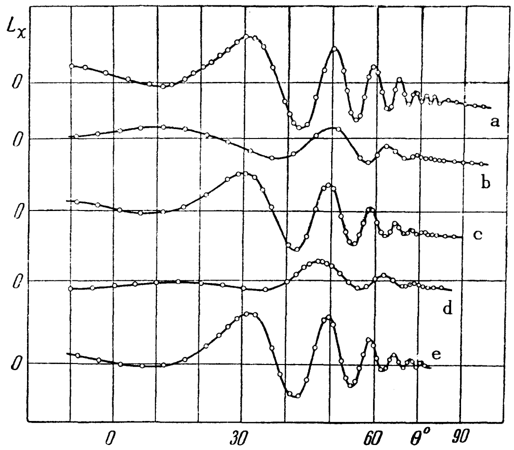

FIG. 1. The torque acting on a zinc crystal in a homogeneous magnetic field as a function of the angle θ between the field vector and the hexagonal crystal axis; $T = 4.2°$ K, $H = 8400$ oersteds. (a) $P = 0$ kg/cm^2; (b) $P \sim 1500$ kg/cm^2; (c) pressure removed; (d) pressure $P \sim 1500$ kg/cm^2 reapplied; (e) reapplied pressure removed.

The influence of pressure on the magnetic properties of Bi at low temperatures has already been communicated.[2] It is of interest to perform a more detailed investigation of this effect on zinc, a metal whose magnetic properties at low temperatures have been investigated in detail by several authors.[3-5]

Monocrystals of Zn were prepared in glass by the Obreimov-Shubnikov method, using "Hilger spectroscopic" metal. The method for creating a pressure of about 1500 kg/cm^2 and measuring the differences in the principal specific susceptibilities of a monocrystal were the same as those used previously.[2,6] The crystal was oriented in the field so that the suspension axis was perpendicular to the binary crystal axis. The principal axis of the crystal makes an angle θ with the magnetic field vector **H** in the horizontal plane. The curves shown in Fig. 1 were then obtained for the angular dependence of the torque L_x acting on the crystal at $T = 4.2°$ K and $H = 8400$ oersteds, and those of Fig. 2 were obtained for the function $\chi(1/H)$ at two values of θ (20° and 80°).

As is seen from Fig. 1, the application of pressure causes a significant decrease of the amplitude and increases the period of the oscillations; the amplitude decreases most in the region of high θ, while the period changes most at small values of θ.

When the pressure is removed, the initial curve is re-established with some amplitude hysteresis. Repetition of the application and removal of pressure reproduces the first cycle, except that the amplitude hysteresis is much less after the second application of pressure.

Figure 2 verifies the data obtained from the rotation diagrams. The period is increased both for $\theta = 80°$ and for $\theta = 20°$, with the increase being 52% in the latter case and 43% in the former. The amplitude decreases in both cases, the decrease being greater for 80°. At this value of θ the amplitude hysteresis is also larger, being about 60%, while at 20° it is only 6 — 8%. Removal of the pressure leads to complete re-establishment of the periodicity within the limits of experimental error. The slant of the median line in the $\chi(1/H)$ curves, together with the noncoincidence of the zeroes in the rotation diagrams, is explained by a torque component due to the weak magnet anisotropy of the cylinder.

The pressure effect in zinc is thus found to be quite large. It has the following interesting property. Although pressure makes the zinc lattice more isotropic, causing it to approach dense hexagonal packing, the anisotropy of the angular dependence of the periods (or the anisotropy of the Fermi electron surface, which causes this effect) increases.

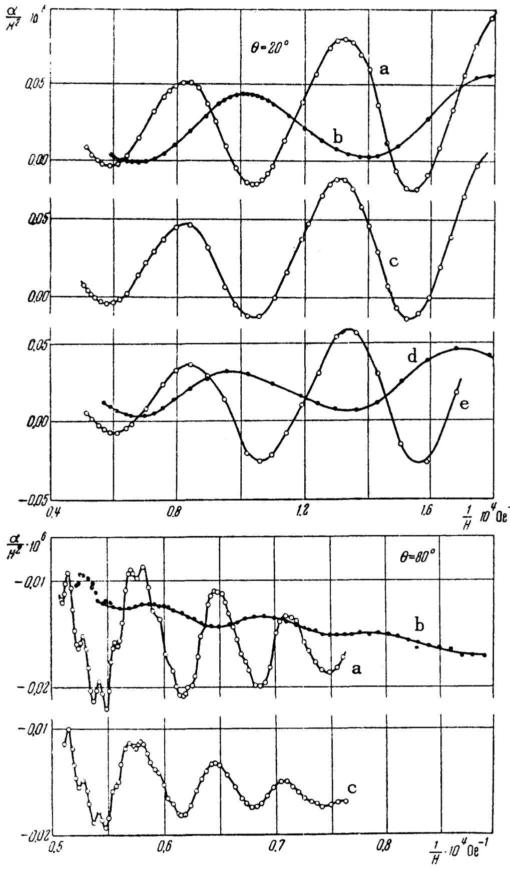

FIG. 2. The differences of the principal specific susceptibilities of a zinc crystal as a function of the applied magnetic field strength at $T = 4.2°$ K. At $\theta = 20°$; (a) $P = 0$ kg/cm^2; (b) P $\sim$ 1500 kg/cm^2; (c) pressure removed; (d) pressure P $\sim$ 1500 kg/cm^2 reapplied; (e) reapplied pressure removed. At $\theta = 80°$: (a) $P = 0$ kg/cm^2; (b) P $\sim$ 1500 kg/cm^2; (c) pressure removed.

Using the data obtained, one can estimate the number of electrons in the group responsible for the investigated longest-period component of the de Haas-van Alphen effect in Zn. If n is the number of electrons in the given group, and Ω is the volume bounded by the corresponding Fermi surface in momentum space, then $n = \Omega V/h^3$, where V is the volume of the metal and h is Planck's constant. The equation $\Omega = \alpha S^{3/2}$ gives the relation between the volume Ω and the extremal cross sectional area of the Fermi surface, and $S = A/\Delta$ [where Δ is the period of the $\chi(1/H)$ curve]. Here α is a form factor that depends in general on the orientation of the field vector relative to the crystal axis. From these formulas we obtain

$$\delta n/n = \delta V/V - {}^3/_2 (\delta \Delta/\Delta) + \delta \alpha/\alpha.$$

In our case, in spite of the significant anisotropy of the compressibility of Zn, the fractional changes of the periods for $\theta = 20°$ and $\theta = 80°$ are close (0.52 and 0.43 respectively). We can thus assume that the shape of the Fermi surface changes but little, and set $\delta\alpha = 0$. Taking next $(\delta\Delta/\Delta)_{av} = 0.47$ and $(\delta V/V) \approx 3.10^{-3}$, we obtain $\delta n/n \approx -0.7$. In other words, the number of electrons responsible for the long-period component in the $\chi(1/H)$ curve for Zn is about 70%. For comparison, we note that a similar evaluation undertaken for Bi [taking $\delta\Delta/\Delta = 0.13$, obtained from the $\chi(1/H)$ curves for $\theta = -70°$] gives only a 10% decrease of the number of electrons responsible for the de Haas-van Alphen effect at a pressure of about 1500 kg/cm^2. This estimate is much rougher than the one performed here for zinc, owing to the way the anisotropy of the Fermi surface of Bi changes under pressure.[2]

Finally, it is interesting to note that the work per atom done by the external forces in compressing the crystal is 2×10^{-6} ev. To some extent this value characterizes the magnitude of the change of the binding forces in the Zn lattice under a pressure of about 1500 kg/cm^2. It is interesting that such a small change in the binding forces leads to so large a change in the parameters of the de Haas-van Alphen effect, owing to the anomalously small group of electrons in zinc with the Fermi energy $E_0 \sim 10^{-2}$ ev.

In conclusion the authors consider it their pleasant duty to thank I. M. Lifshitz for discussing the results of the work.

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