Anisotropy of galvanomagnetic effects in single-crystal cobalt

E. N. Kondorskiĭ, O. S. Galkina, V. I. Ivanovskiĭ, A. V. Cheremushkina, and U. T. Usarov

Moscow State University
(Submitted May 18, 1973)
Zh. Eksp. Teor. Fiz. 65, 1959–1962 (November 1973)

We investigated the normal Hall constant R_0 and the transverse galvanomagnetic effect $(\Delta\rho/\rho)_\perp$ in single crystal Co at low temperatures, 4.2°K and in strong magnetic fields up to 80 kOe. The dependence of R_0 and of $\rho^{-1}\Delta\rho/\Delta H$ on the angle ϕ between the magnetic field H and the hexagonal axis c is obtained. The results are compared with the data on the topolgy of the Fermi surface and with results of investigations of the de Haas–van Alphen effect for cobalt.

The band structure of Co has not been sufficiently well investigated either theoretically or experimentally. The most complete theoretical calculation of the band structure of Co was made by Wakon and Iamashita[1]. It was of interest to investigate the galvanomagnetic effects in single-crystal Co at low temperatures and in strong fields, in order to compare the results with the available data on the topology of the Fermi surface[1-4].

The anisotropy of the Hall effect in Co was previously investigated by Volkenshteĭn, Fedorov, and Shirokovskiĭ[5]. However, the value of the applied field did not exceed 30 kOe. Transverse magnetoresistance was investigated by Marker, Richard, and Coleman[3] in single-crystal Co whiskers at T = 4.2° K and in magnetic fields 80 kOe. It was demonstrated on the basis of the data of Wakon and Iamashita[1] and Ishida[2], and on the basis of the data on the de Haas-van Alphen effect[3,4] and the galvanomagnetic effect[6], that open orbits exist in the plane parallel to the hexagonal axis and closed orbits exist in the basal plane of the crystal.

In this paper we investigate the Hall effect and the resistivity changes of single-crystal Co in a transverse magnetic field at 4.2°K and in external magnetic fields up to 80 kOe.

SAMPLES AND MEASUREMENT PROCEDURE

The Hall emf and the transverse magnetoresistance were measured on a series of samples of single-crystal Co with resistivity ratio $\rho(293°K)/\rho(4.2°K) = 74$. Samples in the form of plates measuring 0.2 × 2.5 × 7 mm were cut from a single-crystal ingot together with the potential electrodes by the electric-spark method. The normal to the plane of the samples (which coincided with the direction of the magnetic field H) made different angles φ with the hexagonal axis c of the crystal (0, 20, 30, 45, 60, 90°) (in the 11$\bar{2}$0) plane. The orientation of the c axis in each sample was determined by x-ray diffraction. After cutting, the samples were etched, and then the epigrams were again plotted, thus confirming the correctness of their orientation. The current and potential leads were secured with a low-temperature solder. The current flowed through the sample in the [11$\bar{2}$0] direction. The magnetic field was produced by a superconducting solenoid with a permendur insert, in which it was possible to obtain magnetic fields up to 80 kOe. The measurements were performed by a potentiometer method using an FÉOU-18 amplifier. The sensitivity of the setup was 5×10^{-9} V.

RESULTS AND DISCUSSION

Figure 1 shows the Hall emf $\mathscr{E}$ of Co, calculated per unit current density and measured at 4.2°K, as the func-

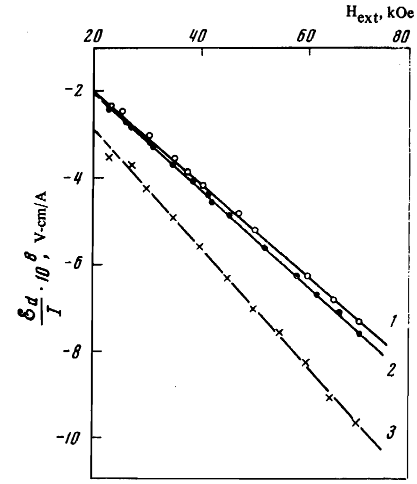

FIG. 1. Dependence of the Hall field (per unit current density), on the external magnetic field: 1—H⊥c, 2—H∥c, 3—angle between H and c equal to 30°. The current flows along the [11$\bar{2}$0] axis.

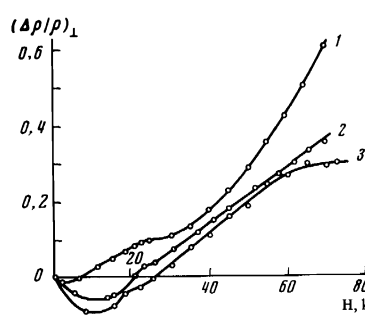

FIG. 2. Dependence of the transverse magnetoresistance $(\Delta\rho/\rho)_\perp$ on the external magnetic field. 1—H⊥c, 2—H∥c, 3—the angle between H and the c axis is equal to 30°.

tion of the external field H. The straight lines correspond to the variation of the Hall emf $\mathscr{E}$ in strong fields at three orientations of the magnetic field **H** relative to the hexagonal axis c (φ = 0, 30, 90°) and the current direction [11$\bar{2}$0] (the remaining lines were omitted in order not to clutter up the figure). The Hall emf, as shown by the figure, is anisotropic, and has a maximum absolute value when the external field makes an angle φ on the order of 30° with the c axis, and a minimal absolute value at φ = 90°. The Hall constant R_0 was determined from the slope of the linear section of the $\mathscr{E} = f(H_{ext})$ plot. We measured the transverse magnetoresistance $(\Delta\rho/\rho)_\perp$ of the same samples at 4.2°K. The results of these measurements are shown in Figure 2, where the quantity $(\Delta\rho/\rho)_\perp$ as a function of H is given for φ = 0, 30, and 90°. We see that at different values of φ the quantity $(\Delta\rho/\rho)_\perp$ changes in different manners with

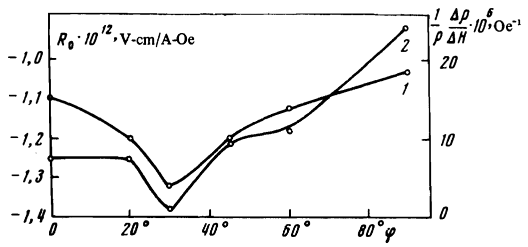

FIG. 3. Dependence of the Hall constant R_0 (curve 1) and of the quantity $\rho^{-1}\Delta\rho/\Delta H$ (curve 2) on the angle φ.

increasing H. For $\varphi = 90°$, $(\Delta\rho/\rho)_\perp$ in strong magnetic fields is a quadratic function of H, thus demonstrating the presence of open cross sections in planes parallel to the c axis. For $\varphi = 0$, the plot of $(\Delta\rho/\rho)$ against H, in fields up to 80 kOe, has a much smaller slope than curve 1. It is possible that in stronger fields this curve tends to saturate, inasmuch as $\omega_c t$ was of the order of unity for our samples. In the case $\varphi = 30°$, the curve characterizing $(\Delta\rho/\rho)_\perp$ with increasing H, reaches saturation in strong fields.

These results agree with the data of Mark, Richard, and Coleman[6]. The obtained plots of the magnetoresistance against the field correspond to the topology of the Fermi surface of Co, given in [1-4]. Namely, the closed sections of these surfaces lie in a plane whose normal makes approximate angle 30° with the c axis.

Figure 3 shows a curve characterizing the dependence of $\rho^{-1}\Delta\rho/\Delta H$ on the angle φ between the direction of the magnetic field and the c axis of the crystal. The same figure shows the values of the constant R_0, calculated from the data given in Figure 1. We see that there is a definite correlation between the changes of R_0 and $\rho^{-1}\Delta\rho/\Delta H$. Both quantities have maximal and minimal values at the same φ.

For the case of a closed Fermi surface, the Hall constant in strong fields is $R_0 = -1/ec(n_e - n_h)$, where n_e and n_h are the numbers of electrons and holes. To estimate the different $n_e - n_h$, we chose the value $R_0 = 1.32 \times 10^{-12}$, corresponding to a field inclined 30° to the c axis of the crystal, in which the magnetoresistance tends to saturation in strong magnetic fields. At this value of R_0, the value of $n_e - n_h$ calculated from the formula given above is $n_e - n_h = 0.525$ per atom. It should be noted that in[3], where the structure of the Fermi surface of Co was determined by measuring the de Haas–van Alphen effect, it is indicated that an extremal cross section is present likewise at $\varphi = 30°$, in agreement with our results for $\Delta\rho/\rho$ and R_0.

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Translated by J. G. Adashko
201