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Abstract

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ANISOTROPY OF THE HALL EFFECT IN TIN

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With the appearance of a new theory of galvanomagnetic phenomena in metals ($^{1-3}$), it became clear that an experimental study of the anisotropy of the Hall effect and of the resistance in large effective magnetic fields makes it possible to study in detail the topology of the Fermi surfaces. The investigations of the anisotropy of resistance in a magnetic field carried out in works (^{4,5}) gave important results in this respect. As for the Hall effect, the works published up to the present time, in particular (^{6,7}), do not fully meet the problems posed by the new theory. In connection with this, a detailed investigation of the anisotropy of the Hall effect in tin was undertaken, some results of which are published in the present article. Because the Hall field is not perpendicular to the magnetic field (^{6}), the Hall-field vector was constructed from its two projections, measured with the aid of two pairs of contacts. This made it possible to construct rotation diagrams for the Hall-field vector.

All measurements were carried out at a temperature of 4.2° K. The magnet, which gave a maximum field of about 7 kOe, was powered by a storage battery of large capacity, which ensured sufficient stability of the field. The specimens were cylindrical single crystals of tin 2–3 cm long and 1.5 to 3 mm in diameter. High-purity tin with $\rho_{290^\circ\mathrm{K}}/\rho_{4.2^\circ\mathrm{K}}$ from 5000 to 60 000 was used for preparing the specimens. This made it possible to attain sufficiently large effective fields ($H\rho_{290^\circ\mathrm{K}}/\rho_{4.2^\circ\mathrm{K}} \sim 10^8$ Oe). The orientation of the single crystals was determined by the optical method on a goniometer. Five leads were soldered to each specimen, arranged as shown in Fig. 1a. The leads were copper wires 0.15 mm in diameter; Wood' s alloy was used as the solder, and the diameter of the solder drop did not exceed 0.3 mm. Contacts 1, 2, 3, and 4 were located in a plane perpendicular to the axis of the specimen, with an accuracy of up to 0.1 mm. In addition, the straight lines connecting contact 1 with 3 and 2 with 4 were perpendicular to within 2–3°. The voltages were measured by the compensation method, using as a null indicator a dc amplifier with a superconducting modulator, similar to that described in (^{8}), with a sensitivity of up to $5 \cdot 10^{-10}$ V. The use of such an amplifier, in which parasitic thermoe.m.f.' s in the measuring circuit, entirely immersed in liquid helium, are absent, made it possible to carry out measurements with sufficiently high accuracy at comparatively small currents through the specimen (from 1 to 5 A). In addition, the

Fig. 1

Figure 1: Fig. 1

need to commutate the direction of the current through the specimen was eliminated. The reproducibility of the results reached ±2%. The angles between the principal crystallographic directions of the specimen and the magnetic field (lying in the plane perpendicular to the axis of the specimen) were measured with an accuracy of ±1°. For each specimen, rotation diagrams of the resistance in a magnetic field were recorded using contacts 1, 5; the rotation diagrams obtained in this way agree with the diagrams given for tin in work (^{4}).

The Hall-field vector $\mathbf{E}_h$ was found by geometrical construction from its projections E_x and E_y, namely

$$E_x = \frac{1}{d}\frac{V_{1,3}(+H) - V_{1,3}(-H)}{2}, \qquad E_y = \frac{1}{d}\frac{V_{2,4}(+H) - V_{2,4}(-H)}{2},$$

where $V(+H)$ and $V(-H)$ are the potential differences on the corresponding pairs of contacts for two mutually opposite directions of the magnetic field, and d is the diameter of the specimen.

Fig. 1. Specimen Sn-7. *a* —arrangement of contacts; *b* —vector diagrams of rotation of the Hall field for two values of the magnetic field. The diagram corresponding to the field 5.6 kOe is shown in only one quadrant. For the direction $\mathbf{H} \parallel [110]$, the mutual arrangement of the vectors $\mathbf{E}_h$ and $\mathbf{H}$ is shown. Current density 134 A/cm^2.

In Fig. 1*b* diagrams are presented that show the change in the magnitude and direction of the Hall-field vector $\mathbf{E}_h$ when the direction of the magnetic field is changed for specimen Sn-7, in which the [001] axis is parallel to the current direction ($\rho_{290^\circ\mathrm{K}}/\rho_{4.2^\circ\mathrm{K}} = 60\,000$). The points on the diagram correspond to the tips of the vectors $\mathbf{E}_h$ drawn from the origin, and the numbers near the points indicate the corresponding directions of the magnetic field (the circle inside the diagram is the scale of magnetic-field directions). For directions of $\mathbf{H}$ parallel to the axes [110], [100], and [010], minima are visible in the diagram, the depth of which increases sharply with increasing field. Near these minima the angle $\mathbf{E}_h\mathbf{H}$ differs from 90°; this is especially noticeable for the directions [100] and [010]. It should be noted

the difference in the shape and width of the minima along the directions [100] and [110], corresponding to the difference in the shape of the minima in the angular dependence of the resistance in a magnetic field (^{4}). The dependence of $|E_h|$ on the magnitude of the magnetic field for the direction corresponding to the angle 66° in Fig. 1b can be approximated, for fields from 1 to 6 kOe, by the expression
$|E_h| = 10^{-7}(0.8H + 0.17H^2)$ ($|E_h|$ in V/cm, H in kOe). An analogous character

Fig. 2. Vector rotation diagrams for sample Sn-8. a –for E_h, b –for E_q. Current density through the sample 75.4 A/cm^2.

Figure 2: Fig. 2. Vector rotation diagrams for sample Sn-8. a –for E_h, b –for E_q. Current density through the sample 75.4 A/cm^2.

is possessed by this dependence also for other directions of the magnetic field, with the exception of the directions corresponding to the minima, where $|E_h|$ increases with field somewhat more slowly than according to a linear law.

Fig. 2. Vector rotation diagrams for sample Sn-8. *a* –for E_h, *b* –for E_q. Current density through the sample 75.4 A/cm^2.

In Fig. 2a the vector rotation diagram of E_h is given for sample Sn-8, whose axis lies in the (110) plane and makes an angle of 64° with the direction [001] ($\rho_{290^\circ\mathrm{K}}/\rho_{4.2^\circ\mathrm{K}} = 5000$). In the direction $\mathbf{H} \parallel (001)$ the Hall effect changes sign.

In addition to the component of the transverse field–the Hall field–which is odd with respect to the direction of the magnetic field, an even component was observed for all samples. The vector of the even component E_q was found analogously to the Hall-field vector from its components E_{qx} and E_{qy}, with

$$E_{qx} = \frac{1}{d}\,\frac{V_{1,3}(+H) + V_{1,3}(-H)}{2}$$

and so on. In Fig. 2b the vector rotation diagram of E_q is given for sample Sn-8. It should be noted that the maximum possible voltage drop at the contacts due to inaccuracy in their placement is 10–20 times smaller than the observed magnitude of the even component.

For specimens whose axes did not coincide with the symmetry axes of the crystal, the value of E_q proved to be large; moreover, for magnetic-field directions corresponding to the minimum on the rotation diagram for the resistance, a deep minimum was observed in the angular dependence of E_q (Fig. 3). For specimen Sn-7, oriented along a fourth-order axis, and Sn-10, oriented along the [010] axis, the even component was small in magnitude (and comparable with the possible voltage drop at the contacts) for all directions of the magnetic field.

Fig. 3. Sn-8. Rotation diagrams for the current field along the specimen axis (1) and for $|E_q|$ (2).
$H = 5.6$ kOe.

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Note: Figure translations are in progress. See original paper for figures.