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ANISOTROPY OF THE GALVANOMAGNETIC PROPERTIES OF ALUMINUM IN STRONG EFFECTIVE FIELDS

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The anisotropy of the resistance and Hall field in a magnetic field was investigated for aluminum single crystals of various orientations. The dependence of these quantities on the magnetic field was recorded. The measurements were carried out at 4.2°K in fields of up to 25 kOe. From the results obtained by measuring the Hall effect the hole density per atom of aluminum was found to be $n/N_a = 0.98 \pm 0.03$.

FROM the work of several authors [1-3] it is known that the anisotropy of galvanomagnetic properties makes it possible to obtain information on the topology of the Fermi surface of metals.

The following behavior in strong effective fields is characteristic of metals with a closed Fermi surface: the resistance anisotropy is weak, the Hall field is isotropic, and the dependence of the resistance on the magnetic field is the same for all field orientations with respect to the crystallographic axes.

The published data [4-7] are in accord with the assumption that aluminum is one of the metals with a closed Fermi surface, but no measurements of the resistance and Hall effect anisotropy in strong effective fields have yet been reported. In the work of Lüthi, [8] which is the only recent study of single crystals, the effective field was one order of magnitude smaller than that used by the present author.

SAMPLES

The anisotropy of the Hall field and the electrical resistance were measured on single-crystal samples having axes close to the principal crystallographic axes. The sample orientation was determined optically.

The Hall coefficient was calculated from measurements of the Hall effect on polycrystalline plates of regular shape. All the test samples were of high purity, which permitted work in the region of strong effective fields.

The measurements were carried out at 4.2°K in fields of up to 27,000 Oe, using a potentiometer circuit of 10^{-8} V sensitivity. In all these experiments the current was directed along the sample axis and the magnetic field at right angles to the current. The temperature dependence of the sample resistance is given in the table.

Samples	$\frac{10^4\, r(4{,}2°K)}{r\,(273°K)}$	Remarks
Al-1	5.5	Single-crystal samples with axes close to two-fold, three-fold and four-fold crystallographic axes respectively
Al-2	6.1	
Al-3	5.2	
Al-4	7.7	Polycrystalline plates
Al-5	6.6	
Al-6	3.8	

EXPERIMENTAL RESULTS AND DISCUSSION

The anisotropy of the magnetoresistance was investigated on the single crystals Al-1, Al-2, Al-3 in a magnetic field of 22,000 Oe at T = 4.2°K. The results for Al-1 and Al-2 are given in Fig. 1. This figure shows that the magnetoresistance anisotropy is weak, not exceeding 40% for any orientation. The magnetoresistance anisotropy of sample Al-3 was less than 20% and, therefore, its curve is not given.

The dependence of the resistance on the magnetic field along the directions of minima and maxima in the rotation diagrams was investigated

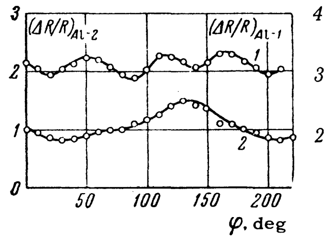

FIG. 1. Anisotropy of the magnetoresistance of aluminum single crystals: 1) Al-2; 2) Al-1; φ is the angle between the magnetic field and some fixed direction in the plane at right angles to the current.

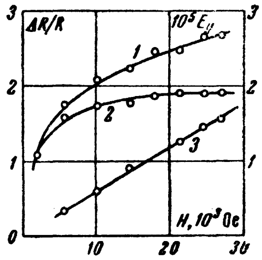

FIG. 2. Dependence of the change in the resistance and Hall field on the magnetic field for sample Al-1: 1) $\Delta R/R$, $\varphi = 130°$ (max.); 2) $\Delta R/R$, $\varphi = 40°$ (min.); 3) E_y.

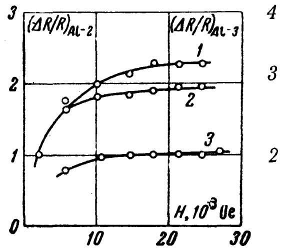

FIG. 3. Dependence of the change in the resistance on the magnetic field: 1) $\Delta R/R$ for Al-2, $\varphi = 20°$; 2) $\Delta R/R$ for Al-2, $\varphi = 60°$; 3) ΔR for Al-3.

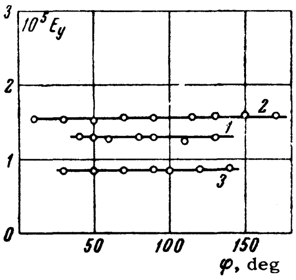

FIG. 4. Anisotropy of the Hall field: 1) Al-1; 2) Al-2; 3) Al-3.

using the same single-crystal samples (Figs. 2 and 3). For Al-3 only the curve along the maximum is given (curve 3 in Fig. 3) because of its weak magnetoresistance anisotropy. The magnetoresistance tends to saturate in strong fields for almost all directions. The exception is curve 1 in Fig. 2, which does not show saturation in strong fields. (Assembly errors were avoided as indicated in [7].) This observation means that further studies of the anisotropy are needed on purer samples or in stronger magnetic fields.

The Hall field measured for sample Al-1 varied linearly with the magnetic field (curve 3 in Fig. 2), i.e., the Hall coefficient was independent of the field in the range of fields employed. The anisotropy of the Hall effect was investigated using the same single crystals (Al-1, Al-2, Al-3). Figure 4 gives the dependence of the Hall field E_y on the angle between the magnetic field and some fixed direction in the plane perpendicular to the current. This figure shows that the Hall field is isotropic for all the orientations investigated.

The weak anisotropy of the resistance in a magnetic field, the isotropy of the Hall field and the identical dependence of the resistance on the magnetic field for different directions allow us to assume that the Fermi surface of aluminum is closed. Some doubt, however, exists due to the incomplete saturation in the direction of the maximum for Al-1 (curve 1 in Fig. 2).

The isotropy of the galvanomagnetic properties of aluminum allows us to use polycrystals, which can be prepared more easily in a regular shape, in determination of the Hall coefficient. The Hall field was measured and the Hall coefficient calculated using several polycrystalline plates (Al-4, Al-5, Al-6) of the same purity as the single crystals.

I. M. Lifshitz, Azbel', and Kaganov showed [1] that from the Hall coefficient R we can obtain the difference of the hole and electron densities n using the formula $R = 1/nec$, derived on the assumption of an arbitrary dispersion law. From the experimental results we calculated the quantity $n/N_a = 0.98 \pm 0.03$, where N_a is the number of atoms per unit volume.

Our experimental results do not, in the first approximation, contradict the Harrison model, [9] which predicts that the conduction band of aluminum contains only holes at a density of one hole per atom. However, a more thorough inspection of the experimental results gives rise to some doubts. First, the increase of the resistivity at saturation is $\Delta\rho/\rho \approx 2$, which is difficult to explain by means of the Harrison model. The observed sign of the Hall effect is positive but measurements at room temperature [10] gave a negative sign. As shown by Borovik, [5] reversal of the sign of the Hall effect occurs at low temperatures on transition to stronger effective fields. Such a reversal is also difficult to explain within the framework of the model predicting the presence of holes only.

We conclude that the absence of saturation obtained for one of the orientations of a single crystal indicates the need for further studies on purer aluminum, as pointed out above. Such studies are being completed and their results will be published.

Concluding, the author thanks E. S. Borovik for his interest in this work and discussion of the results.

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