Temperature dependence of the magnetoresistance of cadmium and antimony whisker crystals

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The dependence of the magnetoresistance of cadmium and antimony whisker crystals on the temperature was measured in the interval 4.2–80°K. An anomalous increase of the magnetoresistance with increasing temperature was observed. This anomaly is attributed to the presence of specular reflection of conduction electrons from the surfaces of the metals.

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To investigate the character of the reflection of the conduction electrons from the surface of whiskers, we have measured the dependence of the resistivity $\rho(H)$ on the magnetic field at various temperatures in the interval 4.2–80 °K.

The objects of the investigation were cadmium and antimony whiskers in the form of narrow ribbons. For all the measured samples of these metals, the planes of the ribbons coincided with the basal planes of the crystals. The measuring current I was directed along the bisector axis. The thickness d of the measured samples was 0.1–10 μ. At the same time, the conduction-electron mean free path l^{∞}, connected with the scattering by impurities and phonons, was of the order of 1 mm at $T = 4.2$ °K. This made it possible to carry out the measurements in a wide temperature range under condition $l^{\infty} \gg d$ of the strong size effect.

The methodological features of working with whiskers were described earlier.[1]

The measurements were performed at $\mathbf{I} \perp \mathbf{H}$ for two principal orientations of the magnetic field H relative to the ribbon plane, namely perpendicular and parallel to the surface (the magnetic field was respectively parallel or perpendicular to the principal axis of the Cd or Sb crystals).

We performed preliminary experiments with bulk samples ($d = 2$ mm) of Cd and Sb having the same orientation as the ribbon. It was found that at any orientation of the magnetic field, the magneto-resistance (MR), equal to

$$\Delta\rho^{\infty}(T;H) = \rho^{\infty}(T;H) - \rho^{\infty}(T;0)$$

decreases with increasing temperature T. We henceforth designate the resistivity of bulky samples by the symbol ∞.

This behavior of the MR is normal for metals in which $\rho^{\infty}(H) \propto H^2$ and in which the carrier spectrum does not depend significantly on the magnetic field. A similar behavior is exhibited by the MR of ribbon whiskers if the magnetic field is perpendicular to the plane of the ribbon (Fig. 1).

An entirely different behavior of the MR is observed if the magnetic field is parallel to the plane of the ribbon (Figs. 2 and 3). With increasing temperature, the

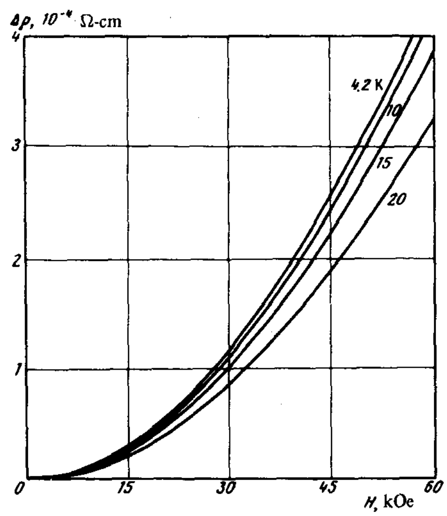

FIG. 1. Dependence of the resistivity of antimony whiskers on the magnetic field at various temperatures. The field is perpendicular to the plane of the sample. The sample thickness if 0.4 μ and its width is 52 μ.

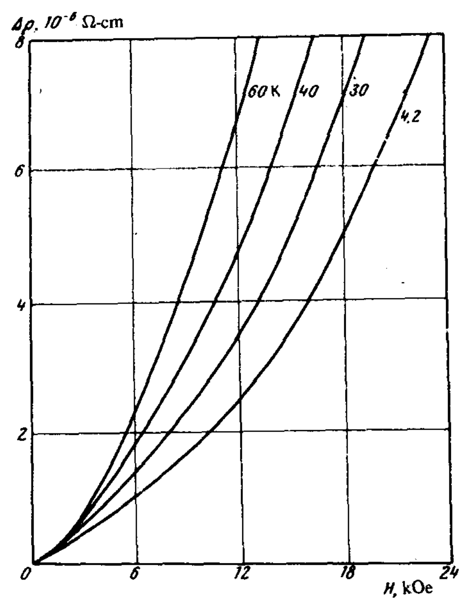

FIG. 2. The same as in Fig. 1. The field is parallel to the sample plane.

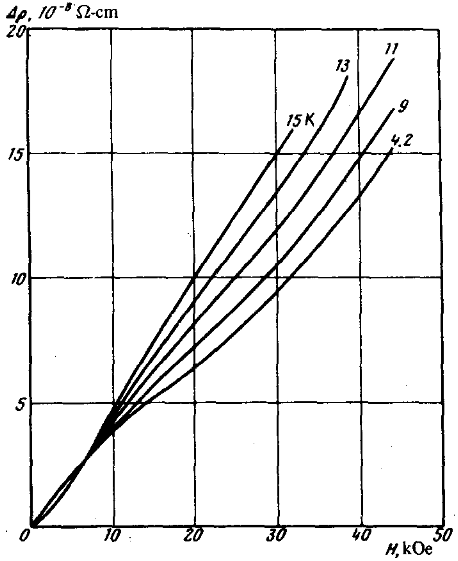

FIG. 3. Dependence of the resistivity of a cadmium whisker on the magnetic field at various temperatures. The field is parallel to the plane of the sample. Sample thickness 2.5 μ, width 35 μ.

MR also increases, reaches a maximum, and then begins to decrease as in the preceding two cases. At a thickness $d = 1$ μ, the maximum value of the MR is reached at approximately 30 °K for cadmium and 70 °K for anitmony.

The results admit of the following interpretation: in bulky samples ($l^\infty \ll d$) we have $\Delta\rho^\infty(T; H) \propto \rho^\infty(T; 0)(l^\infty H)^2 = Al^\infty(T)H^2$, where $A = \rho^\infty l^\infty = \text{const}$. Thus, the decrease of the mean free path with increasing temperature slows down the growth of the MR.

In thin plates with the magnetic field perpendicular to the surface, there is no size effect in the monotonic part of the MR. There should therefore be no qualitative difference in the temperature dependence of the MR in comparison with bulky samples.[2] When the field is parallel to the surface, an appreciable role is assumed in the conductivity by the electrons that collide with the surface. As shown in[3], the resistance of a plate can in this case be expressed in the form

$$\Delta\rho(T;H) \approx \rho^\infty(T;0)(l^\infty d/r^2) \backsim AH^2 d \qquad \text{for } p = 0,$$

$$\Delta\rho(T;H) \backsim (1-p)AH^2 d + B(Hd/l^\infty) \qquad \text{for } p \approx 1,$$

where r is the Larmor radius of the electron, p is the specularity coefficient, and B is a constant. Thus, in the case of diffuse reflection ($p = 0$) the MR should be independent of the temperature, and in the case of specular reflection (p close to unity) it should increase with increasing temperature. The latter is observed in our experiments. The fact that the MR goes through a maximum can be attributed to the increasing contribution made to the conductivity by the electrons that do not collide with the surface. That is to say, at sufficiently high temperatures the quantity $\Delta\rho(T; H)$ should tend to $\Delta\rho^\infty(l^\infty H)^2$.

The results point to a significant possibility of drawing conclusions concerning the presence of specular reflection of the conduction electrons under the conditions of the size effect.

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[2] V. G. Peschanskiĭ, Candidate's dissertation, Khar'kov, 1970.
[3] M. Ya. Azbel' and V. G. Peschanskiĭ, Zh. Eksp. Teor. Fiz. 55, 1980 (1968) [Sov. Phys.-JETP 28, 1045 (1969)].