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MAGNETORESISTANCE OF BISMUTH IN STRONG MAGNETIC FIELDS

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By virtue of the specific features of the energy spectrum of the carriers - small effective masses and low degeneracy temperature [1,2] - the quantization of the energy levels in Bi becomes appreciable in relatively weak magnetic fields. The condition $\hbar\omega \sim \epsilon_F$ ($\omega = eH/m^*c$ = cyclotron frequency, ϵ_F = Fermi energy) is satisfied for certain electrons in fields of approximately 20 kOe. At magnetic-field directions in which several essentially different extremal sections of the electronic part of the Fermi surface of bismuth are realized, satisfaction of this condition will lead to "spilling" of electrons from certain ellipsoids into others [3]. This assumption has been confirmed by observations of the periodic growth of the magnetic-susceptibility oscillation frequency with increasing magnetic field [4].

We shall use the data of [2], which contain, besides the value of the limiting Fermi energy in bismuth ($\epsilon_F^{(1)} = 0.031$ eV) also the energy distance to the "openness" closest to the Fermi level ($E_0^{(1)} = 0.048$ eV, "openness" - value of the energy at which the conditions for the closure of the Fermi surface are violated). By virtue of the foregoing, a change of $\Delta = E_0^{(1)} - \epsilon_F^{(1)}$ due to "spilling" of the electrons in a magnetic field should give rise to an open trajectory. We shall attempt to estimate roughly the possible change in the Fermi level, assuming "total spilling" of the electrons from one sphere to another. In this case [5], $n \sim \epsilon^{3/2}$ (n = number of electrons, ϵ = energy). After the "spilling" the number of electrons in one of the sphere doubles, i.e., equals $2n \sim \epsilon_1^{3/2}$. Consequently $\Delta_1 = \epsilon_1 - \epsilon = 0.589\epsilon$. Assuming $\epsilon = \epsilon_F^{(1)}$, we obtain $\Delta_1 = 0.018$ eV, which agrees well with Δ.

The foregoing qualitative treatment shows that in principle open trajectories can be produced in bismuth by means of a unique magnetic breakdown.

The occurrence of open trajectories greatly influences the behavior of the magnetoresistance [6]. In this connection, we investigated the electric resistivity of single-crystal Bi samples of varying purity and orientation in transverse pulsed magnetic fields ($\vec{H} \perp \vec{I}$, $\vec{H}$ = magnetic field, $\vec{I}$ = current through sample) up to 80 kOe at temperatures 4.2 and 20.4°K.

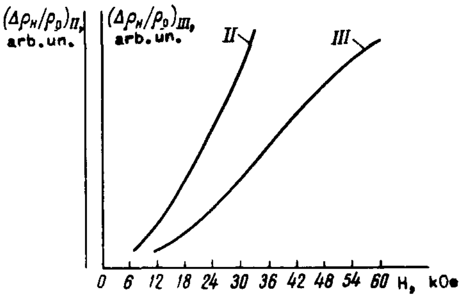

Fig. 1. $Bi(\rho_{300°K}/\rho_{4.2°K}) = 150$, $\Delta\rho_H/\rho_0$ (H), II -- T = 20.4°K, III -- T = 77°K, $\Delta\rho_H/\rho_0 = (\rho_H - \rho_0)/\rho_0$.

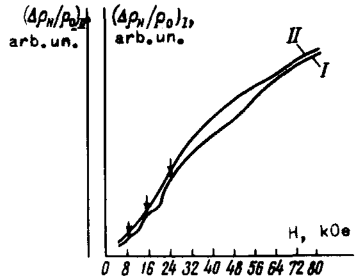

Fig. 2. Bi, $\Delta\rho_H/\rho_0$ (H); I -- T = 4.2°K, II -- T = 20.4°K (the arrows indicate the positions of the oscillation maxima on curve I).

At 77°K the magnetic field reaches only 60 kOe. The measurements were made on the decreasing part of the pulse. The samples were plates measuring 1 x 1 x 12 mm. It was observed that for certain magnetic field directions, when H > 30 kOe, the character of $\Delta\rho_H/\rho_0$ (H) changes appreciably, with a tendency to saturate. This peculiarity of magnetoresistance is clearly pronounced at helium and hydrogen temperatures (Fig. 2), is somewhat smoothed at T = 77°K (Fig. 1), and appears at all temperatures in the vicinity of 30 kOe. Measures were taken during the course of the experiment to exclude extraneous effects connected with incorrect mounting and wiring [7] - the samples were remounted, the current and potential leads were interchanged, measurements were made with different samples at identical orientation. The variation in the character of $\Delta\rho_H/\rho_0$ (H) occurred in samples with room- to helium-temperature resistivity ratios 70 and 150. The ratio $\rho_{300°K}/\rho_{4.2°K} = 150$ corresponded to samples 99.9999% pure and with $(\Delta\rho_H/\rho_0) \simeq 10^5$ at H = 80 kOe and T = 4.2°K (ρ_H = resistivity in magnetic field H, ρ_0 = resistivity at H = 0).

The occurrence of the effect in identical fields but different temperatures, and also the purity of the investigated samples, offer evidence that the observed anomaly is not connected with any impurities.

The foregoing analysis and experimental results suggest that the change in the character of $\Delta\rho_H/\rho_0$ (H) is due to the appearance of open trajectories in fields close to 30 kOe. We must point out also the possibility that magnetic breakdown in the usual sense [6] may occur in bismuth, owing to the small values of Δ and m^*.

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