Behavior of the thermo-emf of bismuth whiskers associated with a 2.5-order transition

Yu. P. Gaĭdukov, N. P. Danilova, and E. V. Nikiforenko
M. V. Lomonosov State University, Moscow

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The dependence of the differential thermo-emf (α) on elastic elongation up to 1.2% at $T = 5.5$ K is measured for bismuth whiskers 1–2 μm thick. A distinct nonmonotonic dependence, which is associated with a 2.5-order transition, is observed.

As shown in Refs. 1 and 2, anomalies in the electronic characteristics of the metal accompanying 2.5-order transitions are manifested most distinctly in α. In the case of both deformations and the addition of impurities, the behavior of α in the limit $T \to 0$ must have the form $(\pm z)^{-1/2}\theta(\pm z)$. Here $z = \mu - \mu_c$ (μ is the chemical potential of electrons, and μ_c is its critical value) is a parameter indicating the proximity to the transition and is proportional, for example, to the pressure, elongation, or impurity concentration; $\theta(x) = 0$ if $x < 0$ and 1 if $x > 0$. These results of the theory were first checked for the alloys $Li_{1-x}Mg_x$,[3] in which an anomalous behavior of $\alpha(x)$ was observed for Mg concentrations $\sim 20\%$: α passes through a maximum near $x_c = 0.2$. This concentration agrees well with the computed region, in which the Fermi surface (FS) touches the boundaries of the Brillouin zone. This situation suggests that the observed phenomenon is associated with a 2.5-order transition. Although this is a plausible proposition, it is nevertheless necessary to have direct experimental proof of the existence of the transformation of the FS in the alloys investigated, as well as of the critical value of the impurity concentration at which the topological transition occurs. The $Li_{1-x}Mg_x$ alloys do not present such a possibility. On the other hand, the 2.5-order transition observed with elastic elongation of bismuth and aluminum whiskers[4,5] makes it possible to perform an experiment, in which a relationship between the appearance of anomalies in α and the change in the topology of the FS can be clearly established.

For this purpose we investigated bismuth whiskers. The elastic elongation of the whiskers was realized on the apparatus described in Ref. 6, which was modified for measuring α. This apparatus permits obtaining easily a large temperature differential over comparatively small distances of $\sim$0.3–0.5 mm. The samples were mounted using electrically conducting glues, which formed mechanical and electrical contacts. The temperature drop along the sample was measured with the help of a differential thermocouple with a sensitivity of ~ 10 μV/deg in the region of liquid-helium temperatures. The working length of the samples was 0.3–0.5 mm and the temperature gradient was 10–50 deg/cm. The measurements were performed with an average sample temperature of ~ 5.5 K. The samples investigated had a diameter of 1–2 μm. The value of α for the samples was measured by a differential method with automatic recording of the curves. Approximately 40 samples were investigated. The negative

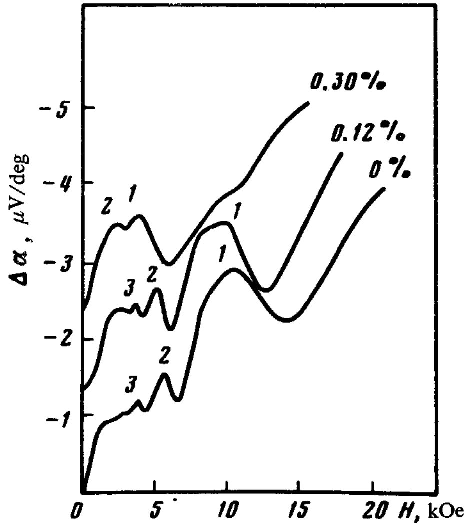

FIG. 1. Effect of elongation on quantum oscillations of the thermo-emf of a bismuth whisker in a magnetic field: $\Delta\alpha = \alpha(H) - \alpha(0)$. The relative elongation is indicated for each curve. Curves for 0.12 and 0.3% are displaced along the ordinate. The numbers of the Landau levels are indicated above the peak.

values of α_0 with $\Delta l/l_0 = 0$ ($\Delta l/l_0$ is the relative elongation, and l_0 is the initial length of the samples) exhibit some spread around the average value $\alpha_0 = -7\ \mu$V/deg.

Two series of measurements were performed. In the first series the dependence of α on the magnitude of the magnetic field, oriented along the axis of the sample, was measured for fixed values of $\Delta l/l_0$ (Fig. 1). It is evident that this dependence has a distinct oscillatory character. The periods of the observed oscillations permit referring the sample to a definite orientation, denoted conditionally as type I or II.[3] Figure 1 refers to samples of the type I,[1)] which undergo 2.5-order transition with $\Delta l/l_0 \cong 0.5\%$. By successively increasing $\Delta l/l_0$ we can follow the change in the period of quantum oscillations, which in turn permits marking precisely the onset of the stretching of the sample and the moment at which the topology of the FS of bismuth changes (one of the three electronic ellipsoids vanishes). Primary attention was devoted to samples with this orientation. In the second series of measurements we measured the dependence of α on $\Delta l/l_0$ in the absence of a magnetic field. In this case the reversibility of the observed phenomena was specially checked. Figure 2 shows the dependence of $\Delta\alpha$ on $\Delta l/l_0$ for type-I samples. For all samples of this type a positive correction $\Delta\alpha$, which increases sharply, reaching a maximum at $\Delta l/l_0 \cong 0.5\%$, and then sharply decreases and remains virtually constant at $\Delta l/l_0 > 1\%$, appears in α with the onset of deformation. For type-II samples, for which the topological transition can occur only at $\Delta l/l_0 \gtrsim 2\%$, only a small monotonic change of α is observed for elongations up to 1%.

Comparison of the changes of the period of quantum oscillations with the dependence of α on $\Delta l/l_0$ leads to the conclusion that the observed nonmonotonic behavior of type-I samples is associated with a 2.5-order transition. In this case it must be

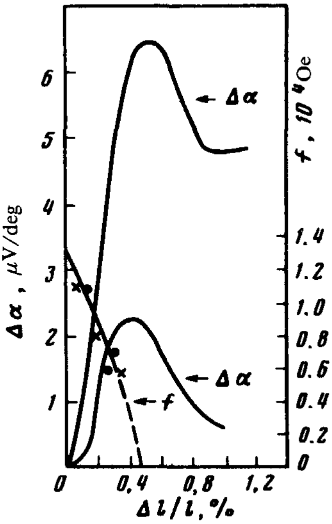

FIG. 2. Dependences of the period of quantum oscillations f and the magnitude of the thermo-emf of bismuth whiskers on the relative elongation. $\Delta\alpha = \alpha(\Delta l/l_0) - \alpha(0)$. The dots (●)—sample No. 1, $\alpha_0 = -10$ μV/deg, and $\Delta\alpha$ is represented by the upper curve; X—sample No. 2, $\alpha_0 = 4.5$ μV/deg, and $\Delta\alpha$ is represented by the lower curve.

assumed that the maximum of α coincides with the moment at which one of the electronic ellipsoids of the FS of bismuth vanishes. We note the qualitative agreement between the experiment and theory[2]: α passes through a maximum, $\Delta\alpha$ is positive, and the magnitude of $\Delta\alpha$ at the maximum is comparable to the initial value of α_0. We also note that according to Refs. 1 and 2, a jump-like change in α should be observed (the derivative becomes infinite) at the time $z=0$. This behavior has not been observed experimentally, possibly because of the temperature-induced smearing, although a comparison of the Fermi temperature ($T_F \approx 300$ K) with the temperature of the experiment does not support this viewpoint. In order for a final conclusion to be drawn, the measurements must nonetheless be performed in a broad range of temperatures.

[1)]The axes of these samples are tilted approximately by 15° away from the binary axis of the crystal.

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