Giant quantum oscillations of the thermoelectromotive force in bismuth and in submetallic Bi-Sb alloys

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Giant quantum oscillations of the coefficient of thermoelectromotive force in longitudinal magnetic fields were observed.

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In this paper we investigate the coefficient of thermoelectromotive force in longitudinal (up to 65 kOe) and transverse (up to 12 kOe) quantized magnetic fields in Bi single crystals and in a submetallic $Bi_{0.97}Sb_{0.03}$ alloy. Figure 1 shows the dependences of the α_{33} component of the thermo-emf tensor of bismuth and of $Bi_{0.97}Sb_{0.03}$ alloy on the longitudinal magnetic field, which were taken without any compensation for the monotonic motion. The characteristic feature of the given dependences is the giant oscillations of the electromotive force with an amplitude that reaches 500%. A corresponding picture pertains to a temperature of 6–8 K; the oscillation amplitude decreased as a result of increasing the temperature and at 15–20 K it comprised not more than 10%.

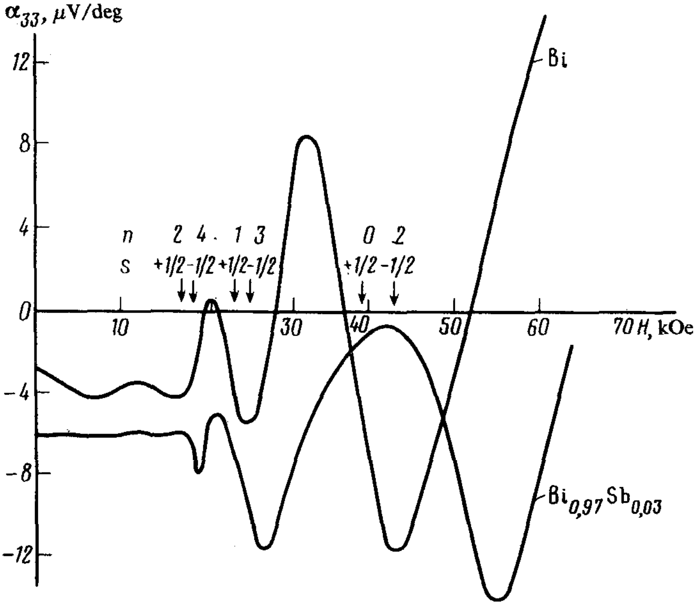

FIG. 1. Experimental dependences of the thermoelectromotive force of bismuth ($T = 7.7$ K) and of $Bi_{0.97}Sb_{0.03}$ alloy ($T = 6$ K) on the intensity of the longitudinal magnetic field $\mathbf{H}\|\vec{\nabla}\mathbf{T}\|C_3$.

The investigated samples, $3\times3\times20$-mm^3 parallelepipeds, were cut out along the trigonal axis (C_{33}). The thermo-emf was measured at a temperature of 6–20 K; the temperature gradient parallel to the trigonal axis was measured with an accuracy of better than 2% by two thermocouples.

The giant quantum oscillations of the thermo-emf (i.e., oscillations with an amplitude exceeding the monotonic component) of some metals were observed earlier (for example, Ref. 1), but they were associated with quantization of the spectrum of the charge carriers under conditions of magnetic breakdown. Investigation in Ref. 2 of quantum oscillations of thermo-emf of the Shubnikov-de Haas type in InSb in transverse magnetic fields showed no evidence of anomalous oscillations.

The thermo-emf of the investigated samples in the absence of a magnetic field at $T > 5$–6 K has an electron sign and is determined by

$$a = \frac{a_e\sigma_e + a_h\sigma_h}{\sigma_e + \sigma_h},$$

where α_e and α_h are the partial thermo-emf of the electrons and holes and σ_e and σ_h are the corresponding contributions of electrons and holes to the electrical conductivity. The oscillations of the thermo-emf in a longitudinal magnetic field $\mathbf{H}\|C_3\|\vec{\nabla}\mathbf{T}$ are due to the oscillating hole contribution to the total thermo-emf. The values of the orbital n, of the spin s quantum numbers, and of the magnetic fields corresponding to the point at which the Landau level comes in contact with the Fermi surface of the holes, are shown, according to the data of Ref. 3, in Fig. 1 for bismuth. The moment at which a regular quantum tube breaks away from the Fermi level is accompanied by the absolute maximum (α_{33}) on the oscillating thermo-emf curve, which corresponds to the minimum of the hole contribution at this point.

The behavior of thermo-emf in a standard band is quantized, longitudinal, magnetic fields was analyzed theoretically in Ref. 4.

According to the results of Ref. 4, the corresponding oscillations turn out to be weak in the region of small fields (large values of n), but giant oscillations can occur in the region of large magnetic fields ($n \sim 1$); in this case the crossing of the Landau level and the Fermi level is accompanied by a deep minimum of the thermo-emf with a reversal of its sign. According to Ref. 4, similar oscillations can be observed if T_D—the Dingle temperature ($T_D \sim h/\tau$, where τ is the relaxation time of the charge carriers) is much smaller than T. The conditions of the experiment ensure that this inequality is fulfilled (which is not so rigorous for the $Bi_{0.97}Sb_{0.03}$ alloy), and the behavior of the oscillating part of the thermo-emf in the longitudinal field qualitatively corresponds to the predicted behavior.

As far as the Bi-Sb alloys are concerned, as follows from Ref. 5, an addition of small quantities of Sb to bismuth decreases the relaxation time of electrons by an order of magnitude as compared with the pure bismuth, and the relaxation time of the holes decreases even more markedly. Therefore, a decrease of the oscillation amplitude due to transition from bismuth to the Bi-Sb alloys in our view is attributable, first, to a decrease of the relative contribution of the holes to the total thermo-emf and, second, to an increase of the Dingle temperature as the main parameter of the theory.[4]

The oscillations of the thermoelectromotive force observed in the transverse magnetic fields up to 12 kOe ($\mathbf{H} \perp \vec{\nabla} \mathbf{T}$, C_3) are caused by quantization of the electron spectrum. The maximum oscillation amplitude with small quantum numbers in this case did not exceed 80% of the monotonic component.

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