THE CHANGE IN THE CONCENTRATION OF CURRENT CARRIERS IN BISMUTH DUE TO ADMIXTURES OF SELENIUM

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The galvanomagnetic properties of bismuth containing admixtures of selenium have been investigated. From the values of the Hall constant in high fields it was established that one selenium atom changes the electron concentration in bismuth by $3 \times 10^{-2} \pm 10\%$ electrons per atom.

BASED on the results of investigations of the de Haas-van Alphen effect,[1,2] cyclotron resonance,[3] the anomalous skin effect,[4] and of its galvanomagnetic properties,[5] bismuth can be classified as a metal with a closed Fermi surface. For this group of metals the asymptotic behavior of the resistance tensor in a magnetic field is determined by the relation between the number of electrons n_1 and of holes n_2. Owing to the small number of carriers (10^{-5} electrons per atom) small admixtures of other elements to bismuth exert a great influence on its magnetic and electrical properties, and as we have shown,[6] bismuth can be taken out of one group of metals (with $n_1 = n_2$) to another (with $n_1 \neq n_2$) by a relatively small number of admixtures. It seemed of interest to make a detailed study of the effect of small admixtures on the galvanomagnetic properties of bismuth and to estimate the change in the carrier concentration produced by the admixtures.

The initial bismuth of 99.998 purity ($r_{300°K}/r_{4.2°K} = 30$) was purified by zone refinement. After 20 — 30-fold recrystallization the ratio $r_{300°K}/r_{4.2°K}$ reached 260. Radioactive selenium was introduced as the impurity, and its concentration was monitored by the specimen's γ-ray intensity. Specimens with 0.5×10^{-4} and 3.05×10^{-4} selenium were studied. Single crystal specimens in the form of 2 — 2.5 mm diameter rods, 30 mm long, were prepared by Kapitza's method.[7] In all the investigations the trigonal axis of the specimens coincided with the specimen axis.

Figure 1a shows the dependence of $\Delta r_{HT}/r_{0T} = \{r_H(T) - r_0(T)\}/r_0(T)$ on the field for specimens Bi-1 (pure bismuth with $r_{300°K}/r_{4.2°K} = 260$) and Bi-2 (selenium admixture 0.5×10^{-4}, $r_{300°K}/r_{4.2°K} = 62$). While specimen Bi-1 shows the characteristic quadratic dependence of $\Delta r/r$ on field with the quantum oscillations, already observed by Shubnikov,[8] superimposed on it, the resistance of Bi-2 tends to saturation in the same effective fields ($H_{eff} = H_0 r_{300°K}/r_{4.2°K}$)*. As is well known,[9] if the number of electrons is not equal to the number of holes ($n_1 \neq n_2$), then in large fields the resistance tends to saturation, the value of which depends on the temperature, on the purity of the metal and on the direction of the magnetic field relative to the crystallographic axes, while the Hall "constant" tends to the constant value $R = 1/ec\,(n_1 - n_2)$.

Figure 2 shows the dependence of the Hall constant R on field for specimens Bi-2 (0.5×10^{-4} selenium) and Bi-3 (selenium admixture 3.05×10^{-4}). It can be seen that the Hall constant R tends to saturation for both specimens, but we did not observe any appreciable reduction in the anisotropy of R with respect to the direction of the magnetic field relative to the crystallographic axes. Having determined the values of n_1 and n_2 from the Hall constant for both specimens, the change in carrier concentration, produced by one atom of admixture, can be evaluated from their difference. If it is assumed that the Fermi surface for the holes changes little for these concentrations, then one atom of selenium produces a change of $3 \times 10^{-2} \pm 10\%$ electrons per atom in the electron concentration.[6]

*We should point out that a second quadratic dependence, $\Delta r/r = f(H)$,[9] should be observed for metals with an equal number of electrons and holes ($n_1 = n_2$) in sufficiently great magnetic fields. Figure 1b shows the ratio $\Delta r/r$ for Bi-1 as a function of H^2. Two regions of a quadratic dependence of $\Delta r/r$ on field are clearly seen.

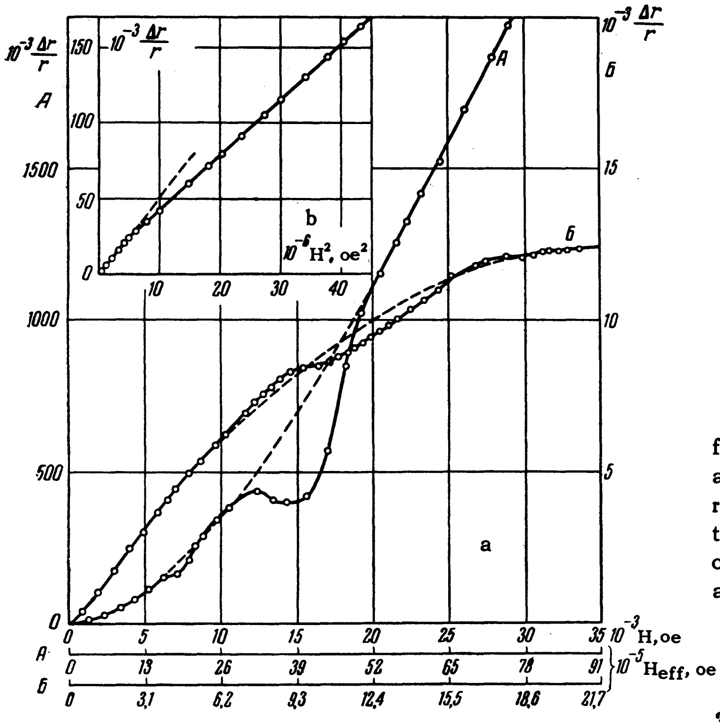

FIG. 1. a – The dependence of $\Delta r/r$ on the intensity of the magnetic field; T = 4.2°K, current parallel to the trigonal crystal axis, field parallel to the binary axis: curve A – for specimen Bi-1, curve B – for Bi-2; b – the dependence of $\Delta r/r$ on H^2 for specimen Bi-1 in the range of magnetic fields from 0 to 6.6 koe.

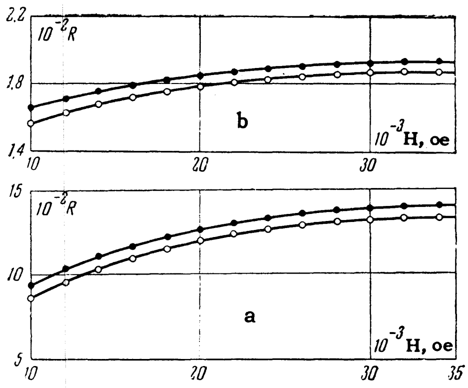

FIG. 2. The dependence of the Hall constant on magnetic field strength (T = 4.2°K): a – for specimen Bi-2 (0.5×10^{-4} Se) and b – for specimen Bi-3 (3.05×10^{-4} Se). Full circles – current parallel to the trigonal axis of the specimen, field parallel to the binary axis; open circles – current parallel to the trigonal axis of the specimen, field perpendicular to the binary axis.

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