Hall effect in rhenium single crystals at low temperatures in strong magnetic fields

E. I. Kondorskiĭ, O. S. Galkina, A. V. Cheremushkina, U. T. Usarov, and G. E. Chuprikov

Moscow State University

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The Hall effect has been studied in single crystals of rhenium at 4.2 °K in magnetic fields of 80 kOe. In plots of the Hall emf as a function of magnetic field in strong magnetic fields a break is observed and is considered to be the consequence of magnetic breakdown. The Hall constants have been determined in weak and strong magnetic fields as a function of the angle between the hexagonal crystal axis *c* and the magnetic-field direction. The number of hole-type carriers in rhenium has been determined. The value estimated is $n = 0.292$ per atom.

The Hall effect in rhenium has previously been measured in polycrystalline and monocrystalline samples [1,2] in the temperature range 77–300°K in magnetic fields up to 15 kOe. In the present article we report an experimental study of the Hall effect carried out by us in monocrystalline rhenium at 4.2°K in magnetic fields up to 80 kOe. It was of interest to compare the results obtained by us with the data on the Fermi-surface topology existing in the literature.[3,4]

Measurements of the Hall emf were carried out in a series of samples cut from monocrystalline rhenium with a resistivity ratio $\rho(293°K)/\rho(4.2°K) = 250$. The orientation of the crystals was determined by an x-ray diffraction method. The samples in the form of plates had dimensions $0.4 \times 2.5 \times 7$ mm and were cut in such a way that the normal to the plane of the plate along which the magnetic field H was directed lay in the $(10\bar{1}0)$ plane and formed various angles φ with the hexagonal crystal axis c (0, 15, 30, 45, 60, 75, and 90° with an accuracy of ±2°). In this same plane was located the long side of the plate along which the electric current was passed. In addition, we prepared a sample whose long side was parallel to the hexagonal axis c while the normal to the plane of the plate lay in the direction of the $\langle 11\bar{2}0\rangle$ axis. The technique of measuring the Hall emf has been described previously[5]. The magnetic field was produced by a superconducting solenoid in which magnetic fields up to 80 kOe could be obtained.

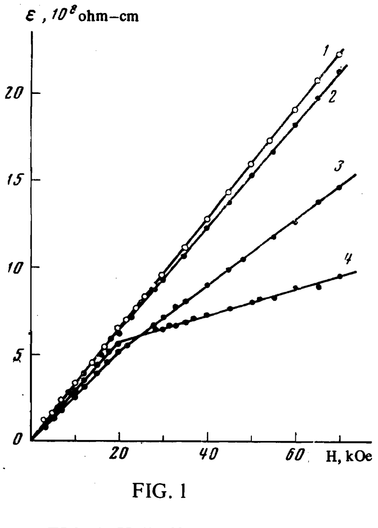

FIG. 1

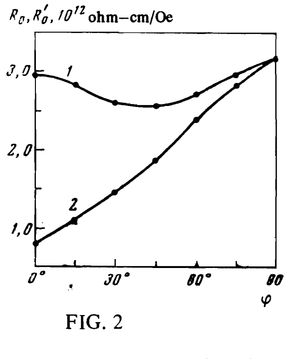

FIG. 2

FIG. 1. Hall effect in rhenium (per unit current density) as a function of external magnetic field H: 1–H⊥c (magnetic field directed along $\langle 10\bar{1}0\rangle$ direction), 2–H⊥c (magnetic field along $\langle 11\bar{2}0\rangle$ direction), 3–$\varphi = 45°$, 4–H⊥c.

FIG. 2. Hall constants R_0 and R_0' as a function of the angle φ between the magnetic field and the crystal axis c: curve 1–$R_0(\varphi)$, curve 2–$R_0'(\varphi)$.

In Fig. 1 we have shown the Hall emf ϵ (calculated per unit current density) as a function of the magnetic field strength H for three orientations of the magnetic field relative to the hexagonal crystal axis (0, 45, 90°) in the $(10\bar{1}0)$ plane. The current density vector **J** lay in the same plane. In plots of $\epsilon = f(H)$ in fields of the order of 20 kOe we observed a break; for $\varphi = 0°$ (φ is the angle between the hexagonal axis and the magnetic-field direction), the deviation from a straight line has its greatest value, then gradually decreases, and for $\varphi = 90°$ (H in the $\langle 11\bar{2}0\rangle$ direction) the break disappears. If the magnetic field is directed perpendicular to the c axis along the $\langle 10\bar{1}0\rangle$ direction, a small break is observed in the $\epsilon(H)$ lines. The observed break in strong magnetic fields may be the result of magnetic breakdown, a possibility which has been pointed out previously.[3,6,7] If the magnetic field is directed along the c axis ($\varphi = 0°$, $J \parallel \langle 10\bar{1}0\rangle$; in what follows the indices are given in reciprocal-lattice space), then as the result of magnetic breakdown open orbits will appear along the $\langle 10\bar{1}0\rangle$ direction at some field value H_k. This may lead to a change in the slope of the lines representing the function $\epsilon(H)$, such as is observed in the case under discussion.

If the magnetic field is along the $\langle 11\bar{2}0\rangle$ direction ($\varphi = 90°$), magnetic breakdown is possible between the sections of the Fermi surface which are tangent at a point lying on the AL axis (the degeneracy point). As the result of the breakdown, new closed orbits arise which lie in the plane ALMΓ. In this case a change in the slope of the $\epsilon(H)$ line is also possible. However, our measurements have shown that this change in slope is significantly less than in the case $\varphi = 0$. Apparently the main contribution to the Hall emf is provided by hole-type carriers, as was indicated by Mattheiss,[3] and therefore the addition, after breakdown, to the closed trajectory of additional segments lying in the electron surface does not substantially change the function $\epsilon(H)$. It can be seen from Fig. 1 that in the case in which the magnetic field is directed along the $\langle 10\bar{1}0\rangle$ axis, the break in the $\epsilon(H)$ plot is not observed. In this case, as follows from consideration of the Fermi surface corresponding to the electronic structure proposed by Mattheiss,[3] magnetic breakdown cannot occur.

Figure 2 shows the Hall constants R_0 and R_0' determined respectively in weak and strong magnetic fields as a function of the angle φ between the magnetic-field direction and the crystal axis c. On the basis of the suggestion made by Mattheiss[3] and confirmed by our experimental data that the principal current carriers in rhenium are holes, we can estimate from the value of R_0 the number of these carriers. The estimate leads to a value $n = 0.292$ per atom.

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