# Hall effect accompanying a static skin effect

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(Submitted 30 August 1984; resubmitted 30 January 1985)
Pis'ma Zh. Eksp. Teor. Fiz. **41**, No. 9, 376–378 (10 May 1985)

The Hall effect and the magnetoresistance of tungsten single crystals with $\rho_{293\mathrm{K}}/\rho_{4.2\mathrm{K}} = 80\,000$ have been measured at 4.2 K in magnetic fields up to 150 kOe. The results reveal that a static skin effect gives rise to an anomalously pronounced increase in the Hall coefficient.

Tungsten is a compensated metal, with equal numbers of electron and hole current carriers ($n_e = n_h$). All sheets of its Fermi surface are closed. In experiments on the Hall effect in pure tungsten single crystals we have observed that in magnetic fields up to 150 kOe the Hall coefficient $R_H = U_H c/JH$ ($U_H$ is the Hall voltage, $c$ is the plate thickness, $J$ is the current in the sample, and $H$ is the magnetic field) increases linearly by several factors of ten. According to the electron theory for the galvanomagnetic properties of metals, the Hall coefficient should be independent of the magnetic field. The suggestion that the reason for the field dependence of $R_H$ of tungsten might be some deviation from compensation ($n_e \neq n_h$) due to impurities and defects[1] does not correspond to reality, since the anomalous increase in $R_H$ not only does not fade but in fact becomes more pronounced as the purity of the crystal and the electron mean free path $l$ are increased.

A linear increase in $R_H(H)$ is observed under the condition $r \ll d < l$ ($d$ is the transverse dimension of the sample, and $r$ is the Larmor radius), so it might be suggested that the increase stems from an interaction of conduction electrons with the surface of the compensated metal, i.e., from a static skin effect.[2] The static skin effect can be summarized by saying that a direct current is not distributed uniformly in the volume of the sample and instead flows predominantly in a surface layer with a thickness on the order of $r$. The behavior of the magnetoresistance under conditions of a static skin effect ($r < d \leqslant l$) was studied experimentally in Refs. 3 and 4, and the results support the predictions of Ref. 2.

It can be expected that a significant nonuniformity of the current in the sample will also cause a nonuniform distribution of the Hall field in the sample. There has been no previous experimental study of the Hall effect under the conditions corresponding to a static skin effect. Measurements of the anisotropy, of the field depen-

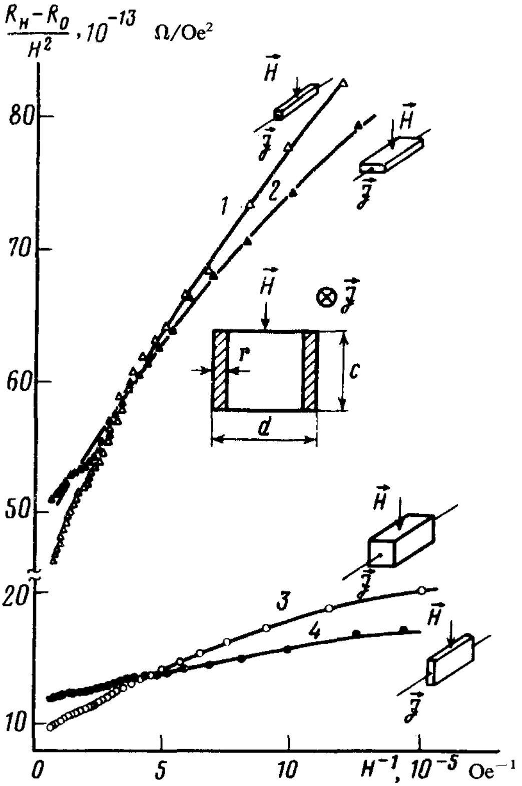

FIG. 1. Field dependence of the magnetoresistance of tungsten single crystals of various dimensions with (110) faces in the coordinates $(R_H - R_0)/H^2 = f(H^{-1})$ at $T = 4.2$ K. The distance between the potential contacts is 10 mm for all the samples. The inset shows the experimental geometry. 1, 2—Samples with relatively small dimensions $C$ (0.330 and 0.335 mm); 3, 4—relatively large values of $C$ (1.389 and 1.380 mm).

dence of the transverse magnetoresistance, and of the Hall effect of tungsten single crystals have accordingly been carried out[1)] at temperatures of 4.2 and 25 K in magnetic fields in the range 10–150 kOe. Three groups of samples with the same current orientation, $\mathbf{j} \| \langle 100 \rangle$, but differing in purity, transverse dimensions, and the crystallographic orientation of the faces were studied.

In the present letter we discuss only the results obtained from samples with "specular" (110) faces—with a specularity coefficient $q = 0.6$, $\rho_{293\mathrm{K}}/\rho_{4.2\mathrm{K}} = 80\,000$, $l = 3$ mm, and the following dimensions: 1) $1.389 \times 1.429 \times 12$ mm; 2) $1.380 \times 0.335 \times 12$ mm; 3) $0.330 \times 0.340 \times 12$ mm. The magnetoresistance and the Hall coefficient were measured by the standard dc method (with a regulated current). To eliminate the thermal emf and the transverse even voltage, both the electric current and the magnetic field were switched.

**Magnetoresistance.** Figure 1 shows the field dependence of the magnetoresistance, $\Delta R(H)/H^2$ ($\Delta R = R_H - R_0$), for samples with specular (110) faces. Samples with "diffuse" (100) faces ($q = 0.15$) have similar field dependence $\Delta R(H)/H^2$, but the values of $\Delta R$ are half as large. We find the following experimental facts:

1. *In strong magnetic fields, the curves of $\Delta R(H)$ do not show a simple $H^2$ dependence*; instead, they have an additional component which is approximately linear.

2. The value of the resistance in strong magnetic fields is determined not by the cross-sectional area of the sample but by the area of the lateral face parallel to **H**.

3. Using a procedure for separating the surface and volume resistances, we found that the resistivity of a surface layer with a thickness on the order of $r$, $\rho_{\|}$(140

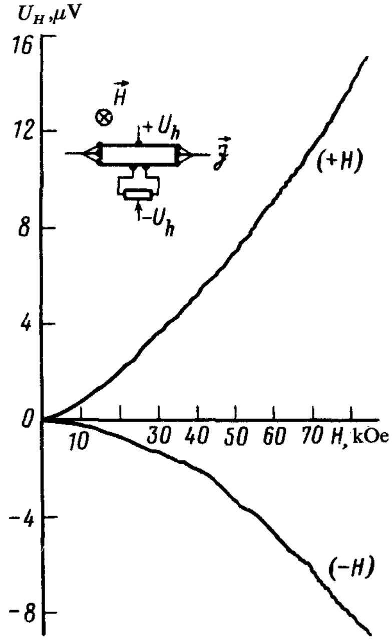

FIG. 2. Field dependence of the Hall voltage $U_H$ of a tungsten plate with (110) faces, measured by the three-point method (see the inset), for two (opposite) directions of the magnetic field, at $T = 4.2$ K. The current through the sample is 0.385 A.

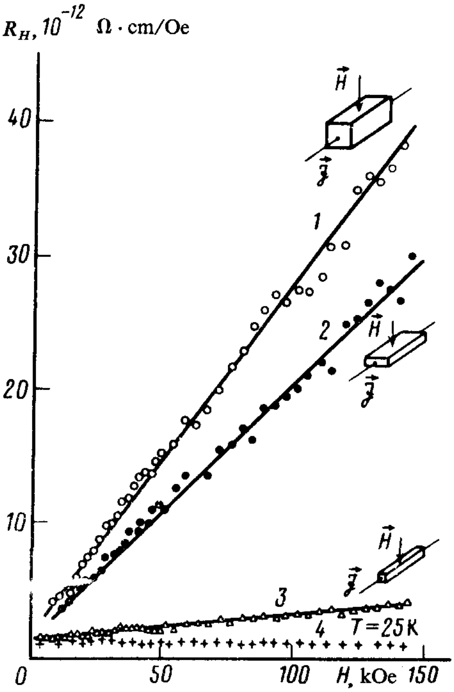

FIG. 3. Field dependence of the Hall coefficient $R_H(H)$ of tungsten single crystals of various dimensions with (110) faces at $T = 4.2$ K (curves 1, 2, 3) and $T = 25$ K (curve 4). Curves 4 coincide for all the samples. The insets near the curves show the experimental geometry.

kOe) $= 0.4 \times 10^{-6}$ Ω · cm, is four orders of magnitude lower than the volume resistance, $\rho_{\rm vol}$ (140 kOe) $= 3 \times 10^{-3}$ Ω · cm.

4. The value of $\Delta\rho$ is sensitive to the nature of the electron reflection from the surface. In both "dirty" and "clean" samples, but at $T = 25$ K, i.e., under the condition $l \ll d$, the features described above disappear, and we find $\Delta\rho(H) \sim H^2$.

These facts are evidence that a static skin effect is occurring in tungsten under these experimental conditions $(r \ll d < l)$.

**Hall effect.** Figures 2 and 3 show the results of measurements of the Hall coefficient of the same samples. From Fig. 2 we see that in strong magnetic fields the Hall voltage $U_H$ which is measured is odd in the magnetic field and shows a quadratic increase, while the Hall coefficient $R_H$ (Fig. 3) increases linearly with the field. At 4.2 K, $R_H$ (140 kOe) is 40 times $R_H$ (140 kOe) at $T = 25$ K for both the dirty and clean samples. The anomalous increase in $R_H(H)$ becomes more pronounced with increasing transverse dimensions of the samples, i.e., with increasing ratio $d/r$. A linear growth of $R_H$ is also observed in samples with diffuse faces. In both the dirty and clean samples, but at $T = 25$ K, we observe no anomalous increase in the Hall coefficient (Fig. 2).

In summary, it has been found experimentally for the first time that the Hall coefficient increases with increasing magnetic field and with increasing transverse dimensions of the samples under conditions corresponding to the static skin effect. This result may be evidence that the electric current flows in a skin layer in metallic crystals with $n_e = n_h$, regardless of the dimensions of the samples.

[1] The measurements were carried out in the International Laboratory of High Magnetic Fields and Low Temperatures, Wrocław, Polish People's Republic.

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Translated by Dave Parsons