THE FERMI SURFACE OF TUNGSTEN

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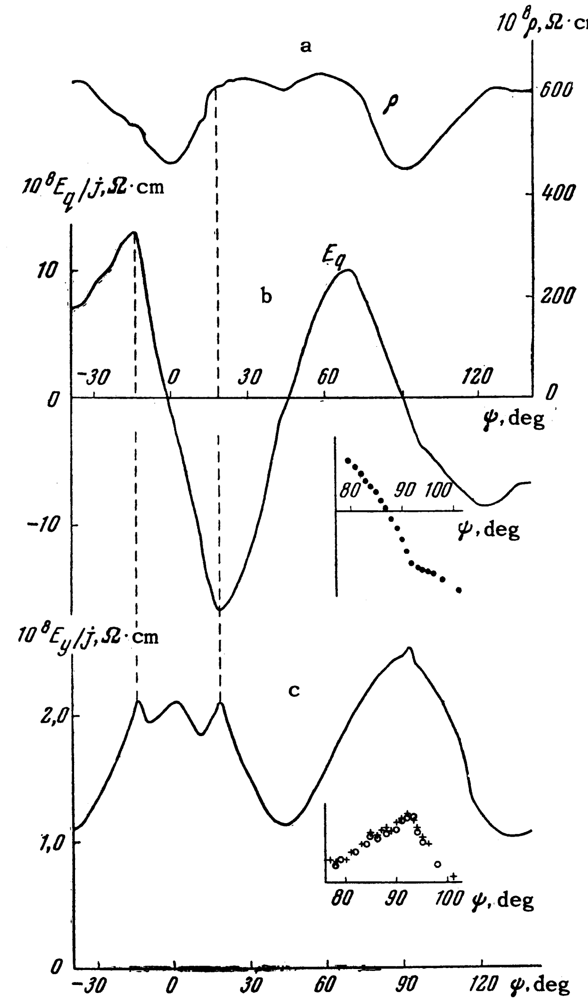
Measurement of galvanomagnetic phenomena on single crystals of pure tungsten at low temperatures has shown the presence of a strong anisotropy of the Hall effect and of the even transverse voltage with singularities in the form of rather sharp peaks.

WE have investigated galvanomagnetic phenomena [electrical resistance in a transverse field, the Hall effect, and the even (relative to the magnetic field) transverse voltage on Hall contacts] in single crystals of pure tungsten at a temperature of 4.2°K ($\rho_{290°K}/\rho_{4.2°K}$ = 13,000). The specimen had the shape of a cylinder of diameter 2.5 mm; the angle between the axis of the specimen and the [001] axis was 16°; the projection of the axis of the specimen on the (001) plane formed an angle of 20° with the [100] axis. The specimen was obtained by non-crucible zone melting with the zone heated by electron bombardment, using apparatus described previously (see [1]). Contacts of platinum wire of 0.1-mm diameter were welded by a spark method. In all other respects, the measurements and treatment of the results were the same as those reported by one of the authors (see [2]). The decrease in the voltage on the Hall contacts, associated with the inaccuracy of their location, did not exceed 10 per cent of the observed values of the even transverse voltage and was excluded in the reduction of the results.

The dependences of the resistance, even voltage, and Hall effect on the direction of the magnetic field (which rotates in a plane normal to the axis of the specimen) are shown in the drawing. The dependence of the resistance on the field direction and the quadratic character of the growth in resistance with the field for all directions were similar to those obtained by Fawcett;[3] in particular, small projections were observed on the curve of the angular dependence of the resistance (for $\psi = -14°$ and $\psi = +18°$). However, the angular dependences of the Hall effect and especially the even transverse voltage, which were not investigated in tungsten under the identical conditions, have a more complicated character than for the resistance. The weak projections on the



Rotation diagrams of the resistance ρ (a), the even transverse field (b), and the Hall-field component normal to the magnetic field H (c); the latter two quantities have been divided by the current density j. The angle ψ is measured from the direction H ‖ (100; H = 7 kOe. (The vertical dashed lines correspond to $\psi = -14°$ and $\psi = +18°$.)

curve of the angular dependence of the resistance correspond to rather sharp maxima in the Hall effect and in the even transverse voltage. These singularities correspond to the passage of the magnetic field through two-fold planes ($0\bar{1}1$) and (011) (ψ is equal to $-14°$ and $+18°$); furthermore, hardly noticeable but well reproducible singularities of the Hall effect and the even transverse voltage correspond to the ($\bar{1}01$) plane ($\psi = +93°$).

Experimental studies of the even transverse voltages, carried out recently on Sn,[4] Cu,[5] and Ga[6] have shown that the singularities of the rotational diagrams of this effect, which have the form of sharp peaks, are associated with the appearance of open trajectories of the current carriers (the appearance of a smooth component of this voltage is associated with the equality of the number of electrons and holes[7]). The appearance of open trajectories leads also to singularities of the Hall effect.[2] These results suggest that the singularities observed by us in tungsten can be connected with the open trajectories of isolated directions (with small density of states) parallel to the binary axes, or with the appearance of closed trajectories that are strongly elongated in these directions. The insignificance of the singularities of the resistance does not contradict the possibility of the existence of open trajectories; a similar phenomenon was observed in specimens of tin at certain orientations—insignificant singularities of the resistance associated with open trajectories with a small density of states corresponded to sharp singularities of the Hall effect and the even voltage (see Fig. 2 in [2]). The absence of even-voltage singularities for a magnetic field parallel to the ($\bar{1}10$) and (110) planes ($\psi = \pm 45°$) can explain the fact that the direction of openness (or the direction of greatest extension of closed trajectories) makes in this case an angle close to 90° with the direction of the current in the specimen, and under such conditions the even transverse voltage is small.[4,5] The directions corresponding to the (101) and ($\bar{1}01$) planes (ψ equal to 86 and 93°), the angle between which is equal to 7° at most, are also unfavorable for observation of singularities for the available orientations of the specimen and not very large effective field (the corresponding parts of the curves are shown in drawings b and c in an enlarged scale). It must be noted that it is precisely binary directions which correspond to open Fermi surfaces in the model obtained for tungsten in the approximation of orthogonalized plane waves.[3]

On the basis of the results obtained, it is established tentatively that the Fermi surface of tungsten is open. However, the complicated character of the anisotropy of the Hall effect and the even transverse field compels us to think that the conclusions as to the absence of open trajectories in tungsten[3] must not be regarded as final.

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