# FEATURES OF GALVANOMAGNETIC PROPERTIES OF ANTIMONY

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We report here the results of investigations of the galvanomagnetic properties of antimony in transverse magnetic fields up to 100 kOe at temperatures 4.2, 20.4, and 77°K.

Samples with dimensions (1 - 1.5) x (1 - 1.5) x (10 - 12) mm were cut by electroerosion from single-crystal ingots of Su-0000 antimony, and then annealed at 400°C in a helium atmosphere. The annealing time was 24 - 30 hrs. The measurements were made both in pulsed and in stationary magnetic fields. The maximum value of the constant field did not exceed 20 kOe. The time dependence of the pulsed magnetic field was aperiodic. The duration of the leading edge of the pulse did not exceed 5 msec, and that of the trailing edge 30 msec; at a constant field amplitude, the duration could be varied by smoothly changing the parameters of the capacitor bank used to supply the energy.

For measurements in pulsed magnetic fields, the sensitivity of the system [1] was chosen such that the output signal due to stray pickup was zero in the absence of current through the sample.

The dependence of the voltage drop on the magnetic field $U_I(H)$ was investigated in sample Sb-2a, so oriented that the current I was parallel to $C_2$ and H was in the $C_1C_3$ plane, at different values of the current I through the sample. ($C_1$, $C_2$, and $C_3$ are the bisector, binary, and trigonal axes, respectively.)

At T = 20.4°K and for H nearly parallel to $C_3$ ($H \parallel C_3$ corresponds to the maximum on the rotation diagram [2]), it was observed that when $I > 0.4$ A the dependence of the voltage drop on the magnetic field is not the same on the leading and trailing edges of the pulse, i.e., hysteresis takes place (Fig. 1, curves 1 and 2). The shape of the hysteresis "loop" depends strongly on the electric current, and at certain values of the current the "loop" turns into a "figure-8." The complicated and tangled texture observed for the set of curves $U_I(H)$ becomes perfectly mamageable after these curves are transformed into a family of current-voltage characteristics $U_H(I)$ (Fig. 2, the $U_H(I)$ curves were plotted for the leading edge of the pulse). At H = 31 kOe, the $U_H(I)$ plot is linear if $I < 0.75$ A. When I = 0.75 A, the derivative dU/dI increases sharply, and then vanishes (I = 0.8 A) and becomes negative with further increase of current. With increasing magnetic field, the current-voltage characteristic changes and a minimum appears (H = 90 kOe, $I \simeq 0.87$ A), after which the derivative dU/dI again becomes positive. When H = 100 kOe, the $U_H(I)$ plot has an S-shape (Fig. 2).

If the magnetic field direction deviates by more than ±20° from the trigonal axis, the foregoing anomalies are not observed, Ohm's law is satisfied, and the dependence of the resistance on the magnetic field is close to quadratic [2].

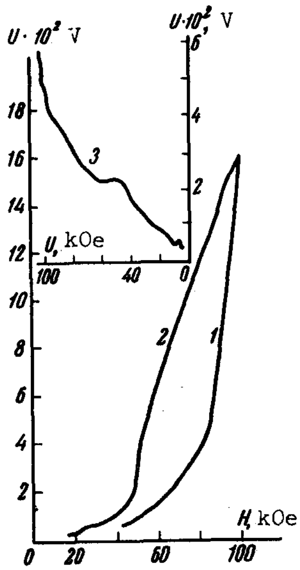


Fig. 1. Dependence of the voltage drop on the magnetic field. 1 - Sb-2a, leading edge; 2 - Sb-2a, trailing edge; 3 - Sb-4a, leading edge; T = 20.4°K; I = 1.2 A.

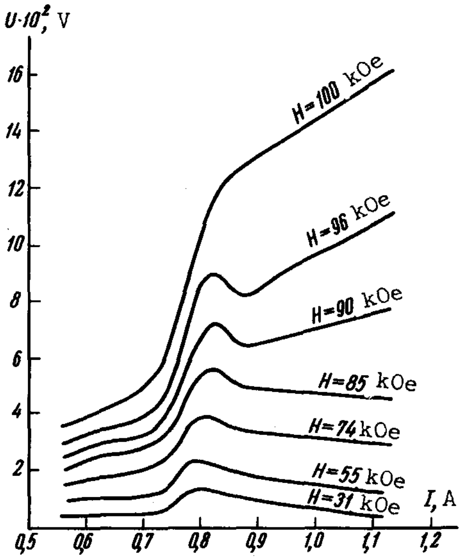


Fig. 2. Family of current-voltage characteristics for sample Sb-2a at T = 20.4°K.

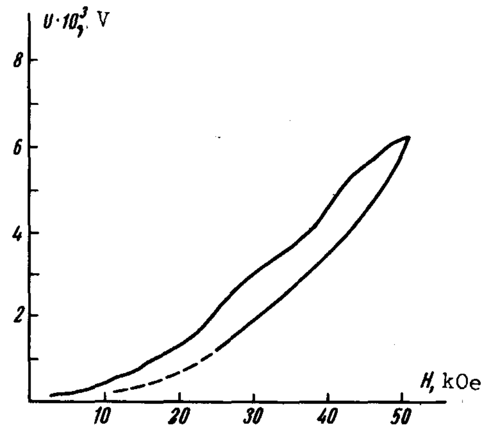


Fig. 3. Dependence of the voltage drop on the magnetic field for sample Sb-2a, T = 77°K, I = 1 A.

Satisfaction of Ohm's law and a near-quadratic dependence of the magnetoresistance on the field take place at T = 4.2°K for all magnetic-field directions in the $C_1C_3$ plane without exception. Experiments performed in helium vapor have shown that the anomalies begin to appear in the region of 10°K.

At 77°K, for field directions close to $C_3$, there is also hysteresis of the $U_I(H)$ dependence. In addition, oscillations have been observed on the trailing edge of the curves (Fig. 3). The investigation of these oscillations entails great difficulties, since their amplitude decreases from pulse to pulse.

A careful study of the voltage-drop curves on the trailing edge of the pulse at hydrogen temperature shows that in the 20 kOe region there are also oscillations of $U_I(H)$ (Fig. 1, curve 2). A study of these oscillations, naturally, must be carried out without changing the experimental conditions, i.e., without lowering the maximum value of the magnetic field. To increase the resolution in weak fields it is necessary here to increase the sensitivity of the system, giving rise to a large error due to the increased stray-pickup signal. Assuming that the oscillations at T = 77 and 20.4°K are of the same nature and taking into account the foregoing experimental difficulties, we attempted to find a sample for which the oscillations of $U_I(H)$ at T = 20.4°K would appear in the 20 - 80 kOe region. Sample Sb-4a (I $\parallel$ $C_1$ and H in the $C_2C_3$ plane) just met these requirements (Fig. 1, curve 3). Variation of the amplitude and of the duration of the magnetic-field pulse shows that the oscillations of the voltage drop are oscillations in time, and their frequency increases with increasing maximum value of the magnetic field. It is interesting to note that the oscillations, as well as the hysteresis, take place in sample Sb-4a at field directions close to the trigonal axis. When T = 77°K, the oscillations do not last long, just as in the case of Sb-2a. No anomalous voltage drop was observed at T = 4.2°K.

We also measured the volt-ampere characteristics and the $U_{I<1\,A}(H)$ dependence in stationary fields not exceeding 20 kOe. During the measurement of the current-voltage characteristics, the maximum current through the sample was 7 A, and a current pulse of duration 0.1 sec was shaped with the aid of an RC network. No deviations from Ohm's law, hysteresis, or voltage-drop oscillations were observed in these experiments.

The observed anomalies of the voltage drop are connected with Joule heat released in the sample. This is evidenced by the following facts: 1) anisotropy of the effects (hysteresis, deviation from Ohm's law, and oscillations appear at the minimum of the rotation diagram but not at the maximum, where the voltage drop is several times larger); 2) absence of anomalies at 4.2°K; 3) linearity of the current-voltage characteristics in stationary magnetic fields. (The amount of Joule heat released in this case is several times larger than in experiments with pulsed magnetic fields up to 100 kOe.)

It can be assumed, first of all, that the deviation from Ohm's law and the oscillations of the voltage drop are related phenomena. Our estimates allow us to state that they are not connected with the Esaki effect - the drift velocity of the carriers under the experimental conditions is smaller by three orders of magnitude than the sound velocity in the antimony.

One of the possible causes of the observed phenomena may be overheating of the electron gas in crossed electric and magnetic fields [3]. However, no suitable estimates can be made at present, in view of the lack of a theory of nonlinear effects in semimetals in crossed fields and in view of the insufficient amount of experimental data.

On the other hand, the results of the present investigation are similar to some degree to the results of the experiment aimed at observing helicons in sodium [4]. In both experiments, the frequency of the oscillations increases with increasing magnetic field and the attenuation decreases with increasing relaxation time. (These effects were not observed in the non-annealed samples described in this paper.) As is well known, the helicons do not propagate in a metal having an equal number of electrons and holes (see, e.g., [5]). Nonetheless, plasma waves of other types can be excited in these metals [6].

On the basis of the results of experiments in stationary fields, we are inclined to assume that the overheating of the electron gas can hardly be the cause of the anomalies.

For a final clarification of the nature of the observed effects we shall set up in the nearest future experiments which exclude the possibility of overheating of the electron gas.

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# MEASUREMENT OF THE THRESHOLD PARAMETERS FOR THE BREAKDOWN OF LIQUID AND GASEOUS HELIUM BY A LASER BEAM

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The phenomenon of "laser spark" in media that are normally transparent at optical frequencies has been described in many papers (see the review [1]). The gas becomes ionized under these conditions if the radiation intensity reaches a certain threshold value. Many authors describe the results of measurements of the threshold parameters for the breakdown of gases at different pressures [2,3].

For a given gas, the threshold radiation intensity is determined by its density and should apparently not depend on the temperature (at least from helium to room temperature). This makes it possible, when investigating the breakdown, to work with a dense gas at low temperatures, instead of making the medium denser by increasing its pressure at room temperature.

We have measured the threshold radiation power for the breakdown of helium at low temperatures.