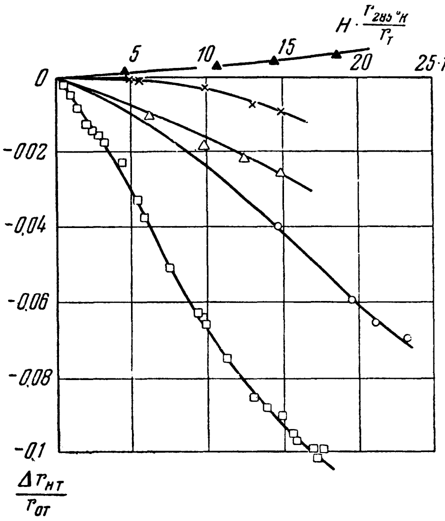

FIG. 8. Sample Au–3: ▲–T=8 °K; X–T= 4.2 °K; Δ–T=1.61 °K; O–T= 1.36 °K and □ –T=0.14 °K.

and lg T seem to be associated with different laws from those which govern the effect described in the preceding sentence. Similar observations have been made by other authors.[2,3,4]

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[1] B. Keesom, *Helium*, IIL, Moscow (1949) p. 201 (Russian translation).

[2] A. I. Croft, Phil. Mag. **44**, 289 (1953).

[3] E. Mendoza and I. G. Thomas, Proceedings of the International Conference on Low Temperature Physics (1951) p. 39.

[4] Guy K. White, Canad. J. Phys. 33, 119 (1955).

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SOVIET PHYSICS JETP VOLUME 4, NUMBER 6 JULY, 1956

Critical Currents in Superconducting Tin Films

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Measurements of critical currents in tin films were performed, using a pulse method with specimens in the shape of a disk. These measurements were made in the temperature region $\Delta T = T_c - T = 0.5$ °K for a range in thickness between 6.9×10^{-6} and 6.4×10^{-5} cm. For four of the specimens the external critical magnetic fields parallel to the film surface were also measured. For one film, in the form of a flat ring 2×10^{-5} cm in thickness, critical currents were measured over the temperature interval from 3.7 to 1.6 °K from the damping of a current induced in the ring.

THE problem of investigating critical currents in films has been taken as the subject of a comparatively small number of papers. The first results, obtained by Shal'nikov[1], showed Silsbee's rule to be completely disobeyed in thin films. This result was seen to be in qualitative agreement with the results of the theoretical work of London, in which it was concluded that as the external magnetic field parallel to the film increases, a decrease in the magnitude of the critical currents for the film should be observed. Quantitative verification of the experimental data was, however, impeded by the fact that in investigating critical currents in thin superconductors it was usually found difficult to determine the magnetic field at the surface of the superconductor due to the current. In addition, it was possible to assume that some of the experimental results would show reduced values for the critical currents due to the influence of heating and boundary effects. It seemed, therefore, of interest to conduct an investigation of critical currents in films under somewhat more favorable experimental conditions.

An attempt has been made by authors to obtain values of the critical current for a plane film in the form of a disk. The current was introduced through a lead perpendicular to the plane of the disk and was taken out at its periphery, For this case the field at the surface of the disk due to the current has a configuration analogous to that of the field surrounding a cylindrical conductor; i.e., $H = 2I/R$, where r is the distance from the center to the point at which the field at the surface of the disk due to the current is measured.

The films were prepared by sputtering tin in the

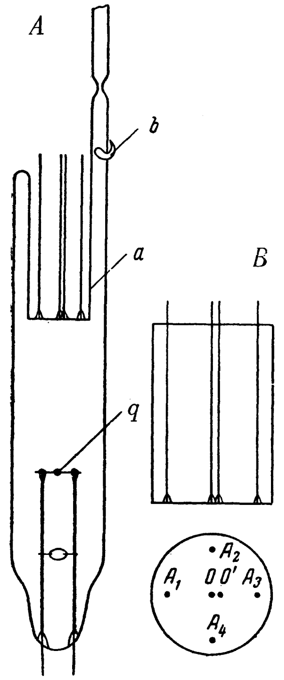

FIG. 1. Apparatus for measuring critical currents by the pulse method. A—general layout of the apparatus: q—sputtering source, a—glass vessel onto which film was sputtered, b—glass spur for admission of liquid helium to the system; B—glass vessel and distribution of leads on its surface: O—central current lead, A_1, A_2, A_3, A_4—peripheral current leads, O'—potential lead. Potential difference measured between O' and one of peripheral leads.

glass system shown in Fig. 1. The tin film was deposited from a point source under high vacuum. The sputtering was done at the temperature of liquid nitrogen under the vacuum produced by a diffusion pump; the system was then warmed up to room temperature, sealed off, and placed in the Dewar flask.

In view of the possibility that the accuracy of the results might be affected by heating in the connecting wires, we made use of specially-prepared superconducting leads and of a pulse method; the film, moreover, was placed in direct contact with liquid helium during the measurements.

To establish direct contact between the film and the liquid helium, the thin-walled glass "spur" b shown in Fig. 1 was broken off with the aid of a rod passing through a sliding seal in the Dewar cap and the system was filled with liquid helium.

The superconducting leads were prepared by drawing through a die a 0.3×0.9 mm platinum capillary through which was run a tantalum wire 0.3 mm in diameter. After drawing, the wire was baked out under vacuum and then sealed into the apparatus.

The current pulses through the specimen were generated by applying a voltage source across a circuit consisting principally of a circuit-breaking relay, a choke, a variable resistance, and the specimen under study. The current and voltage pulses were recorded on a Shleifov oscillograph. The circuit was driven by a 220 V laboratory battery. By varying the circuit parameters it was possible to obtain pulses of various durations and amplitudes (the usual pulse length was about 0.1 sec).

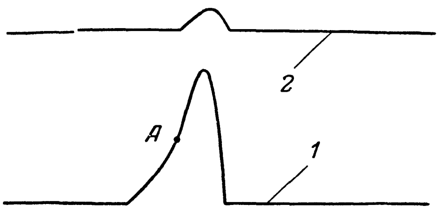

FIG. 2. Oscillograms: 1—current pulse flowing through film, and 2—potential difference between O' and A_3 .

Figure 2 shows an oscillograph recording of the voltage and current pulses. It is evident from these oscillograms that the voltage pulse begins at some definite value for the current flowing through the specimen (point A in Fig. 2). This value is that of the critical current for the given experimental conditions.

To verify the radial character of the distribution of current over the film, the critical currents were measured with an apparatus incorporating three potential leads placed at different distances from the center lead. The linear dependence obtained for $I_c(r)$ testifies to the nearly radial current distribution and to the small effect of heating during the pulse within that part of the film lying between the central and potential leads.

Measurements of critical currents in the films were conducted over the temperature interval $\Delta T \approx 0.5\,^\circ\mathrm{K}$. The films thus investigated ranged in thickness from 6.9×10^{-6} to 6.4×10^{-5} cm; more than 20 films were studied. For four of the films, in addition to the fields H_{cI} of the critical currents, measurements were made on the external magnetic fields parallel to the film surface. These results for H_c agree satisfactorily with the data obtained by other authors.

Figure 3 shows the dependence of H_{cI} and H_c upon temperature for a film of thickness $d = 3.27 \times 10^{-5}$ cm. In Fig. 4 the variation of H_{cI} with ΔT is shown on a logarithmic scale, for films of various thicknesses. Figure 5 shows the dependence, also on a logarithmic scale, of H_{cI} upon the thickness d, for two values of the temperature.

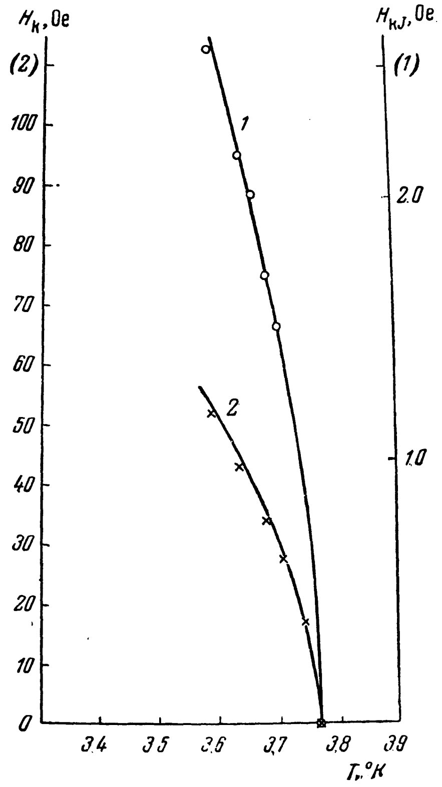

FIG. 3. Dependence of the critical current field and the external magnetic field parallel to the film upon temperature. Film thickness $d=3.27 \times 10^{-6}$ cm. 1—curve for critical current field, 2—curve for critical field parallel to film surface.

The observed dependence $H_{cJ}(\Delta T)$ can be represented in the form $H_{cJ} \sim \Delta T^n$, where $n < 1$ (approximate evaluation yields $n \approx 0.6$). The dependence of H_c upon d may be approximately described as linear.

In order to verify the results obtained with pulses a study of the critical current in tin films was made using a different method. A film in the form of a flat ring of width $2a = 1.5$ mm was deposited under vacuum from a point source onto a flat, polished glass surface without leads. At the lowest helium temperature which could be reached an undamped current was induced in the film by means of a magnetic field. The magnitude of the critical current was determined by measuring the magnetic field of the current flowing in the plane ring. Measurements were continued as the film warmed up, using a ballistic method whose sensitivity was improved by a factor of about 100 through the use of a photo-relay. The temperature was measured with a phosphor-bronze thermometer, contact being made with the helium inside the apparatus through a thick (diameter 1mm.) platinum rod. The galvanometer deflection, proportional to the change in magnetic flux $\Delta\Phi$ through the flat measuring coil, was subsequently calibrated in a separate experiment, in which current from an external source was passed through an open copper ring of the same dimensions as the ring of superconducting film. The advantage of this method lies in the absence of contacts and the heating they cause in the film. Substantial difficulties are encountered, however, in obtaining numerical values for the fields due to the critical currents determined in this manner.

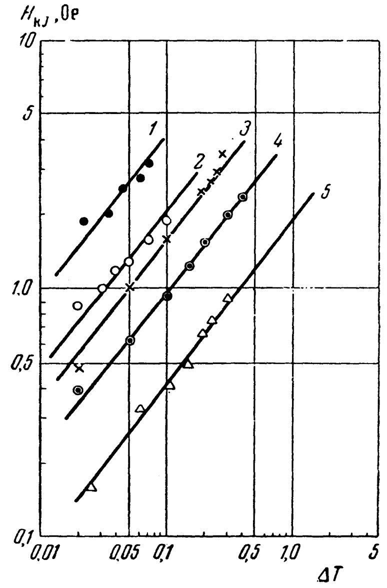

FIG. 4. Dependence of critical current fields upon temperature for tin films of varying thickness. 1—$d=6.4\times10^{-5}$, 2—$d=3.3\times10^{-5}$, 3—$d=2.29\times10^{-5}$, 4—$d=9.85\times10^{-6}$, 5—$d=6.9\times10^{-6}$ cm.

This method made it possible to carry out measurements of the critical current for a film 2×10^{-5} cm in thickness over the temperature interval from 1.6 to 3.7° K. The curve obtained for $I_c(T)$ has a break at $T \approx 3$°K. Near T_c the behavior of the $I_c(T)$ curve obtained in this manner is in approximate accordance with the results of our pulse measurements.*

Consideration of the results of this experiment shows that the fields due to the critical currents obtained by the first method agree** in order of magnitude with the results of the Landau-Ginzberg theory.[2] The temperature dependence of the critical current fields, however, is not in accordance

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*It should be mentioned that for a film 2×10^{-5} cm in thickness at $T=1.6$° K the critical current was found to be 10.8 a.

**The agreement is best in the vicinity of T_c.

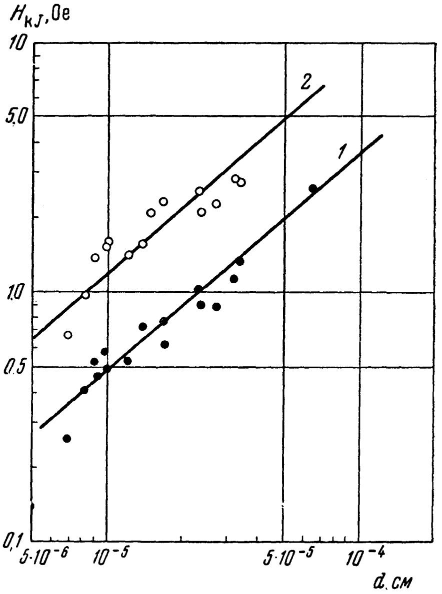

FIG. 5. Dependence of critical current fields upon film thickness for two temperatures. 1—$\Delta T = T_c - T$ = 0.05 ° K, 2—ΔT= 0.2 °K.

with the theoretical preduction; this may be due to inapplicability of the theoretical formulas derived for thin films to the film thicknesses we have been studying. For the future, a similar investigation of critical currents in films, covering a greater range of thicknesses and temperatures, seems to be in order.

1 A. L. Shal'nikov, J. Exptl. Theoret. Phys. (U.S.S.R.) 10, 630 (1940).

2 V. L. Ginzburg and L. D. Landau, J. Exptl. Theoret. Phys. (U.S.S.R.) 20, 1064 (1950).

Translated by S. D. Elliott
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Investigation of the Effect of Pressure on the Galvanomagnetic Properties of Tellurium at Low Temperatures

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An investigation has been conducted of the galvanomagnetic properties of tellurium and of the effect of hydrostatic pressure on these properties for samples of tellurium of various purity in the temperature range 1.4°–4.2°K, 14°–20°K and 60°–78° K and in magnetic fields as high as 2.0×10^4 oersteds.

THE existence of a minimum in the curve of the dependence of the electrical resistance on the intensity of the magnetic field at liquid helium temperatures has been confirmed. It was found that the depth of the minimum is a function of the impurity content and that it increases under hydrostatic pressure. The appearance of the minimum in the curves of the dependence of the electrical resistivity on the intensity of the magnetic field is attributed to the Zeeman splitting of impurity levels.

During an investigation of the galvanomagnetic properties of tellurium at the temperatures of liquid helium, Chentsov[1] discovered an anomalous behavior of the dependence of the electrical resistivity of tellurium on the intensity of the applied magnetic field. As the magnetic field was increased, the resistivity of tellurium decreased, passed through a minimum and then increased again. The effect increased as the temperature was lowered; it depended on the orientation of the samples in the field. Because the reason for the existence of the minimum remained unknown, it became interesting to investigate this effect in greater detail in samples of tellurium of varying degrees of purity, and also to investigate the way the effect