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Galvanomagnetic Properties of Gold

N. E. ALEKSEEVSKII AND IU. P. GAIDUKOV
Institute for Physics Problems, Academy of Sciences, USSR

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The dependence of the electrical conductivity on temperature of four samples of gold of various purities has been investigated in the temperature range 0.05°–20.4°K. In this temperature range observations were also made of the dependence of the electrical conductivity on the magnetic field.

THE present communication is concerned with a study of the anomalous behavior of the resistivity of gold at low and very low temperatures. In spite of the fact, that a considerable amount of work has been devoted to this problem, there still remain many aspects of this phenomenon which have not been explained.

We have conducted experiments on the dependence of the resistivity of gold on temperature in the range 20.4° to 0.05°K. We have also observed the dependence of the resistivity on the magnetic field in this same temperature interval. Temperatures above 4.2°K were obtained by means of the method proposed by Keesom[1]. Temperatures below 1.4°K were attained by the adiabatic demagnetization of iron-ammonium alum. Figure 1 shows the apparatus, adapted by us for the observation of the relation between electrical resistance and magnetic field in the region of very low temperatures. A glass ampoule contained a block of alum, 1, into which strips of copper were pressed. A copper "cold conductor" was soldered to these strips. The "cold conductor" was terminated by a wider portion, 3, onto which the samples to be investigated, 4, were attached by means of BF–2 cement. During demagnetization, the "exchange gas" is absorbed on the alum block and the "dessicating" salt, 5, thus breaking thermal contact between the helium bath and the internal parts of the ampoule. At this point the apparatus was transposed in such a way, that the alum was inserted into a magnetic screen 6, made of Armco iron, while the sample of gold found itself in a homogeneous magnetic field.

The samples attained the same temperatures as the alum block. The validity of this assumption was proven in separate experiments.

Four samples of gold were investigated. Some of the characteristics of the samples are shown in the accompanying Table.

The potential leads were either cut out of the sample itself (for the case of flat samples) or (for the case of wires) they were prepared from the same material as the sample and were brazed to the samples with an oxygen torch.

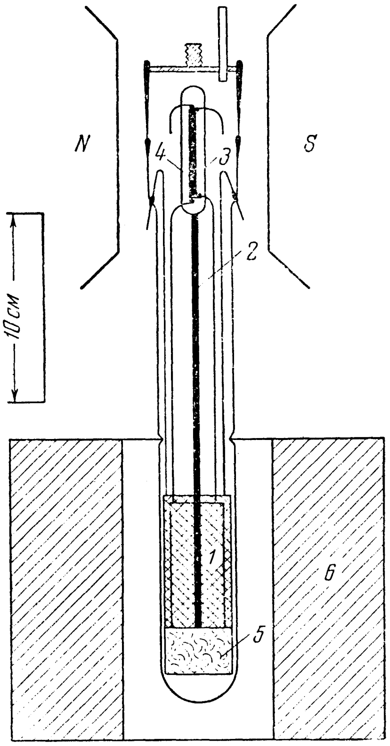

FIG. 1.

Figure 2 presents the results of the measurement of the resistance, at various temperatures of four samples, plotted on semilogarithmic coordinates. The resistance of three samples showed an anomalous behavior. It follows that for the samples which have a minimum in the $r(T)$ curve, the resistance is independent of the temperature in the region 0.05°–0.3° K, and at higher temperatures the resistance becomes a linear function of lg T.*

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*This portion of the $r(T)$ curve can be represented satisfactorily by the equation $r = A \lg (T/T_{\min}) / (1 + B \lg (T/T_{\min}))$ where A and B are constants and $T_{\min}$ is the temperature of the resistance minimum.

TABLE

№	purity rating in %	$\frac{r_{295° K}}{r_{min}}$	Fe impurity in %	Temperature Curve	$\frac{r_0 - r_{min}}{r_{min}}$ in %
Au-1	99.99	92	—	Anomalous	13.2
Au-2	99.999 Hilger	159	0.0001	Anomalous	11.3
Au-3	99.99	9.8	0.001	Anomalous	7.2
Au-4	99.99	172	—	Normal	0

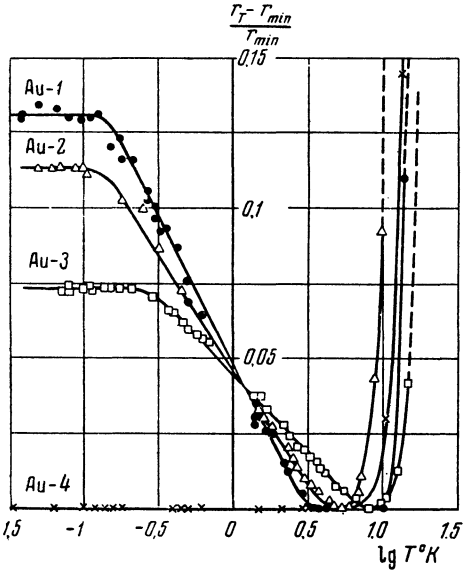

FIG. 2.

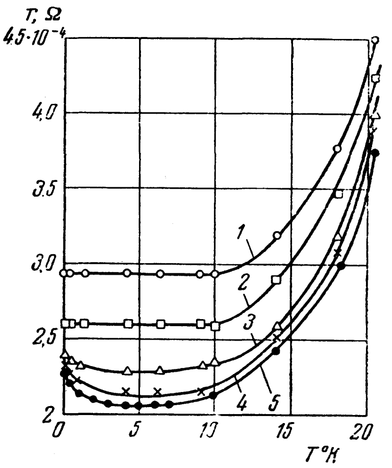

FIG. 3. Au–2; 1–H= 14 Koe; 2–H = 10 Koe; 3–H = 6 Koe; 4–H = 3 Koe, and 5–H = 0.

If, analogously, the dependence of the resistance on temperature in a magnetic field is determined, it is found that as the intensity of the field is increased, the depth of the resistance minimum decreases and for a certain value of the field the minimum disappears completely. Figure 3 illustrates this situation. The results shown are for sample Au–2; similar results were, however, found for samples Au–1 and Au–3.

If we observe the dependence on the magnetic field of the quantity

$$\Delta r = \frac{(r_0 - r_{min})}{r_{min}},$$

where r_0 is the resistance in the saturation region at very low temperatures and r_{min} is the minimum resistance of the sample, it is found, that for all three samples (Au–1, Au–2, and Au–3) this quantity approaches zero for $H \approx 8$ K oe (Fig. 4). Preliminary measurements of the Hall constant for Au–1 have shown that for this field intensity the Hall constant increases almost discontinuously, where the magnitude of the increase depends on the temperature.

In Figs. 5–8, we show the dependence of the resistance on the magnetic field for various temperatures. From these drawings it is evident, that, while for Au–4 and curves of $r(H)$, taken at various temperatures can be practically superimposed on each other, this is not true for Au–1, Au–2 and Au–3. Thus for Au–3, a decrease of resistance is observed in a magnetic field up to the same high fields intensities, i.e., $H \approx 23$Koe. On the other hand, for Au–1 the resistance decreases for small fields but increases for larger fields.

We must admit that it is hard to believe the hypothesis which has been suggested by a number of authors, namely, that the inclusion of very small amounts of ferromagnetic impurities in gold brings about a decrease in the overall resistance of the samples. We are inclined to reject this hypothesis on the grounds that the spectroscopic analysis which was described above, showed that even in Au–3 (which had the highest Fe content) the Fe concentration does not exceed 0.001 percent. Furthermore magnetic measurements which were conducted on sample Au–1 showed that the sample remains diamagnetic even at liquid He temperatures. It can be safely said, however, that the anomalous behavior of gold in the low temperature region is

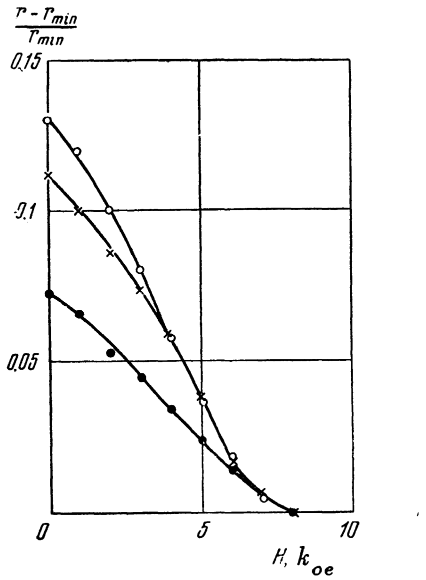

FIG. 4. O-Au–1:X–Au–2 and ●–Au3.

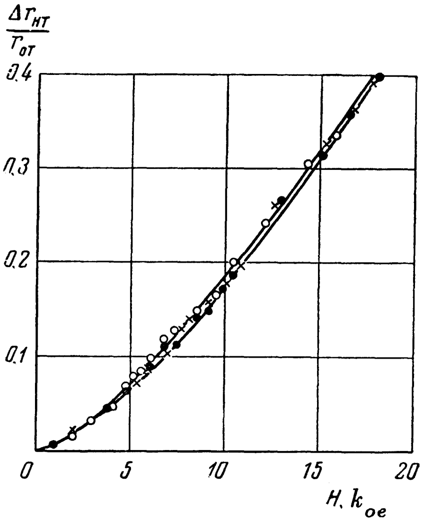

FIG. 5. SampleAu–4:O–T=4.2°K; X–T= 1.4 K; ●–T= 0.05° K.

caused, apparently, by extremely small concentrations of impurities, in the presence of which the dependence of the magnitude of the effect on the impurity concentration can be visualized from the curves which have maxima. We do not exclude the possibility that the impurities which are responsible for the anomalous behavior of the resistivity of gols are metals with unfilled d–shells.

Although for a final explanation of the cause of the anomalous behavior of the resistivity of gold further experimental investigation of the effect are necessary, on the basis of the experiments which have been performed it is possible to say that the magnitude of the increase of the resistance when

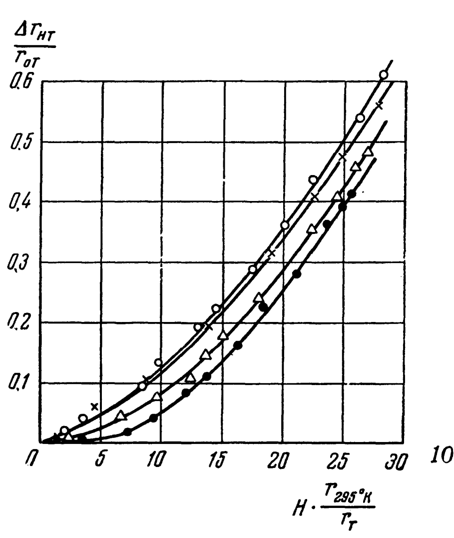

FIG. 6. SampleAu–2:O–T=4.2° K; X–T=1.4°K; Δ–T= 0.46°K; ●–T= 0.1° K.

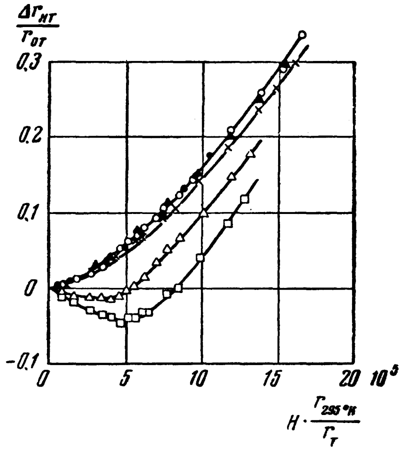

FIG. 7. SampleAu–1:O–T=4.2°K; X–T=1.69°K; Δ–T=0.25°K; □ –T=0.05°K; ●–T=20.4° K and ▲–T= 10.5° K.

the temperature is lowered, turns out to be a function of the magnetic field and approaches zero for certain critical values of field intensity. The existence of such a critical field, as well as a comparison of the behavior of r (T) and r (H) permit one to conclude, that the resistivity increase accompanying a temperature decrease and the decrease of the resistivity in a magnetic field should be attributed to a single cause and do not appear to be independent effects.** It should also be noted that the existence of a saturation in the curves of r (T) and the linear relation between resistivity

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**It has not been determined whether the disappearance of "antiferromagnetism" in gold should be attributed to this same cause.

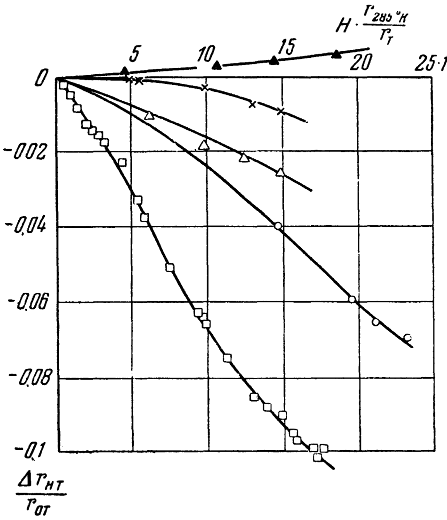

FIG. 8. SampleAu–3: ▲–T≈8 °K; X–T= 4.2 °K; Δ–T=1.61 °K; O–T= 1.36 °K and □ –T≈0.14 °K.

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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207

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Critical Currents in Superconducting Tin Films

N. E. ALEKSEEVSKI AND M. N. MIKHEEVA
Institute for Physical Problems, Academy of Sciences, USSR

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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 $\Delta T = T_c - T \approx 0.5$ °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