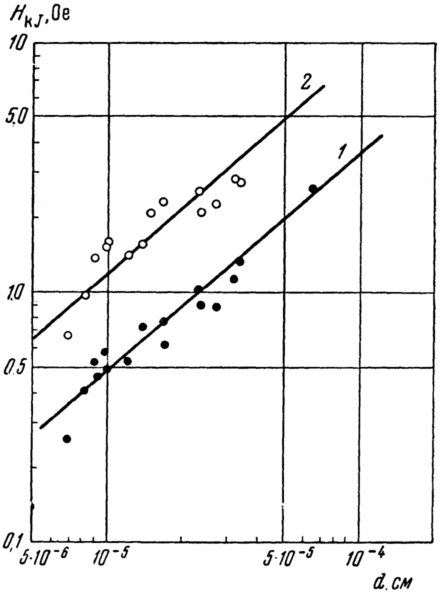

FIG. 5. Dependence of critical current fields upon film thickness for two temperatures. 1–$\Delta T = T_c - T = 0.05\,^\circ$K, 2–$\Delta T = 0.2\,^\circ$K.

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.

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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 changes when hydrostatic pressure is applied. Finally our interest was aroused because of our investigation of the effect of pressure on the galvanomagnetic properties of bismuth with added imputities (in particular, tellurium) at low temperatures, which we recently completed.[2]

In order to obtain pressures at low temperatures the method of freezing water in a bomb of constant volume[3] was used. The magnitude of the pressure was determined by the displacement of the critical temperature of a tin wire, enclosed inside the bomb. Low temperatures were attained by using baths of liquid helium, hydrogen and nitrogen. These baths allowed measurements to be made in the temperature intervals 1.4°–4.2°K; 14°–20°K and 60°–77°K in the usual way. The temperature was determined from the pressure of the vapors above the surfaces of the liquids in the dewar vessels. Measurements in the regions between the specified temperature intervals were performed by warming the apparatus. Warming from 4.2 to 300°K required 4–5 hours which guaranteed sufficient time for the measurements. In this case the temperature was determined by means of a copper–constantan thermocouple fastened to the outer wall of the bomb.

Electrical resistance and Hall voltage were measured with the aid of the usual potentiometer scheme, which used standard elements to produce all possible permutations of direction of the current and magnetic field. The instruments used were a high impedance potentiometer of the type P. P. T. V.–1 and a galvanometer of the type M–21/4 which had a sensitivity of 1×10^{-7} μ V/mm.

The samples, on which the measurements were performed, were cut out of different parts of original samples of tellurium.* Current and potential leads and leads for measuring the Hall voltage were made from platinum or copper wires of 0.05 mm dia. which were soldered onto the samples in various ways. The orientation of the samples were determined from the reflection pattern and from a diagram of the variation of the electrical resistivity in a constant magnetic field. In all the samples the direction of the current which was used for measurement was approximately perpendicular to the direction of the principal axis.

A study of the properties of polycrystalline samples of tellurium was made difficult by the unavoidable cracking of the samples whenever the temperature changed. This is a consequence of the strong anisotropy of the temperature coefficients of expansion.[1,4,5] Experimental investigation of the effect of pressure on polycrystalline samples of Te showed that pressure reduced the resistivity of the samples by an extraordinarily large amount. Thus, for example, for the sample Te–1, a pressure of the order of 1700 atmospheres at 4.2° K produced a decrease in the resistivity by a factor of 27 and at 220° K by a factor of 14.** Therefore an interpretation of the results obtained on polycrystalline samples is difficult. In contrast to the polycrystalline samples, the electrical resistivity of single crystals increased with pressure for the temperature region below 170° K and decreased for higher temperatures. (Fig. 1).

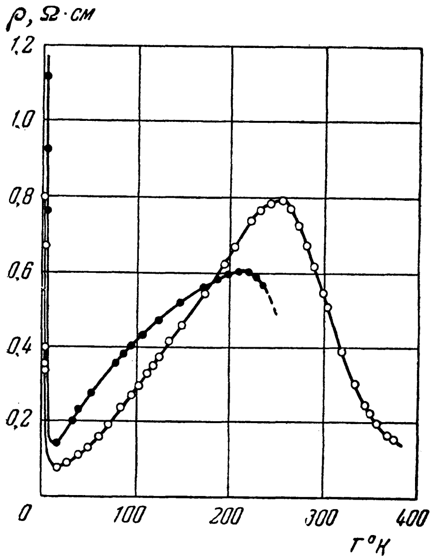

FIG. 1. Dependence of resistivity on temperature for sample Te–3: O–p=0; ●–p= 1700 atmospheres.

For the majority of the samples investigated at helium temperatures, there was observed a minimum in plots of the electrical resistivity vs. the intensity of the magnetic field. Figure 2 shows plots of the change of the electric resistivity in a magnetic field for sample Te–3a for various temperatures and for orientations of the samples in the field which correspond to the largest and smallest values of the effect. The relative depth of the minimum, characterized by the equation

$$(\Delta r_{HT}/r_{0T})_{\min} = [r_{0T} - (r_{HT})_{\min}]/r_{0T},$$

where r_{HT} is the resistivity in field H at temperature T, is greatest for the crystalline direction for

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*The original samples were kindly supplied to us by S. S. Shalyt for which the authors wish to express their gratefulness.

**Similar phenomena have been observed by other authors at room temperature.

which the biggest increase of resistivity is observed at the higher magnetic fields and the minimum is shallowest for the direction perpendicular to this. As is evident from Figure 3, the anisotropy of the depth of the minimum in its dependence on the orientation of the crystals in the field decreases as the temperature is decreased so that for each crystallographic direction there exists a certain temperature T, above which a minimum is not observed.

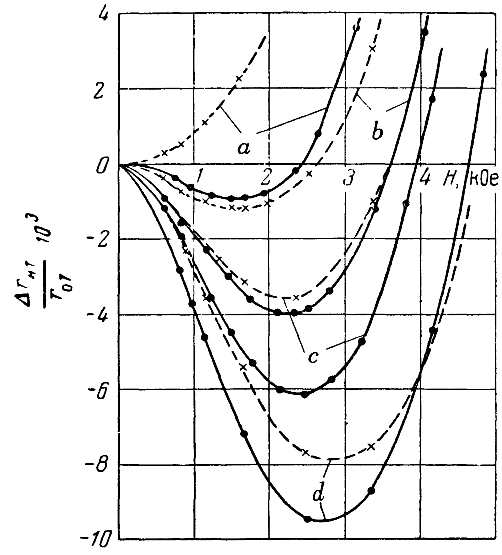

FIG. 2. Change in electrical resistance of sample Te–3a in a magnetic field: ●—for the sample orientation which yields a maximum value of the effect; X—maximum value of the effect; a—$T = 4.2\,^\circ$K; b—$T = 2.55\,^\circ$K; c—$T = 1.95\,^\circ$K and d—$T = 1.5\,^\circ$K.

In order to elucidate the cause of the development of the minimum, experiments were performed, (a) on samples of various shapes and dimensions, (b) on the effect of using different methods of attaching the leads and (c) on samples of different purity. In this way it was determined that the value of the minimum does not depend on (a) or (b). In heavily doped Te samples, which had a metallic behavior of r (T) in the helium temperature region, the minimum is absent down to 1.4 °K. The minimum appears with purer samples of Te, whose electrical resistance in the absence of the magnetic field increases with decreasing temperature below 4.2 °K. In such samples, the value of the minimum increases in proportion to the purity of the samples. However, for the purest samples available to us the magnitude of the effect again decreases. These samples are the basis of the surmise, that the dependence of the magnitude of the effect on the concentration passes through a maximum.

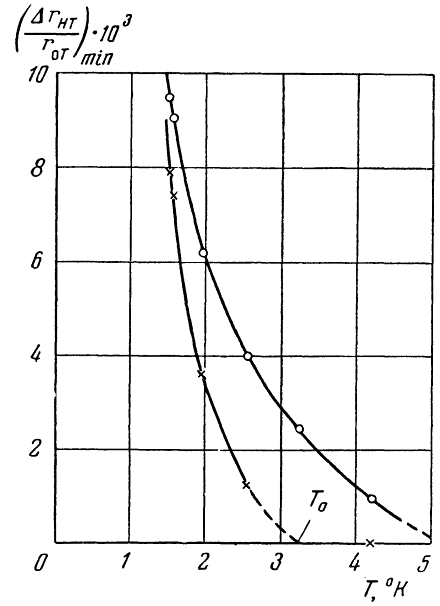

FIG. 3. The dependence of the magnitude of the minimum on the temperature for sample Te–3a, for the orientations which produce the largest (O) and the smallest (X) values of the effect.

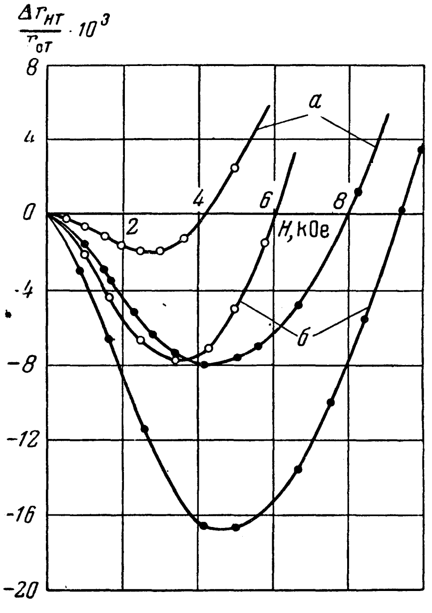

FIG. 4. Change in electiical resistance of sample Te–3b in a magnetic field: O—$p = 0$; ●—$p = 1700$ atmospheres; a—$T = 4.2\,^\circ$K, b—$T = 1.77\,^\circ$K.

It was observed, that hydrostatic pressures in the range of 1700 atmosphere provoke a significant change in the galvanomagnetic properties of Te. Figure 4 shows plots of $\Delta r_{HT}/r_{OT}$ (H) in the vicinity of the minimum for sample Te–3b with and without applied pressure at a temperature of 4.2°

and 1.77 °K. As is evident from these curves, pressure in the vicinity of 1700 atmospheres causes an increase in the minimum by a factor somewhat greater than 2. In the region of highest magnetic fields, hydrostatic pressures produce an increase in the function $\Delta r_{HT} / r_{OT}$ (*H*) at temperatures of 77° K and 20.4° K and a decrease in this parameter at helium temperatures (Fig. 5).

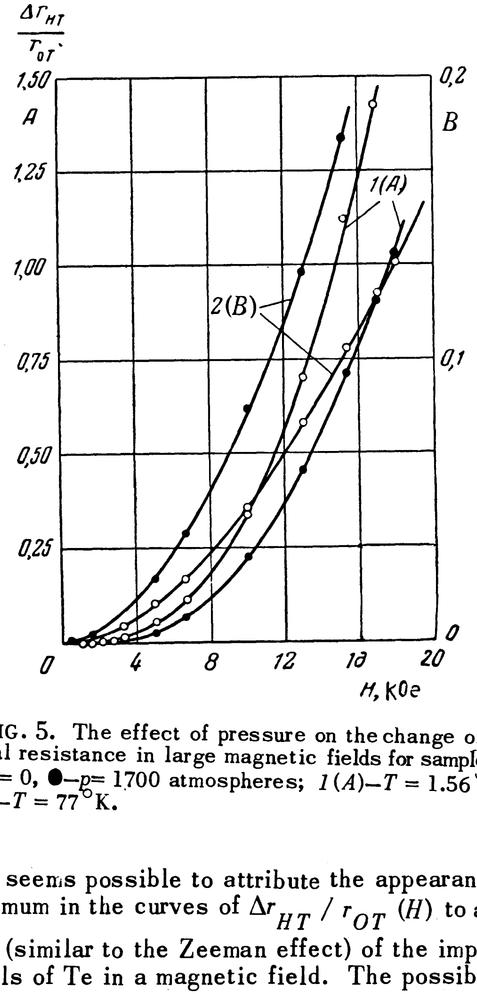

FIG. 5. The effect of pressure on the change of electrical resistance in large magnetic fields for sample Te—3: O—*p*= 0, ●—*p*= 1700 atmospheres; *1*(*A*)—*T* = 1.56°K; *2*(*b*)—*T* = 77°K.

It seems possible to attribute the appearance of a minimum in the curves of $\Delta r_{HT} / r_{OT}$ (*H*) to a splitting (similar to the Zeeman effect) of the impurity levels of Te in a magnetic field. The possibility of splitting impurity levels in a magnetic field has been pointed out in the literature.[6] An estimate of the magnitude of the Zeeman splitting in magnetic fields of about 1000 oersted, is obtained from the equation $\Delta E = 1.16 \times 10^{-5}$ ev. On the basis of this picture, the effect will be observable only for low temperatures, where KT is about 10^{-4} ev. Measurement of the temperature dependence of the electrical resistivity of tellurium in the helium temperature region argues, apparently, for the existence of impurity levels with an activation energy of 10^{-4}–10^{-5} ev. in the samples used in these experiments. It should be possible to demonstrate the splitting of an impurity level in a magnetic field by showing that there is an increase in the concentration of carriers in the conduction band. Observations of the dependence of the Hall constant, (which were performed for this reason) on the intensity of the magnetic field confirmed this hypothesis (Fig. 6). For those fields, in which the minimum of the resistivity occurred, there was a region of an observable decrease in the Hall constant. Furthermore, dR/dH had a maximum in this region. At a temperature of 77° K the Hall constant does not change in the magnetic field.

The absence of a minimum in Te samples which have a metallic dependence of resistance on temperature can be explained, supposedly, by a widening of impurity level responsible for the effect into a band, which blends into the valence band of tellurium.

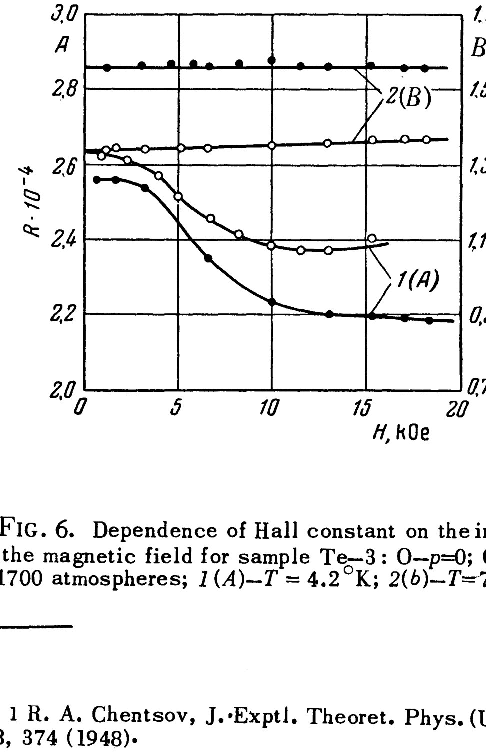

FIG. 6. Dependence of Hall constant on the intensity of the magnetic field for sample Te—3: O—*p*=0; ●—*p* = 1700 atmospheres; *1*(*A*)—*T* = 4.2°K; *2*(*b*)—*T*=77°K.

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