FEATURES OF THE PRESSURE COEFFICIENT OF THE ELECTRICAL RESISTANCE OF SUBSTANCES WITH SPIN ORDERING

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A study was made of the influence of uniform hydrostatic compression on the electrical resistance of the ferromagnetic compound CrTe and of the antiferromagnetic compound MnTe. The measurements were carried out both above and below the magnetic transition temperatures of these compounds ($\Theta_f = 65°C$ and $T_N = 37°C$). A sharp change in the pressure coefficients of the electrical resistance, associated with a departure from spin ordering in these substances, was observed at the transition to the paramagnetic state.

INTRODUCTION

In the pressure range up to about 10000 kg/cm^2 at room temperature, the pressure coefficient of the electrical resistance of the majority of metals is negative.[1] Because of this, the metals whose electrical resistance decreases under the influence of uniform hydrostatic compression are called "normal." Theoretically, the change in the resistance is explained by a change in the interaction forces between electrons and elastic vibrations of the crystal lattice, which is due to the fact that an external pressure raises the characteristic Debye temperature. Changes in the nature of the energy spectrum of the carriers and in the shape of the Fermi surface should appear in these metals at considerably higher pressures.

Those metals which have positive pressure coefficients of the electrical resistance are called "anomalous." The increase in the electrical resistance of these metals with pressure is due to[2,3] a change in their electron energy structure—uniform pressure alters the overlap of the various energy bands. Apart from Li, Ca, Sr, Ba, Bi and Sb, the positive sign of the pressure coefficient of the electrical resistance, $\gamma = R^{-1}dR/dP$, is exhibited by those ferromagnetic alloys whose Curie temperature depends strongly on pressure: CrTe[4] and the Fe–Ni Invar alloys.[5] Therefore, one would expect that the anomalous sign of γ of these alloys is mainly due to a change in the magnetic state of the alloy under uniform compression—a change in the spontaneous magnetization and the Curie point. In view of this, it seemed interesting to investigate substances with other types of spin ordering, having different signs of the $d\Theta_f/dP$ effect (the displacement of the magnetic transition temperature by pressure), and to find the characteristic features of the pressure coefficients of the electrical resistance of these alloys.

The present paper reports the results of an investigation of the influence of uniform compression on the electrical resistance of the ferromagnetic compound CrTe, $d\Theta_f/dP$ of which is negative, and of the antiferromagnetic compound MnTe, whose Néel temperature increases with pressure, i.e., dT_N/dP is positive.[6] In both cases, the measurements were carried out both below and above the magnetic transition temperatures of the compounds.

RESULTS OF MEASUREMENTS AND DISCUSSION

Uniform hydrostatic compression of a sample was produced in a high-pressure chamber; a 50% mixture of transformer oil with kerosene was used as the pressure-transmitting medium. The method of measuring the electrical resistance, temperature, and pressure was analogous to that described earlier by the present author.[4]

1. The data of the measurements of the effect of pressure on the electrical resistance of CrTe at various temperatures are given in Fig. 1. It is evident from the curves that the measurements carried out with the pressure first increasing and then decreasing do not give identical results. Hysteresis is observed at low pressures, leading to an irreversible increase in the initial resistance, amounting in some cases to 4–5%. Because of this, the pressure coefficient of the electrical resistance was calculated beginning from 1500 kg/cm^2. The differences between the R(P)

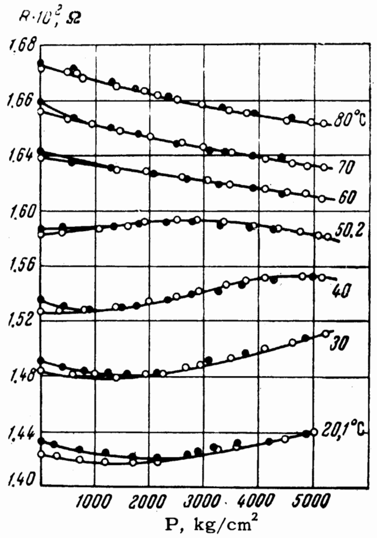

FIG. 1. Influence of pressure on the electrical resistance of CrTe at various temperatures: ○ – increase in pressure; ● – reduction in pressure.

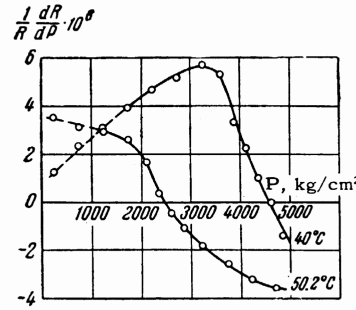

FIG. 2

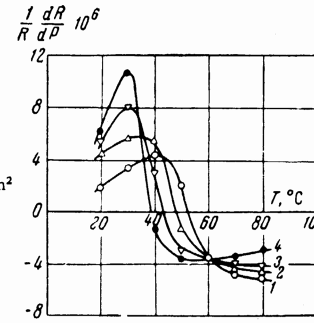

FIG. 3

FIG. 2. Change in the pressure coefficient of the electrical resistance of CrTe with pressure at temperatures of 40 and 50°C.

FIG. 3. Temperature dependence of the pressure coefficient of the electrical resistance of CrTe: 1) at P = 2000 kg/cm²; 2) at P = 3000 kg/cm²; 3) at P = 4000 kg/cm²; 4) at P = 5000 kg/cm².

curves obtained with the pressure increasing and then decreasing were slight in the range of pressures 1500–5200 kg/cm^2. Control measurements, carried out by repeating the compression cycles at various temperatures, confirmed the good reproducibility of the general nature of the R(P) curves. The Curie temperature of the investigated sample, determined at atmospheric pressure from the maximum of the galvanomagnetic effect, was +65°C. Figure 1 shows that at temperatures above Θ_f the electrical resistance of chromium telluride decreases as the pressure increases, i.e., the pressure coefficient of the electrical resistance has its "normal" negative sign. At temperatures below Θ_f, the electrical resistance increases with pressure, i.e., the sign of γ becomes positive. If we assume that the change in the sign of γ is associated with the destruction of the spin ordering in this compound, we may expect, in the region of Θ_f, maxima in the curves R(P), measured in the corresponding ranges of P and T which include the magnetic transition temperature. The measurements carried out at temperatures of 50.2 and 40°C confirm this expectation (Fig. 1). We have shown earlier that the Curie temperature of chromium telluride decreases very strongly with pressure: $d\Theta_f/dP = 6.2 \times 10^{-3}$ deg.kg^{-1}.cm^2.[4] Consequently, Θ_f, equal to 65°C at atmospheric pressure, decreases to 50°C at P = 2500 kg/cm^2 and then to 40°C at P = 4000 kg/cm^2. From the curves given in Fig. 2 it is evident that the sign of the pressure coefficient of the electrical resistance changes in the indicated range of pressures and temperatures. The value of γ was in all cases determined by graphical differentiation of the R(P)/R$_1$ curves, where R$_1$ is the electrical resistance at atmospheric pressure.

Curves showing the temperature dependence of γ, calculated at pressures of 2000, 3000, 4000, and 5000 kg/cm^2, are given in Fig. 3. It is evident from these curves that in the paramagnetic region, i.e., at T > Θ_f, the pressure coefficient of the electrical resistance is negative and its absolute value decreases a little with pressure to become (3–5) $\times 10^{-6}$ kg^{-1}.cm^2. Thus, in the absence of spin ordering, the sign and magnitude of γ are the same as for "normal" nonferromagnetic metals. At T < Θ_f, i.e., in the region where ferromagnetism exists, the sign of γ is positive and the absolute value of the coefficient γ increases as the temperature approaches Θ_f, reaches a maximum, and then begins to change, becoming negative at T > Θ_f. It is evident from Fig. 3 that on increase of pressure the curves γ(T) shift toward lower temperatures, which is associated with the reduction in the Curie temperature under uniform compression; the nature of the γ(T) curves does not alter in this process.

2. The results of the measurements carried out on the antiferromagnetic compound MnTe are given in Fig. 4, which shows the relative change in the electrical resistance R(P)/R$_1$, when the pressure increases. The measurements were carried out in the temperature range 16–65°C at pressures of 1–5300 kg/cm^2. The antiferromagnetic transition temperature at atmospheric pressure was found to be +37°C; according to our measurements,[6] T_N rises as the pressure increases at the rate $dT_N/dP = (2.0 \pm 0.4) \times 10^{-3}$ deg.kg^{-1}.cm^2. It is evident from the R(P)/R$_1$ curves, given in Fig. 4, that uniform compression reduces the elec-

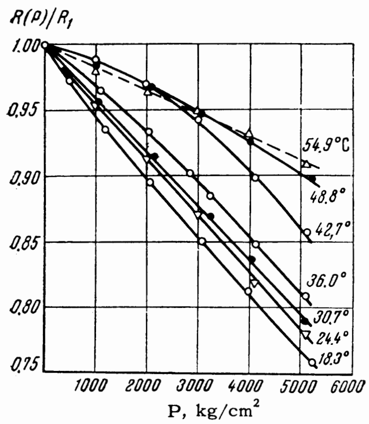

FIG. 4. Effect of pressure on the electrical resistance of MnTe at various temperatures.

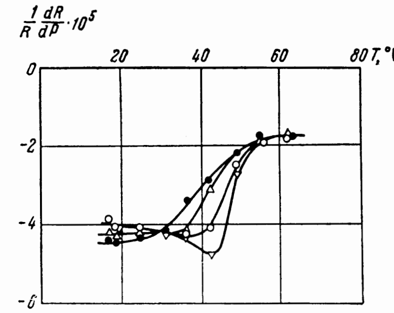

FIG. 5. Temperature dependence of the pressure coefficient of the electrical resistance of MnTe: ● – at P = 2000 kg/cm²; Δ – at P = 3000 kg/cm²; ○ – at P = 4000 kg/cm²; ∇ – at P = 5000 kg/cm².

trical resistance of MnTe, i.e., the pressure coefficient is negative both below T_N and in the paramagnetic region at $T > T_N$. At temperatures far from the Néel point, the electrical resistance depends linearly on pressure. However, in the region of the magnetic transition temperature, the nature of the R(P) curves changes considerably: below T_N, the R(P) curves are convex downward while above T_N, they are convex upward. Figure 5 shows the temperature dependence of the pressure coefficient of the electrical resistance; the $\gamma(T)$ curves were calculated for pressures of 2000, 3000, 4000 and 5000 kg/cm^2. From these curves, it is evident that when the temperature increases in the region of the Néel point the absolute value of the coefficient γ decreases, and when the pressure increases the $\gamma(T)$ curves shift toward higher temperatures, which, as in the preceding case, is due to the effect of pressure on the magnetic transition temperature of the substance.

3. Our experimental data show that the appearance of spin ordering in a substance gives rise to certain features in the pressure coefficient of the electrical resistance. These features are due to the fact that the pressure-induced change in the electrical resistance of ferromagnets and antiferromagnets is governed not only by the change in the electron–phonon interaction but also by the change in the magnetic state of the substance. If uniform compression markedly reduces the relative magnetization ($d\Theta_f/dP < 0$), the usual effect—the reduction of the electrical resistance under pressure—may be masked by the influence of the strong scattering of conduction electrons on spin inhomogeneities, which may result in a net positive sign of the pressure coefficient of the electrical resistance at $T < \Theta_f$. This tendency is particularly strong near Θ_f. The signs of γ in the ferromagnetic and paramagnetic states of a sample are different. If uniform compression increases the magnetization ($d\Theta_f/dP > 0$), then an increase in the degree of magnetic ordering leads to a decrease in the electrical resistance and the sign of the pressure coefficient of the electrical resistance is negative (for "normal" metals) both above and below Θ_f. When external pressure alters little the magnetic state of the substance ($d\Theta_f/dP \approx 0$), the appearance of spin ordering should change neither the sign nor the magnitude of γ. These relationships apply both to ferromagnetic and antiferromagnetic ordering of the spin magnetic moments.

The results obtained in the investigation of the antiferromagnetic compound MnTe are an excellent confirmation of the above conclusions. The positive shift of the Néel temperature of manganese telluride with pressure ($dT_N/dP > 0$) may be regarded as indicating an increase in the degree of antiferromagnetic ordering, which should lead to further reduction in the electrical resistance of MnTe at high pressures in the temperature range $T < T_N$. This was in fact observed.

Kondorskiĭ and Sedov[5] considered the possible causes of changes in the spontaneous magnetization (σ_s) and the electrical resistance (R) of a substance under uniform compression. After making a comparison of the pressure coefficients of these properties of such ferromagnets as Ni and Fe, on the one hand, and of Invar alloys, possessing "latent antiferromagnetism," on the other, Kondorskiĭ and Sedov concluded that the changes in the spontaneous magnetization under pressure in these substances have many causes. In the ferromagnetic metals Fe and Ni, whose pressure coefficients of the spontaneous magnetization and of the electrical resistance are small and have the same sign, the main reason for the change in σ_s and R under pressure is assumed to be the change in the value of the s–d exchange integrals. In the Invar alloys, whose pressure coefficients are relatively large and have different signs ($\gamma_\sigma < 0$, $\gamma_R > 0$), it is assumed that the main cause of the change of σ_s and R under pressure is the change in the d–d exchange interaction integrals. Our experimental data allow us to make the following comments on the different nature of the influence of uniform compression on the electrical resistance of the ferromagnetic metals Fe and Ni and of the Invar alloys, investigated by Kondorskiĭ and Sedov.[5] It is known that the magnetic state of Fe and Ni changes little with pressure ($d\sigma/\sigma_0 dP \approx 10^{-7}$ kg^{-1}.cm^2, $d\Theta_f/dP \approx 10^{-4}$ deg.cm^2.kg^{-1}). In view of this we may assume that the main reason for the change in the electrical resistance of these ferromagnetic metals under pressure is the change in the electron–phonon interaction. The appearance of spin ordering at $T < \Theta_f$ should not alter the magnitude or sign of the coefficient γ. This explains why the pressure coefficient of the electrical resistance of Fe and Ni is the same as for "normal" nonferromagnetic metals.

The main reason for the change in the electrical resistance of Invar alloys under pressure is the great change in the magnetic state of these alloys under pressure.

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