Magnetoresistance of the high-conductivity complex TTT_2I_3

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Single crystals of the complex tetrathiotetracene (TTT) with iodine have positive magnetoresistance that reaches 45% at 1.43 K in a field 55 kOe. The effect is isotropic, proportional to the square of the external field, and inversely proportional to the square of the temperature.

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The complex TTT_2I_3, which has a high conductivity at 10^{10} Hz ($\sigma_{300} \approx 10^3$ Ω^{-1} cm^{-1}) was recently described in[1]. A characteristic feature of the structure of this complex is the disordered arrangement of the iodine atoms. Different iodine chains situated between the conducting stacks of TTT do not correlate with one another.[1] The structural disorder can lead to localization of electronic state of the quasi-one-dimensional conducting system.[2] To obtain additional information on the conduction mechanism we investigated in this study the dc conductivity and the magnetoresistance of TTT_2I_3 single crystals.

The TTT_2I_3 crystals were obtained by slow cooling of the reaction solution in nitrobenzene from 1000 °C to room temperature in the dewar vessel. The ratio of the initial reagents was I/TTT = 1.7. The largest crystals measured $10\times0.2\times0.1$ mm. The smaple resistance was measured by a four-contact method. The contacts between the copper conductors and the crystal were produced with conducting graphite paste, and the junction resistance was usually 10—15 Ω

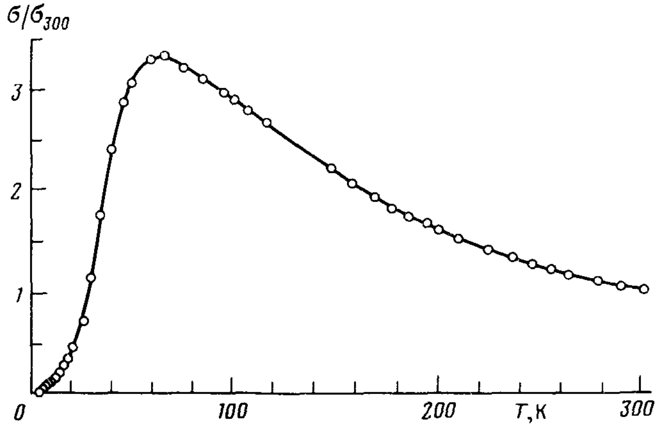

FIG. 1. Temperature dependence of the conductivity of TTT_2I_3.

and depended little on the temperature. A magnetic field up to 55 kOe was produced with a superconducting solenoid.

The conductivity of the crystals along the long axis at room temperature is $1050 \pm 100\ \Omega^{-1}\ cm^{-1}$. With decreasing temperature, the conductivity increases and passes through a broad maximum in the region of 60 K, so that $\sigma_{max}/\sigma_{300} = 3.0-3.7$ for different crystals (Fig. 1). Below 50 K, an abrupt decrease of conductivity begins. If the temperature dependence of the conductivity is described by the usual activation process $\sigma \sim \exp(-W/kT)$, then the activation energy W depends on the temperature. It decreases from $W/k = 95K$ at 30 K to $W/k = 7K$ at 2K. The best agreement is observed for the relation $W \sim T^{2/3}$, in which case $\sigma \sim \exp(-T_0/T)^{1/3}$. This law is well satisfied in the temperature interval 1.4—25K, the characteristic temperature being $T_0 = 1980K$.

At temperatures below 10K the resistance of the samples increases when an external magnetic field is applied. The effect increases at low temperatures (Fig. 2), so that at 1.43 K value of $\Delta\rho/\rho = (\rho(H) - \rho(0))/\rho(0)$ reaches 45% in a field 55 kOe. The single crystals were disposed both across and along the

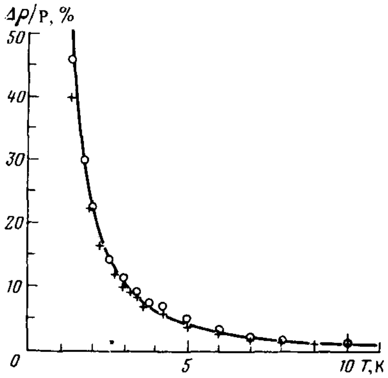

FIG. 2. Temperature dependence of the magnetoresistance of two TTT_2I_3 crystals in a field of 47.2 kOe.

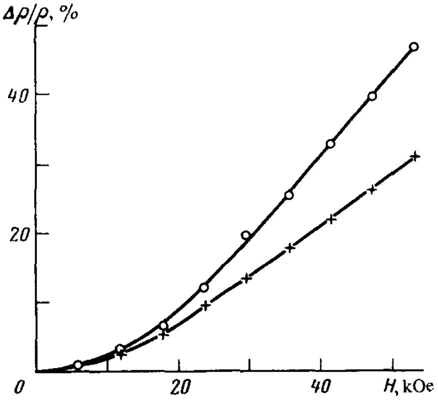

FIG. 3. Field dependence of the magnetoresistance of two TTT_2I_3 crystals, $T = 1.43$ K (circles—crystal with $\sigma_{4.2K} = 21\ \Omega^{-1}cm^{-1}$; crosses—$\sigma_{4.2K} = 31\ \Omega^{-1}cm^{-1}$).

magnetic field, the magnetoresistance being independent of the sample orientation. The observed difference was much less than the scatter in the values of the magnetoresistance for different single crystals.

Figure 3 shows the dependence of the magnetoresistance on the magnetic field at the lowest temperature. Fields up to 30 kOe, a quadratic dependence $\Delta\rho \sim H^2$, is observed, and in stronger fields $\Delta\rho$ becomes a linear function of the field. At temperatures $T > 2$ K, where the magnitude of the effect in a 50-kOe field is less than 20%, the $\Delta\rho \sim H^2$ dependence is preseved in the entire field interval.

Different TTT_2I_3 crystals obtained under identical conditions exhibit different values of the effect, the maximum difference reaching 40%. These crystals have also different conductivities at low temperatures, so that $\sigma_{4.2K}$ lies in the interval 10—30 $\Omega^{-1}cm^{-1}$. The lower the conductivity, the higher the magnetoresistance of the samples.

The decrease of the conductivity at low temperatures is due in all probability to localization of the conducting electrons and not to the Peierls metal-insulator transitions, as is the case for the well known complex TTF-TCNQ.[3] This localization can result from the structural disorder inherent in the TTT_2I_3. It should also be noted that TTF-TCNQ has negative magnetoresistance[4] and its conductivity at 4.2K is lower by 4 orders of magnitude than that of the complex TTT_2I_3. All this demonstrates that the character of the electronic states in TTT_2I_3 and TTF-TCNQ is different.

If the electronic states are localized, then the conduction can be of the hopping type, as is the case in most one-dimensional systems.[5,6] The temperature dependence of the conductivity confirms this assumption. The energy W is the average scatter of the energy levels of the centers over which the electron moves.[7] The experimental results can be described by assuming that the magnetic field increases the scatter of the energy levels of the centers: $W(H) = W(0) + \alpha\mu_0^2H^2/kT$, where α is a constant. The magnetoresistance at $W > \alpha\mu_0^2H^2/kT$ is $\Delta\rho/\rho = \alpha(\mu_0H/kT)^2$. This dependence describes our results well: the curve drawn in Fig. 2 corresponds to $\alpha = 0.094$. However, it is quite difficult to justify our assumption within the framework of the theory of hopping conduction.

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[1] L. I. Buravov, G. I. Zvereva, V. F. Kaminskii, L. P. Rosenbergk, M. L. Khidekel, R. P. Shibaeva, I. F. Shchegolev, and E. B. Yagubskii, Chem. Commun. 720 (1976).
[2] I. F. Shchegolev, Phys. Status Solidi [a] **12**, 9 (1972).
[3] F. Dehoyer, R. Comes, A. F. Garito, and A. J. Heeger, Phys. Rev. Lett. **35**, 445 (1975).
[4] T. Tiedje, J. F. Carolan, and A. J. Berlinsky, Can. J. Phys. **53**, 1593 (1975).
[5] A. N. Bloch, R. B. Weisman, and C. M. Varma, Phys. Rev. Lett. **28**, 753 (1972).
[6] A. A. Gogolin, V. I. Mel'nikov, and E. I. Rashba, Zh. Eksp. Teor. Fiz. **69**, 327 (1975) [Sov. Phys. JETP **42**, 168 (1976)].
[7] N. F. Mott and E. A. Davis, Electronic Process in Noncrystalline Materials, Oxford, 1971.