Anisotropy of the conductivity and upper critical fields in the new organic superconductor $\kappa-ET_2[CuN(CN)_2]$ $Cl_{0.5}$ $Br_{0.5}$

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(Submitted 19 October 1992)
Pis'ma Zh. Eksp. Teor. Fiz. **56**, No. 10, 520–522 (25 November 1992)

A study has been conducted of the anisotropy of the conductivity and upper critical fields of the new organic superconductor $\kappa-ET_2[CuN(CN)_2]$ $\times Cl_{0.5}Br_{0.5}$. It is shown that this compound is substantially more three-dimensional than the superconductor $\kappa-ET_2[CuN(CN)_2]Br$. The obtained results agree with x-ray diffraction data.

The organic superconductor $\kappa-ET_2[CuN(CN)_2]Br$, synthesized about two years ago, continues to be an object of heightened interest. In the first place, this interest is attributable to its superconducting transition temperature at normal pressure,[1] $T_c = 11.6$ K,[1] which is a record for organic salts. Another reason for it is the fact that the isostructural compound $ET_2[CuN(CN)_2]Cl$ is characterized by a metal–insulator transition at low temperatures and normal pressure, and only under external pressure does it undergo a transition to the superconducting state at[2] $T_c = 12.5$ K. A subsequent study of salts of intermediate composition $ET_2[CuN(CN)_2]Br_xCl_{1-x}$ as a function of x has convincingly shown that for $x = 0.5$ a new quasi-two-dimensional complex is formed with superconducting transition temperature at normal pressure[3] $T_c = 11.3$ K. For other values of x the resulting compounds can be considered as just "dirty" chlorides or bromides. The new complex is isostructural with $ET_2[CuN(CN)_2]Br$ and $ET_2[CuN(CN)_2]Cl$ and, like them, possesses a layered structure: highly conductive cation layers lying in the ac plane alternating with insulating anion layers in the b direction. However, according to the x-ray diffraction data the interlayer distance in the new compound is less than in the pure chloride or bromide.[3] It can therefore be assumed that this compound has a lower degree of two-dimensionality than the parent salts. Results of optical studies of single crystals of $ET_2[CuN(CN)_2]Cl_{0.5}Br_{0.5}$ also point to such a possibility.[4]

In the present paper we report the results of an experimental study of the anisotropic characteristics of the new organic superconductor $ET_2[CuN(CN)_2]Cl_{0.5}Br_{0.5}$, specifically, the anisotropy of the conductivity and the upper critical fields.

The measurements were carried out on single crystals with characteristic dimensions $0.8\times0.4\times0.04$ mm. The resistance was measured by the standard four-contact method. A constant current of 100 μA could be directed along the conducting planes $j\perp b^*$ (it was in this case that the longitudinal resistance was measured) and at right angles to them $j\| b^*$ (in this case the transverse resistance was measured). For the measurements in a magnetic field we used a superconducting solenoid with a maximum field of 50 Oe. The upper critical field was determined from the curve of de-

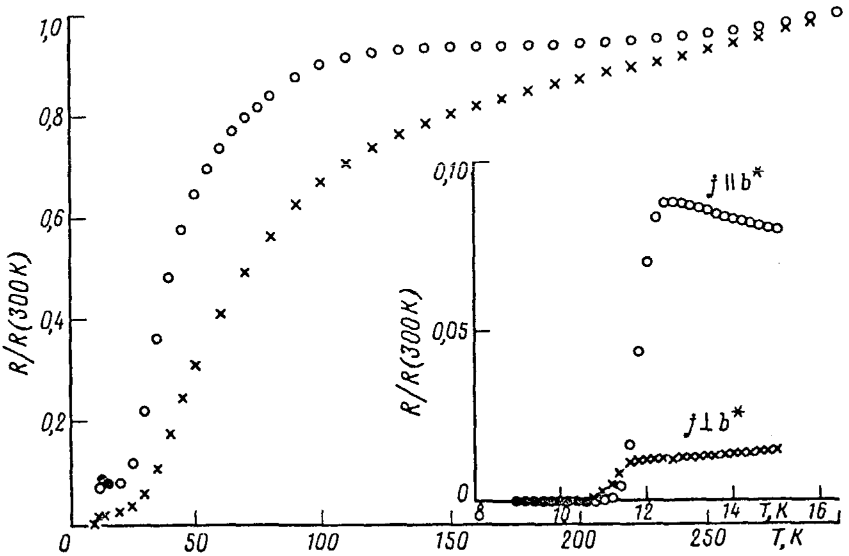

FIG. 1. Temperature dependence of the resistance of a single crystal of $ET_2[CuN(CN)_2]Cl_{0.5}Br_{0.5}$. ×—measuring current in the ac plane; ○—current directed perpendicular to the ac plane. Inset shows the low-temperature part of the dependence of $R(T)$.

struction of superconductivity by a magnetic field $R(H)$. The measuring current in these cases was directed parallel to the good conducting plane of the crystal. As the magnitude of H_{c2} at the given temperature we used the abscissa of the intersection point of the tangent to the point of the maximum of the derivative dR/dH and the line extrapolating the value of the normal state resistance at high fields to the region of small fields. Such a method makes it possible to minimize the distortions of the values of H_{c2} which arise in the study of resistive superconducting transitions and which are probably associated with the motion of the vortices in the region of intermediate fields.[5]

Figure 1 displays the temperature dependences of the resistance for both longitudinal and transverse directions of the measuring current in a single crystal of $ET_2[CuN(CN)_2]Cl_{0.5}Br_{0.5}$. The conductivity in the conducting plane at room temperature is $\sigma_{\parallel} = 2\Omega^{-1}\cdot cm^{-1}$. Thus, the conductivity anisotropy at room temperature in the given compound is $\sigma_{\parallel}/\sigma_{\perp} \cong 100$, which is an order of magnitude smaller than the corresponding value in the superconductor[6] $ET_2[CuN(CN)_2]Br$.[6] As the temperature is lowered, the conductivity anisotropy grows and at $T \cong 12$ K attains a value of the order of 1000, which is again almost an order of magnitude smaller than in $ET_2[CuN(CN)_2]ClBr$ (Ref. 6). At temperatures below 12 K, the $ET_2[CuN(CN)_2]Cl_{0.5}Br_{0.5}$ crystal undergoes a transition to the superconducting state (see the insert in Fig. 1). We estimate the temperature of onset of the transition to be $T_c \cong 11.9$ K. Note that in the temperature dependence of the resistance the maxima recorded in the samples of $ET_2[CuN(CN)_2]Br$ are absent in the entire temperature range over which the measurements were made (see Fig. 1).[6] At the same time, a

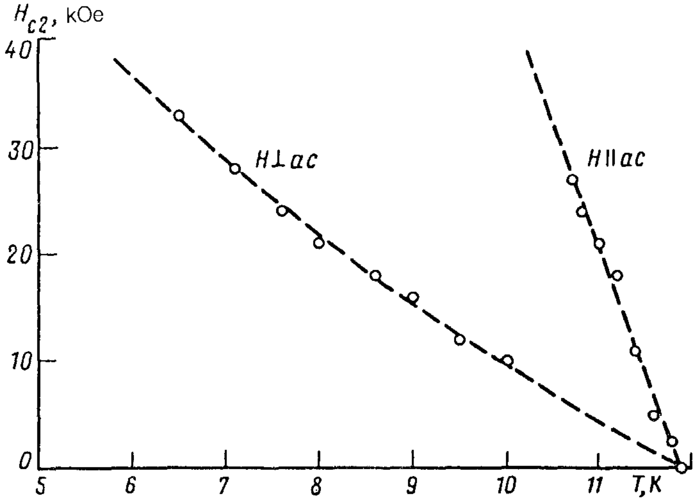

FIG. 2. Temperature dependence of the upper critical fields of a single crystal of $ET_2[CuN(CN)_2]Cl_{0.5}Br_{0.5}$ for different orientations in a magnetic field.

faster decrease of the resistance below 100 K is characteristic for the two compounds. The nature of this behavior requires more detailed study.

The anisotropy of the upper critical fields in a single crystal of $ET_2[CuN(CN)_2]Cl_{0.5}Br_{0.5}$ can be seen in Fig. 2. The correlation lengths, estimated from the values of the derivatives of the critical fields $H'_{c2}(T \to T_c)$, are $\xi_{\parallel}(0) \cong 140$ Å and $\xi_{\perp}(0) \cong 28$ Å, where $\xi_{\parallel}$ and $\xi_{\perp}$ are the correlation lengths in the good conducting plane and in the direction perpendicular to it, respectively. Thus, the critical field anisotropy in the investigated sample is $H'_{c2\parallel}/H'_{c2\perp} \cong \xi_{\parallel}(0)/\xi_{\perp}(0) \cong 5$, which is approximately two times smaller than the corresponding value in $ET_2[CuN(CN)_2]Br$.[7]

Thus, the results of our study of the anisotropy of the upper critical fields and the conductivity in the new organic superconductor $\kappa-ET_2[CuN(CN)_2]Cl_{0.5}Br_{0.5}$ testify in favor of the greater degree of three-dimensionality of this compound than that of the isostructural superconductor $ET_2[CuN(CN)_2]Br$. The difference in the corresponding anisotropic characteristics of the two compounds is significant. It would seem, therefore, that neither insufficient statistics nor possible errors in the measurements can have a substantial effect on the conclusion made here, which is in good agreement with the above-noted x-ray diffraction analysis results and optical measurements.

We are grateful to É. B. Yagubskiĭ for helpful discussions, to Yu. F. Knyachenko for assistance in carrying out the automated experiment, and to V. N. Laukhin for technical assistance.

[1] A. M. Kini, U. Geiser, H. H. Wang *et al.*, Inorg. Chem. **29**, 2555 (1990).
[2] J. M. Williams, A. M. Kini, H. H. Wang *et al.*, Inorg. Chem. **29**, 3272 (1990).

[3] N. D. Kushch, L. I. Buravov, A. G. Khomenko *et al.*, Synthet. Met., in press.
[4] R. M. Vlasova, O. O. Drozdova, V. N. Semkin *et al.*, Fiz. Tverd. Tela, in press.
[5] H. Mori, K. Nakao, S. Nagaya *et al.*, Int'l. Conf. on Science and Techn. of Synth. Met., ICSM-90, Abstracts, Vol. 1, p. 305 (1990).
[6] L. I. Buravov, N. D. Kushch, V. A. Merzhanov *et al.*, J. de Phys. I **2**, 1257 (1992).
[7] W. K. Kwok, U. Welp, K. D. Carlson *et al.*, Phys. Rev. B **42**, 8686 (1990).

Translated by P. F. Schippnick