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## Interlayer Transport in the Organic Superconductor $\kappa$ -(BEDT-TTF)<sub>2</sub>Cu[N(CN)<sub>2</sub>]Br

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Interlayer magnetoresistance as a function of field and temperature with fields parallel and perpendicular to the current direction in the organic superconductor  $\kappa$ -(BEDT-TTF)<sub>2</sub>Cu[N(CN)<sub>2</sub>]Br has been measured. For  $H \parallel I$ , the isothermal magnetoresistance  $R(H)$  displays a peak effect as a function of field. For  $H \perp I$ ,  $R(H)$  increases monotonically with increasing field. Comparison of the peak field with the  $H_{c2}(T)$  data suggests that the peak in  $R(H)$  occurs in the mixed state. We analyze the data in terms of the resistively shunted Josephson junction model and the density of states fluctuation model.

Magnetoresistance in the direction perpendicular to the superconducting layers shows a pronounced peak as a function of field  $H$  and temperature  $T$  in the cuprates, such as  $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$  and  $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$  [1-3]. The results can be interpreted qualitatively in the framework of stacked Josephson junctions between the superconducting layers. Studies in the layered organic superconductor (BEDT-TTF)<sub>2</sub>X [bis(ethylenedithio)tetrathiafulvalene, also abbreviated as ET] superconductors, with X being  $\text{Cu}[\text{N}(\text{CN})_2]\text{Br}^-$  and  $\text{Cu}(\text{SCN})_2^-$  show similar peak effects in the mixed state [6]. Recent synthesis of rod-like sample of  $\kappa$ -(ET)<sub>2</sub>Cu[N(CN)<sub>2</sub>]Br, where the conducting planes (*ac* plane) stack in the long axis direction (*b* axis), makes precise measurements in this direction possible.

Single crystals of the  $\kappa$ -(ET)<sub>2</sub>Cu[N(CN)<sub>2</sub>]Br superconductor were synthesized at the Argonne National Laboratory described elsewhere [4]. Several crystals were used in this study, with extensive measurements made on one crystal with  $T_c = 10.5\text{K}$ . Measurements were performed at the National High Magnetic Field Laboratory with fields up to 18T. The interlayer resistance was measured with use of the four probe technique. Contact of the gold wires to the sample was made with a

Dupont conducting paste. Typical contact resistance between the gold wire and the sample was about 10  $\Omega$ . A current of 1  $\mu\text{A}$  was used to ensure linear I-V characteristics. The samples were cooled slowly to below the superconducting transition temperature with the field parallel and perpendicular to the crystallographic *b* axis.

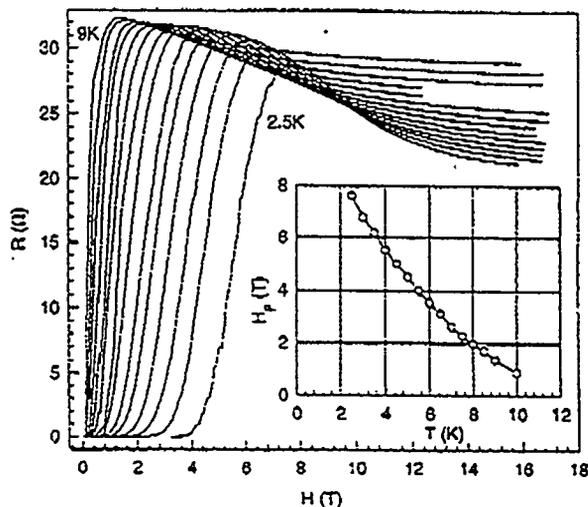


Fig. 1 Magnetoresistance as a function of field and temperature with  $H \parallel I \parallel b$ . The inset plots the  $H_p$  vs.  $T$ .

Shown in Fig. 1 is an overlay of magnetoresistance as a function of field for the  $H \parallel I \parallel b$  geom-

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etry at temperatures from  $T=2.5\text{K}$  to  $9\text{K}$  with an increment of  $0.5\text{K}$ . At a fixed temperature,  $R(H)$  is zero below an onset field  $H_0$ ;  $R(H)$  increases rapidly with  $H$  until a peak  $R_p$  is reached at  $H_p$ ; further increase in  $H$  leads to a negative magnetoresistance. At intermediate  $H$ ,  $R(H)$  crosses each other at different temperatures. At high field ( $\sim 16\text{T}$ ),  $R(H, T)$  increases monotonically with increasing  $T$ . The inset shows the temperature dependence of  $H_p$ .  $H_p$  increases with decreasing  $T$ , with an upward curvature at low temperatures.

Similar measurements have been performed with the field applied parallel to the conducting planes, as shown in Fig. 2. The different curves are for  $T=2.5\text{K}$  to  $10\text{K}$  with increments of  $0.5\text{K}$ . In contrast to the results presented in Fig. 1, no clear peak in  $R(H)$  is observed for all temperatures. At low temperatures, the onset field of measurable resistance is found to be much larger than that of  $H \parallel I \parallel b$ . For example, at  $T=2.5\text{K}$ ,  $H_0$  is about  $13\text{T}$  for  $H \perp I \parallel b$ , compared with  $4\text{T}$  for  $H \parallel I \parallel b$ .

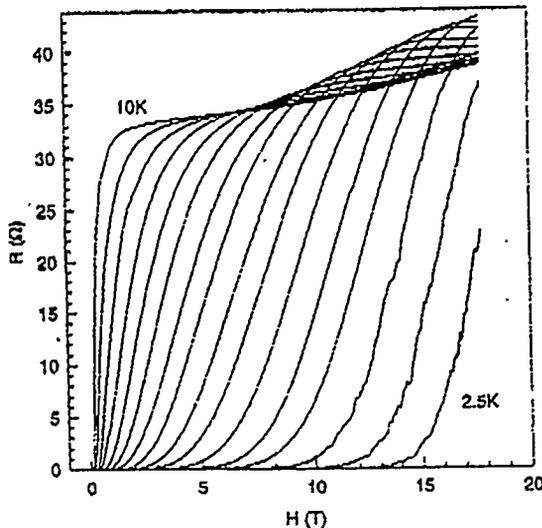


Fig. 2 Magnetoresistance as a function of field and temperature for  $H \perp I \parallel b$ .

For  $H \parallel I \parallel b$ ,  $H_p(T)$  is much smaller than  $H_{c2}(T)$  determined by magnetic measurements[7], suggesting that the peak is in the mixed state. The field dependence of  $R(H)$  can be analysed in terms of a stacked Josephson Junction

model with junction resistance given by  $R(H) = R_n' [I_0(\frac{E_J}{2kT})]^{-2}$ , where  $E_J$  is the Josephson coupling energy,  $R_n'$  is the junction resistance in the mixed state[6]. The negative magnetoresistance above the peak is more controversial. One possible model is that the negative magnetoresistance at high field is due to the increased density of state of quasi particles at Fermi level. The high field suppresses the fluctuations of the energy gap above the field dependent  $T_c$ , resulting in an apparent increase in conductivity[8]. Another possibility is that lattice distortions due to the presence of vortices will be suppressed at high field, leading to the negative  $R(H)$ [6].

For  $H \perp I \parallel b$ , the large  $H_0$  and positive magnetoresistance indicate that a different dissipation mechanism is at work. Qualitatively, the inter-layer resistance can result from phase fluctuations and flux flow. The absence of flux-flow resistance at small  $H$  suggests that the vortices are not the Abrikosov type, but Josephson-like, which contains no normal core. Unlike 2D pancake structure in the  $H \parallel b$ , the phase fluctuations are much suppressed with the parallel field. The positive magnetoresistance may be related to a change in the Fermi surface due to the applied field in the conducting plane. Measurements of angular dependence of magnetoresistance will help to resolve some of these issues.

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