# Flux creep and depth of pinning centers of an organic superconductor κ-(BEDT-TFF)$_2$Cu(NCS)$_2$

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The relaxation time of the magnetic moment $P_m(t)$ of a single crystal of an organic superconductor κ-(BEDT-TTF)$_2$Cu(NCS)$_2$ was investigated. The logarithmic relaxation rate corresponding to a thermally activated flux creep has a sharp maximum in a field $B \sim 3$ mT at 4.2 K. The average depth of the pinning centers was found to be $U_0 \sim 7.2\times10^{-3}$ eV.

Among the organic superconductors of greatest interest in the past two years has been the compound belonging to the family (BEDT-TTF)$_2$X, (BEDT-TTF(ET)—bisethylenedithiotetrathiofulvalene with an inorganic anion $[\mathrm{Cu(NCS)_2}]^{-2}$, with a transition temperature $T_c = 10.4$ K (Ref. 1) at a normal pressure. The effect of a magnetic field on the superconducting properties of (ET)$_2$Cu(NCS)$_2$ was previously studied in Refs. 2–5. The time dependences of the magnetization of this organic superconductor, however, have not yet been studied.

In the present letter we report the results of an experimental study of the relaxation rate of the magnetic moment of a single crystal κ-(ET)$_2$Cu(NCS)$_2$.

The measurements were carried out on a SQUID magnetometer.[6] The κ-(ET)$_2$Cu(NCS)$_2$ crystals were obtained by electrochemical oxidation of BEDT-TTF in 1,2-trichloroethane ($2\times10^{-3}$ mole/l) by passing a dc current ($J = 1.15$ μA) through a platinum electrode held at a constant temperature of 20 °C. As the electrolyte we used Cu(SCN) in combination with K(SCN), which was prepared immediately before the synthesis in an electrochemical cell by dissolving Cu(SCN) ($5\times10^{-3}$ mole/l) in the presence of K(SCN) and cyclic 18-crown-6 ether, used in the 1:1:1 proportion. The single crystal, mounted in the B⊥ *bc* orientation (*bc* is the crystal plane[7]) on the partition of the quartz cell, was attached on one edge by an apieson microdrop. The first critical field $H_{c1}$, determined from the point at which the $P_m(B)$ curve begins to deviate from linear behavior, was on the order of 2.7 mT, without allowance for the demagnetization factor. This value is in good agreement with that obtained in Ref. 2. The amount of the superconducting phase in the sample at 4.2 K in a field $B = 3.7$ mT was ~15%. The measurement procedure was the same as that used in Ref. 6. To measure the time dependences of the magnetic moment $P_m(t)$, we cooled the sample in zero field (the ZFC regime to 4.2 K). We then introduced a field $B_0$ and began to measure the magnetic moment.

The curves of the magnetic moment $P_m$ are shown in Fig. 1. The maximum variation of $P_m/P_{m0}$ in the time interval between $t_0$ and 1 h, is ~40% in a field $B \sim 20$ mT, where $P_{m0}$ is the magnetic moment 45 s after the introduction of the field ($t_0$).

  

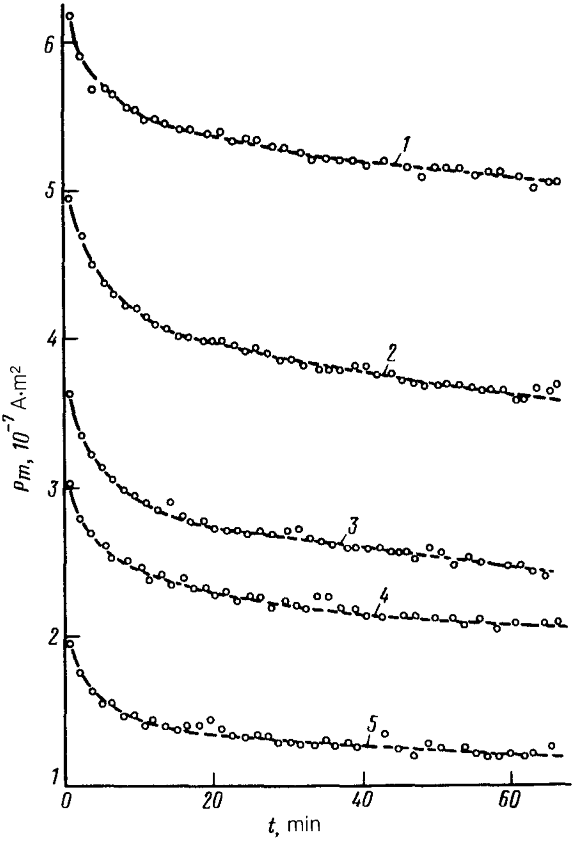


FIG. 1. Time dependences of the magnetic moment $P_m$ of a single crystal of $\kappa$–$(ET)_2Cu(NCS)_2$ at $T = 4.2$ K after ZFC in various fields $B$ for a $B \perp bc$ orientation at $B$ equal to 2.17 (1), 3.76 (2), 6.62 (3), 10.87 (4), and 20.54 (5) mT.

The variation of the magnetic moment of this magnitude is similar to the gigantic flux creep observed in a high-$T_c$ superconductor in Ref. 8. The time dependences of the magnetic moment $P_m(t)$ (Fig. 2) are described well by the dependence $P_m \sim \ln t$, suggesting that the relaxation of the magnetic moment in organic superconductors $\kappa$–$(ET)_2Cu(NCS)_2$ can be explained, just as in classical superconductors[9] and in high-$T_c$ superconductors (see, e.g., Ref. 10), on the basis of the model for the flux creep due to thermally activated motion of vortices. The relaxation rate of the magnetic moment $R = dP_m/d(\ln t)$ can be determined from the slope of the linear parts $P_m = f(\ln t)$ (Fig. 3). In contrast with the relaxation rate $R$, which was previously measured in another organic superconductor $\beta$–$(ET)_2I_3$ (Ref. 12), it has a sharp maximum in a field $B \sim 3$ mT. Such an $R(B)$ dependence is observed previously in high-$T_c$ superconducting single crystals[11] and can be explained on the basis of the

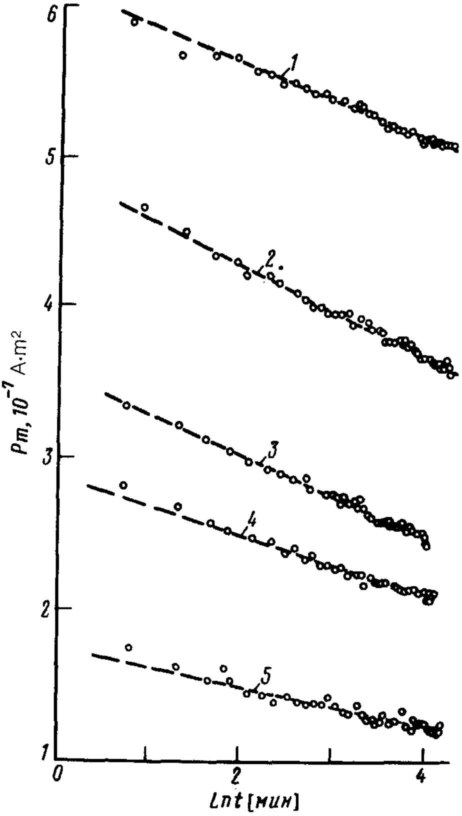


FIG. 2. Dependence of the magnetic moment $P_m$ of a single crystal of $\kappa$-$(ET)_2Cu(NCS)_2$ after ZFC on ln $t$ at 4.2 K and $B$ equal to 2.17 (1), 3.76 (2), 6.62 (3), 10.87 (4), and 20.54 (5) mT.

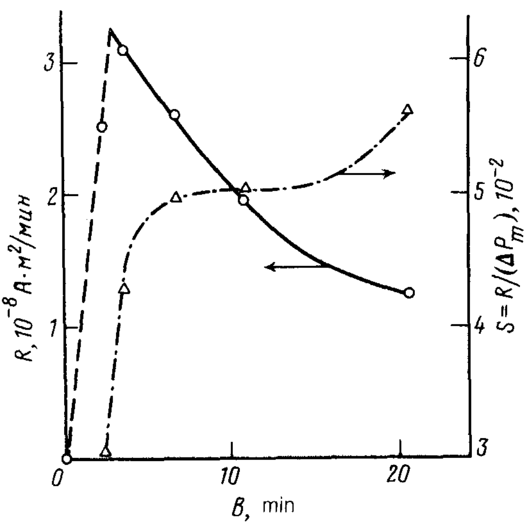


FIG. 3. Logarithmic relaxation rate $R$ and the reduced logarithmic relaxation rate $S$ versus the magnetic field $B$ for a single crystal of $\kappa$-$(ET)_2Cu(NCS)_2$, $B \perp bc$, $T = 4.2$ K.

Kim–Anderson critical-state model[13] in terms of a certain topological transition in the density distribution of the Abrikosov vortices at $B \geqslant B_{c1}(t)$. To eliminate the effect of the critical current on the logarithmic relaxation rate $R$, we introduce the reduced logarithmic relaxation rate $S$ (Fig. 3)[14]

$$S(B) = R/\Delta P_m = kT/U_0 \text{ при } B \geqslant B_t(t),$$

where $\Delta P_m$ is the width of the hysteresis loop, $\sim J_c$. The average pinning energy $U_0$ determined in this manner is on the order of 7.2 meV in a field $B \sim 6$ mT and decreases with increasing field $B$, consistent with an increase in $S$ in large fields (Fig. 3).

The value of $U_0$ turned out to be much lower than that determined for films,[14] polycrystals,[10] and single crystals[15] of high-$T_c$ superconductors and also for classical superconductors.[9] Such a low value of $U_0$ in the organic superconductor $\kappa$-$(ET)_2Cu(NCS)_2$ apparently is attributable to a fairly regular crystal structure, and hence to a small number of defects which could act as pinning centers.

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