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A.C. Susceptibility and Critical Current in the Organic Superconductor κ-$(ET)_2Cu(NCS)_2$*

M.A. Gonzalez,[a] M. Velez,[a] J.L. Vicent,[a] J. Schleuter,[b] J.M. Williams,[b] and G.W. Crabtree[c]

[a]Dpto. Fisica de Materiales, Facultad de Fisica, Universidad Complutense, 28040 Madrid, Spain

[b]Chemistry Division
[c]Materials Science Division
Argonne National Laboratory, Argonne, Illinois 60439

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M.A.Gonzalez[a], M.Velez[a], J.L.Vicent[a], J.Schleuter[b], J.M.Williams[b], G.W.Crabtree[c].

[a]Dpto. Fisica de Materiales, Facultad de Fisica, Universidad Complutense, 28040 Madrid, Spain.

[b]Chemistry Division, Argonne National Laboratory, Argonne IL 60439 (USA).

[c]Materials Science Division, Argonne National Laboratory, Argonne IL 60439 (USA).

The AC susceptibility (χ', χ'') has been measured in a single crystal of the organic superconductor κ-$(ET)_2Cu(NCS)_2$ (T_c = 9.5 K) as a function of the DC magnetic field, for several frequencies (10^2 Hz <f <10^4 Hz) and different AC fields (1μT <h_{ac} <300μT) at fixed temperatures.

Nonlinear AC response appears above 10 μT. We have studied this nonlinear regime and obtained the magnetic field and frequency dependence of the critical current density with a critical state model. J_c shows an exponential decrease as a function of the magnetic field and increases with increasing frequency. This results may be understood in terms of the collective pinning theory.

Despite their relatively low critical temperatures, organic superconductors have attracted a lot of interest because of steady progress in obtaining higher-T_c materials and due to their unusual superconducting and normal state physical properties. On the other hand, they exhibit a number of features (layered structure, anisotropy, short coherence lengths) that are similar to those of the High-T_c superconducting cuprates.

In this paper we report on the field and frequency dependence of the AC susceptiblity of the organic superconductor κ-$(ET)_2Cu(NCS)_2$. This technique has proved to be a very useful tool in the study of flux dynamics in type II superconductors [1,2].

The single crystal of κ-$(ET)_2Cu(NCS)_2$ was grown by electrocrystallization [3] The crystal was platelet like with average dimensions 2 x 1 x 0.2 mm^3. Both the AC and DC magnetic fields (hereafter h_{ac} and H_{dc}, respectively) were applied perpendicular to the plate plane, this is, perpendicular to the conducting organic layers (bc plane of the monoclinic structure). The zero field susceptibility transition occurred at 9.5 K, with a transition width of 0.25 K.

We have measured both the in phase χ' and out of phase χ'' components of the AC susceptiblity (χ=χ'-iχ'') with a 7225 Lakeshore susceptometer at different constant temperatures (± 20 mK). H_{dc} field was increased in 5 mT steps up to 0.3 T, and ac response was recorded for h_{ac} = 1, 10, 100, 300 μT at each point.

The field dependence of the susceptibility χ(H) at 5.5K is shown in figure 1 for two different frequencies (333 Hz and 3310 Hz). Linear response is only found in the low field region near perfect

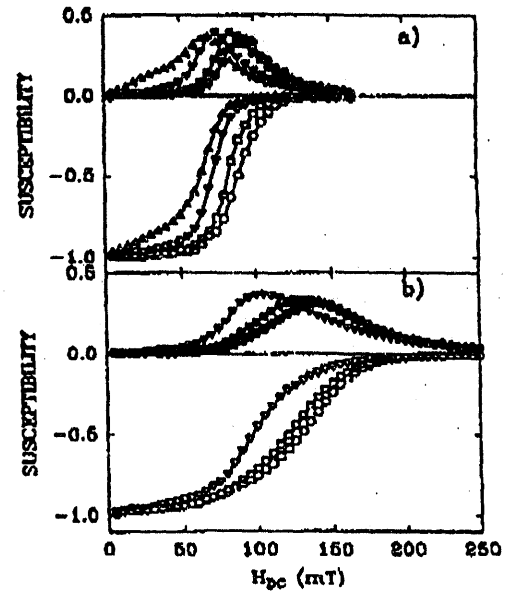

Figure 1. AC susceptibility at 5.5 K, for a) f=333 Hz and b) 3310 Hz, h_{ac} = 1μT ○, 10μT □, 100 μT ▽ 300 μT △ .

diamagnetic shielding. A strong dependence on h_{ac} amplitude is found at the transition. For higher frequencies both the transition and the onset of nonlinearity are delayed to higher H_{dc}, indicating a smaller penetration of the AC field inside the sample. Upon increasing temperature this nonlinear behavior can be found almost from the lowest H_{dc} considered, however it can be completely attributed to nonlinear vortex response since $\mu_0 h_{ac} < 30\ \mu T << 1 mT < \frac{1}{2} H_{dc}$, that is, h_{ac} is always a small perturbation with respect to the applied H_{dc}.

This behavior can be understood considering that the sample is in a critical state with critical current $J_c(T,H,f)$. We observe a linear response while the current induced by the ac field is $J \sim h_{ac} << J_c$, as it increases $J \approx J_c$ and χ is given as a function of the Bean penetration depth $\lambda = h_{ac}/J_c$. We can thus obtain the field and frequency dependence of J_c using the following inversion procedure [4]. For a fixed value of $\chi'(h_{ac},H_{dc})=c$, λ is also fixed and $J_c = \lambda h_{ac}$. We may plot pairs of points $\lambda(c)h_{ac}$ vs H_{dc}, choosing the $\lambda(c)$ values to obtain a smooth curve. λ is normalized assuming full penetration at the peak in χ''. In this way we also find the function $\chi(\lambda)$ for our sample geometry. It is somehow different from the theoretical prediction for an infinite cylinder, but it does not depend eihter on frequency or on temperature, as expected. This is reasonable in view of the high demagnetizing factor of our sample $N \approx 0.7$.

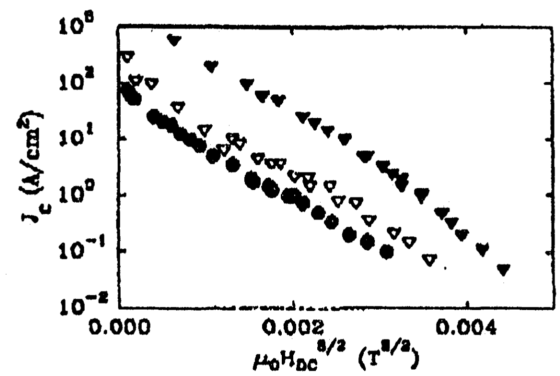

Figure 2. Critical current vs H_{dc} at 7.5 K for f=110 Hz ●, 330 Hz ▽, and 3310 Hz ▼.

The data taken at $h_{ac} = 1\mu T$ always lied below the smooth curve obtained for higher h_{ac}, therefore suggesting that the critical state has not been reached yet and the current flowing in the sample is much smaller than J_c. The field dependence of the critical current at 7.5 K for 110 Hz, 333 Hz and 3310 Hz, obtained in such a way is shown of figure 2. At low H_{dc} it shows an exponential decrease that may be expressed as

$$J_c = J_c(H_{dc}=0,f,T)\exp(-aH^{3/2})$$

with a frequency independent characteristic constant $a = 930\ T^{3/2}$ and $165\ T^{3/2}$ for 7.5 K and 5.5 K respectively. At 7.5 K there is also a steeper decrease towards $J_c=0$ after a frequency independent crossover field $\mu_0 H_{cross} \approx 0.02$ T. This may be interpreted in terms of collective pinning theory in the small bundle regime [5], that predicts

$$J_c \sim \exp(-2c(L_c/a_0)^3)$$

where c is a constant of order unity, L_c is the vortex coherence length and a_0 the vortex lattice constant. A crossover to a large bundle regime should occur at $\mu_0 H_{cross}$, corresponding to $L_c = a_0$. We find $L_c = 300$ nm and c=1.5 in this case.The zero field critical current increases with frequency as expected for a thermal activation mechanism.

In summary, we have studied the AC susceptiblity of the organic superconductor κ-$(ET)_2Cu(NCS)_2$ in the nonlinear regime. The field dependence of J_c can be interpreted in terms of collective creep in the small bundle regime.

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