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Experimental evidence of a non-local resistivity in a vortex line liquid

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We present transport measurements on YBCO single crystals in the vortex liquid regime using the DC flux transformer geometry. We show that the data are inconsistent with the material being an anisotropic, local conductor. The results provided evidence for non-local transport which indicate that there can be correlated vortex motion over macroscopic distances in this system. We have shown that this correlated vortex motion can be destroyed by either thermal fluctuations or the applications of large driving forces.

· The effects of vortex line fluctuations in the mixed state of high temperature superconductors introduces novel physical phenomena important in explaining the experimental results.

In several earlier works[1,2], it has been demonstrated that in the vortex liquid regime of YBCO crystals, the vortices are well connected extended objects at lower temperatures and they becomes decorrelated at a well defined temperature $T_{th}(H)$. This has been probed using the modified DC flux transformer geometry (see inset Fig. 1). The identification of $T_{th}(H)$ as the temperature where the vortex correlation length in the c direction becomes equal to the sample thickness[3], suggest that the correlated vortex motion can induces an electric field **E** related to the current density **j** by a non local constitutive relation[4] of the form

$$E(r) = \int \rho(r - r')j(r')dr'$$

The above equation indicates that a current **j(r')** flowing at position **r'** pushes on the correlated vortices which moves inducing an electric field far away from **r'**[4].

As we will show, the Montgomery[5] type of analysis, which assume a local resistivity, cannot fit consistently the experimental results for temperatures $T > T_{th}$, where we know that the data are in the linear response regime[3].

The results reported here correspond to twinned crystal, grown as those described in ref. 1.

To see the effect of a non-local resistivity on the transport experiments, we follow the argument given by Huse and Majumdar[4].

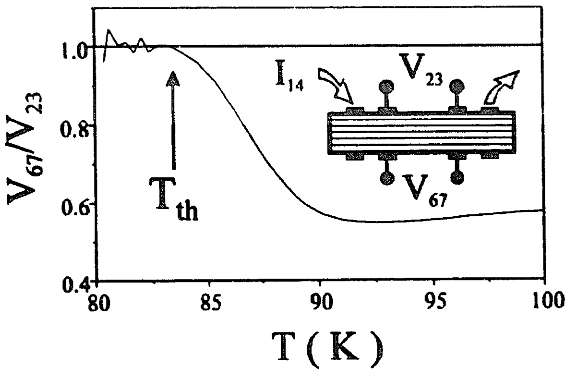

Figure 1. Shown are the measured temperature dependence of V_{67}/V_{23} for applied fields of 50 kOe. The contact geometry is shown in the inset.

Consider two simple experiments to probe the anisotropic resistivities in this system. We will use the notation V_{ij} to designed the voltage drop between the contacts i and j (similar notation we will use for the current injection electrodes). The first is shown in the inset of Fig. 1.: the current is injected primarilly parallel to the ab planes (I_{14})

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and we measured the voltage drops V_{23} and V_{67} as a function of temperature. In Fig. 1 we show the ratios V_{67}/V_{23} versus temperature, for a field H=50 kOe parallel to c axis. In the normal state ($T_c \cong 93K$), $V_{23} > V_{67}$ because of the strong anisotropy with $\rho_c >> \rho_{ab}$. Decreasing the temperature to T_{th}, this ratio approach to 1 ($V_{23} = V_{67}$ at $T = T_{th}$). In a local conductor this will occur if ρ_c decrease faster than ρ_{ab}. Using a Montgomery type of analysis the apparent resistivities ratios (ρ_c/ρ_{ab}) can be extract and the result is shown in fig. 3.

The second experiment is shown in the inset of Fig. 2.: now, the current is injected primarilly parallel to the c axis (I_{15}) and we measured the voltages V_{26},, V_{37} and V_{48} as a function of temperature. In Fig. 2, the measured temperature dependence of the ratios V_{37}/V_{26}, V_{48}/V_{37}, V_{48}/V_{26} is plotted.

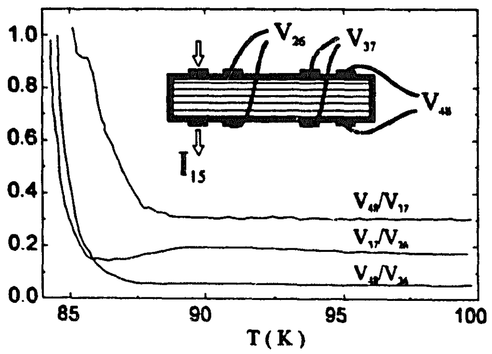

Figure 2. Measured temperature dependence of V_{37}/V_{26}, V_{48}/V_{37} and V_{48}/V_{26}. The inset show the experimental contact configuration.

The data show that these ratios also approach 1 as T_{th} is reached from above. This ocurr in a local conductor only if ρ_{ab} decreased faster than ρ_c, in evident contradiction with the previous result.

The apparent (ρ_c/ρ_{ab}) extracted from the second experiment[1] is shown in Fig. 3.

As is evident, a local analysis can be used to describe the experiments in the normal state, but in the mixed state the huge discrepancies between the results of these two experiments shows clearly where non-local effects become important. A similar analysis in BSCCO crystals[6] shows that in this system a local description of the transport properties can fit consistently the experimental data.

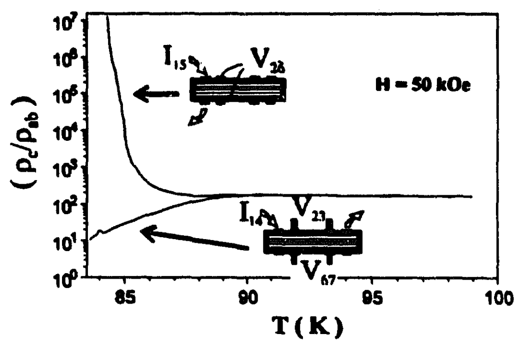

Figure 3. Apparent values of (ρ_c/ρ_{ab}) extracted from the experiments shows in the insets and using a local analisis.

We want to remark, that the linear response has been experimentally checked in the ab as c direction[3] for all the data shown.

In conclusion, we have shown that in the mixed state of YBCO, the experimental results are highly inconsistent with the material being an anisotropic, local conductor, i. e., the local electric field in a superconductor is determined by currents flowing tens of microns away acting on very distant sections of vortex lines.

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