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Physica C 408–410 (2004) 562–563

PHYSICA C

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What a superconducting transition should look like: extrapolating data from scaling plots

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Abstract

We compare measured current–voltage measurements of a $YBa_2Cu_3O_{7-\delta}$ film with data extrapolated from various scaling collapses. We find that in general the extrapolated data show opposite concavity about the transition temperature at all currents; whereas the experimental data do not. This indicates that the experiments do not demonstrate unambiguous evidence for a superconducting transition.

PACS: 74.40.+k; 74.25.Dw; 74.60.Ge
Keywords: Phase transitions; Scaling; Vortex glass

The well-known scaling theory of Fisher et al. [1] that describes superconducting phase transitions is widely used to analyze experimental data, and there is a consensus that data agree with the theory. The scaling theory predicts that DC current–voltage (I–V) measurements near the transition should behave according to

$$V\xi^{2+z-D}/I = \chi_\pm(I\xi^{D-1}/T), \tag{1}$$

where D is the dimensionality, T is the temperature, $\xi \sim |1 - T/T_c|^{-\nu}$ is the diverging correlation length near the transition temperature (T_c, or denoted as T_g in field), ν is the static critical exponent, z is the dynamic exponent, and $\chi_\pm$ are scaling functions.

Although experimental data have been widely reported to agree with Eq. (1), some have argued that I–V scaling has considerable flexibility and may not necessarily represent a continuous superconducting transition [2–5]. We have argued that measured data should satisfy an opposite concavity criterion; as is seen in the data extrapolated from scaling collapses [2]. However, the experimental data do not satisfy this rigorous self-consistency test. Here, we extend the study of extrapolated data to the high current regime and for scaling collapses with various T_gs and exponents.

Fig. 1 is a data collapse of I–V measurements from Ref. [2] taken on a 2200 Å $YBa_2Cu_3O_{7-\delta}$ film in a 4 T perpendicular field. As typically found, these data can be collapsed onto two scaling functions of the form of Eq. (1). The flexibility of the conventional analysis is demonstrated by successfully collapsing I–V data from the same sample by using different exponents and different T_gs (Fig. 2).

Taking either scaling collapse to be the correct representation of the phase transition, we can extrapolate I–V data to currents and voltages outside the experimental range [2]. We choose a temperature and current and substitute these values into $(I/T)|1 - T/T_g|^{-2\nu}$ along the x-axis, as is represented by the vertical line in Fig. 1. We then determine the extrapolated voltage by solving for V in the term $(V/I)|1 - T/T_g|^{\nu(1-z)}$ along the y-axis.

The open symbols in Fig. 3 are the extrapolated data from the collapse of Fig. 1. These data are plotted as $(\partial \log V/\partial \log I)_T$ vs I in order to demonstrate the stark differences with the experimental data. Clearly, the extrapolated $\log(V)$ vs $\log(I)$ data show opposite concavity (equivalent to opposite slope in Fig. 3) at all

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0921-4534/$ - see front matter © 2004 Published by Elsevier B.V.
doi:10.1016/j.physc.2004.03.202

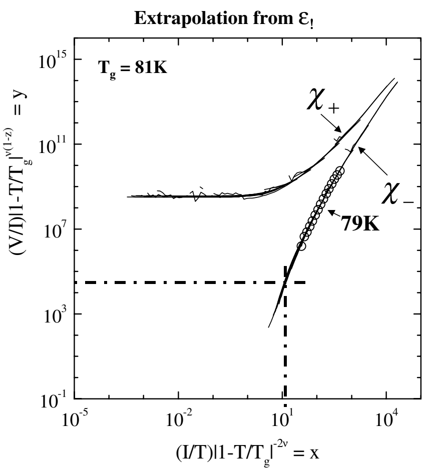

Fig. 1. Collapse of I–V curves from Ref. [2] using conventional analysis and exponents. $T_g = 81$ K; $\nu = 1.5$; $z = 5.46$. The circles represent the data at 79 K.

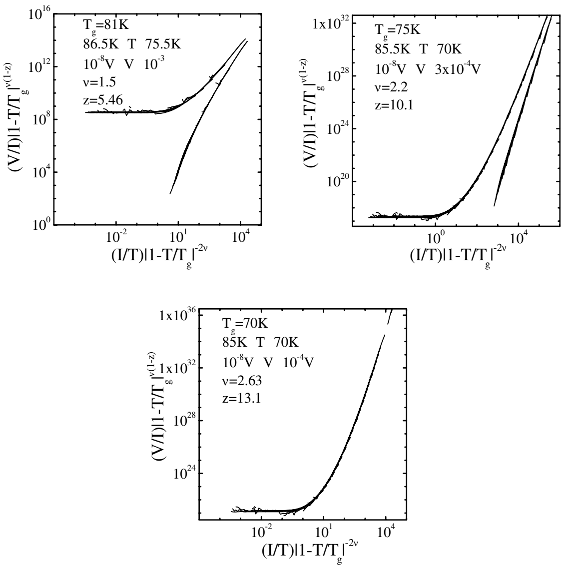

Fig. 2. Data collapse of I–V measurements from Ref. [2] with $T_g = 75$ K, $\nu = 2.2$, and $z = 10.1$.

current values, whereas the experimental data (the small dots) do not.

In Fig. 4 we likewise plot the extrapolated data from the collapse of Fig. 2 and compare it to the same experimental data. Again, we find that the extrapolated data demonstrate opposite concavity (this time about $T_g = 75$ K), whereas the measurements in this regime do not.

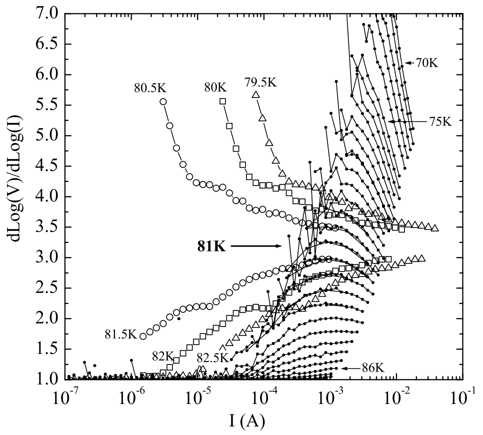

Fig. 3. Extrapolated data from collapse of Fig. 1 plotted as open circles, squares, and triangles. Experimental data from Ref. [2] plotted as small dots.

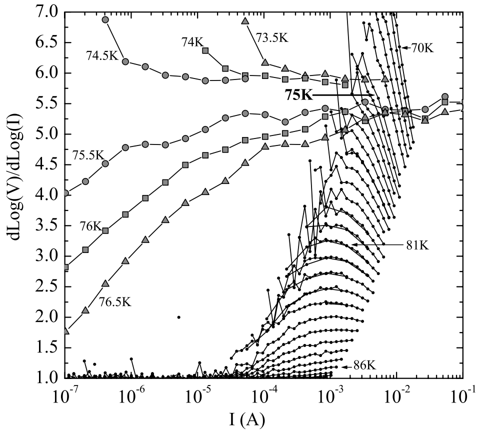

Fig. 4. Extrapolated data from collapse of Fig. 2 plotted as large circles, squares, and triangles. Experimental data from Ref. [2] plotted as small dots.

The behavior of the extrapolated data in Figs. 3 and 4 should not both occur over the same current ranges within the same data set. Therefore, this sort of opposite concavity could be used as an unambiguous signature for a phase transition. Since the measured data do not show this opposite concavity, the experiments do not unambiguously demonstrate evidence of a superconducting transition.

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