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SCALING OF THE IRREVERSIBLE MAGNETIZATION CURVES OF YBaCuO

E. R. Yacoby, Y. Wolfus and Y. Yeshurun
Department of Physics, Bar-Ilan University, Ramat-Gan, Israel
and
I. Felner and H. Sompolinsky
Racah Institute for Physics, Hebrew University, Jerusalem, Israel

A one-parameter scaling of the magnetization curves of the high-temperature superconductor YBaCuO cause all data points in the irreversible regime to collapse into a single curve. We show that this scaling feature is predicted by the Bean model.

1. INTRODUCTION

The field and temperature dependence of the magnetization in the irreversible regime is conventionally described by the Bean model.[1] This model has also been extensively used[2,3] to explain magnetic data for high – temperature superconductors (HTSC). In an effort to explore experimentally the validity of the Bean model in HTSC we have recently[4] presented a detailed study of the field dependence of the magnetization of a ceramic $Tl_2Ba_2Ca_2Cu_3O_{10}$ with a superconducting transition temperature $T_c = 113K$. For this sample we have found a surprising new feature: A one-parameter scaling of the magnetization curves causes all data points in the irreversible regime to collapse into a single curve $M = H^*f_\pm(H/H^*)$. The scaling field H^* is inversely proportional to temperature and f_+ and f_- are the scaling functions for fields H above and below H^*. Under certain conditions, these scaling features are intrinsic to the Bean model and are thus expected to occur in all type II superconductors and, in particular, for other HTSC. The purpose of this article is to support experimentally this prediction of the Bean model. We exhibit detailed magnetic data for YBaCuO, and demonstrate the scaling features for this material.

2. EXPERIMENTAL

In Ref. 5 we describe sample preparation. The magnetization M of the 119 mg disk-like sample (diameter: 5 mm, thickness: 1.3 mm) is measured with a commercial (SHE) SQUID magnetometer with the field oriented in the disk plane in order to minimize demagnetization corrections. We follow a conventional procedure: The sample is cooled in zero field to temperature T and the magnetization curves M(H) are recorded up to 35 kOe.

3. RESULTS

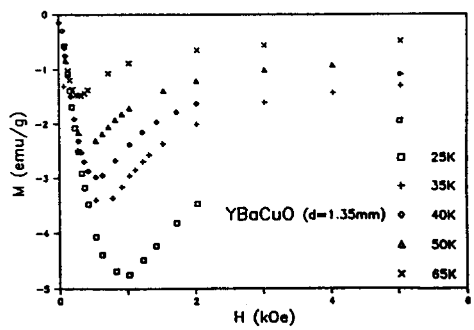

FIGURE 1

Magnetization curves for YBaCuO at the indicated temperatures. (High field data is not shown here.)

Fig. 1 exhibits typical M vs H data at temperatures ranging from 25 to 60 K. Correction for demagnetization fields have a negligible effect (less than 2%) on data points. We note that as temperature decreases, the minimum in the magnetization curves is pushed to higher fields and to larger absolute

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values. This last observation is the basis for our scaling procedure. We define H_m as the field for which M reaches its minimum value M_m. We then scale the field values of each isotherm by H_m, and similarly, we scale the magnetization values by M_m. As a result of this simple scaling procedure, data points for a wide range of temperatures and fields collapse into a single curve, as shown in Fig. 2. The success of this scaling procedure is even more impressive once we appreciate the implication of the temperature dependence of the two scaling parameters. Fig. 3 demonstrates that both H_m and M_m scale with the inverse of the temperature. In other words, $M_m \propto H_m$, and hence the scaling procedure is actually a one parameter scaling.

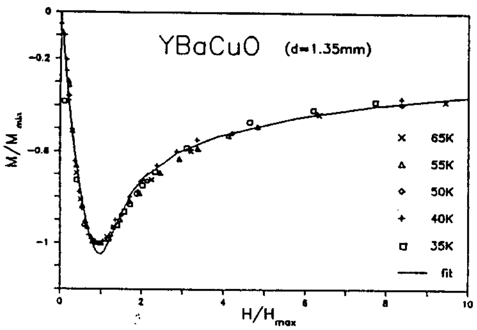

FIGURE 2

Scaled magnetization curves for YBaCuO ($H/H_m \leq 10$). Solid line is a fit to Eqs. 3 and 4 with n=0.4.

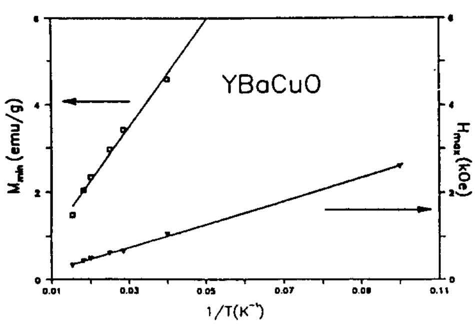

FIGURE 3

The scaling parameters H_m and M_m as a function of the inverse temperature.

4. DISCUSSION

The scaling features of the irreversible magnetization can be explained in the framework of the Bean model. In Ref. 4 we show that the original Bean equations[1] for a slab of thickness D may be transformed to

$$\frac{4\pi M}{H^\star} = -\left(\frac{H}{H^\star}\right) + \frac{n+1}{n+2}\left(\frac{H}{H^\star}\right)^{n+2}, \qquad (1)$$

$$\frac{4\pi M}{H^\star} = -\left(\frac{H}{H^\star}\right) + \frac{n+1}{n+2}\left[\left(\frac{H}{H^\star}\right)^{n+2} - \left\{\left(\frac{H}{H^\star}\right)^{n+1} - 1\right\}^{(n+2)/(n+1)}\right], \qquad (2)$$

where $C \equiv 0.4\pi(n+1)J_{c1}H_{c1}^{n}$ and $H^\star \equiv (CD/2 + H_{c1}^{n+1})^{1/(n+1)}$ is the lowest field for which currents flow through the entire volume of the sample. In summary,

$$4\pi M = H^\star f_\pm(H/H^\star), \qquad (3)$$

where f_- and f_+ are the scaling functions for $H/H^\star \leq 1$ and for $H/H^\star \geq 1$ respectively. Thus, a one parameter scaling is an intrinsic feature of the extended Bean model.

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