Irreversible Magnetization above Critical Temperature in Superconducting $Y_{0.47}Pr_{0.53}Ba_2Cu_3O_{7-\delta}$

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Abstract. Using magnetization measurements, we report the existence of an irreversibility in the magnetization in $Y_{0.47}Pr_{0.53}Ba_2Cu_3O_{7-\delta}$ single crystals above the critical temperature (T_c = 13 K) that is visible up to 200 K. Magnetization vs temperature displays irreversibility up to an applied field of 500 Oe. We noticed a weak irreversibility at high temperatures and a stronger one at low temperatures. In the weak irreversibility regime, both zero-field- and field-cooled magnetization follow similar Curie-Weiss (C-W) dependences, with slightly different parameters. The C-W parameters, decrease fast with increasing field. The C-W temperature is negative, suggesting that the average interaction between spins is antiferromagnetic. All these data suggest that the paramagnetic state is in fact a free spin liquid containing floating antiferromagnetic clusters as well as superconducting phase fluctuations.

Keywords: $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$,, Irreversibility, magnetic susceptibility, glassiness, superparamagnetism,.
PACS: 75.20, 74.25Ha, 74.72-h, 75.50 Ee

INTRODUCTION

The substitution of praseodymium for Y in $YBa_2Cu_3O_{7-\delta}$ has a charge antidoping effect driving the system in the underdoped state regardless of the oxygen content. In turn, the reduction of free carriers would make the system unstable relative to antiferromagnetic (AFM) ordering. Specifically, it was found that for a Pr content higher than x_c = 0.55 the compound is no longer superconducting (SC) but displays AFM order in both Pr and Cu spins [1,2]. Short range AFM correlations have been reported even in the range $0.04 \le x \le 0.55$, hence, within the superconducting dome [2]. Additionally, the low charge density generates phase separation and, with the reduced dimensionality, strong fluctuations of the competing orders in the vicinity of the phase transitions. There is a complex picture that undoubtedly prolongs at high temperatures changing the expected typical paramagnetic state.

Therefore, it is of interest to investigate the magnetic response of the $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ system at high temperatures for Pr concentrations in the neighborhood of the SC–AFM transition.

EXPERIMENTAL, RESULTS, AND DISCUSSION

The magnetization M of a $Y_{0.47}Pr_{0.53}Ba_2Cu_3O_{7-\delta}$ single crystal of size $0.77 \times 0.57 \times 0.067$ mm^3, grown using a standard procedure, was measured with a SQUID magnetometer. The single crystal was mounted on a Teflon support which was submitted to the same investigations as the sample in order to subtract the background. Each run was performed after the crystal was warmed up to temperatures higher than 200 K and cooled in zero-magnetic field down to the temperature of investigation. The sample has a critical temperature T_c = 13 K as obtained from *ac*-susceptibility and transport measurements

Figure 1 shows the magnetic susceptibility χ vs temperature T for different fields in the range 20 - 800 Oe. There is a salient difference between the zero-field-cooled (ZFC) and field-cooled (FC) branches of the susceptibility. Additionally, the difference is field dependent. The ZFC susceptibility is typical superconducting at low temperatures for fields $H \le$ 100 Oe, exhibits a wide positive maximum, and, at high T, decreases following a Curie-Weiss (CW) law.

CP899, *Sixth International Conference of the Balkan Physical Union,* edited by S. A. Cetin and I. Hikmet
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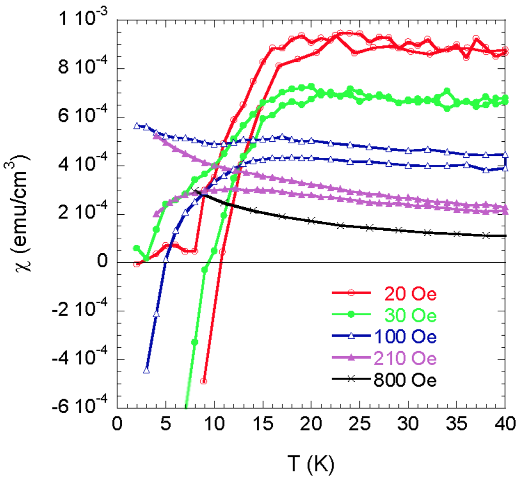

FIGURE 1. DC magnetic susceptibility χ vs temperature at low fields.

The FC susceptibility χ is extremely field sensitive. It hardly reaches a zero value for the lowest field (Fig. 2) and, as T decreases, evolves from a decreasing function for $H \leq 80$ Oe to an increasing one. A conspicuous hysteresis is present up to 200 Oe, with a

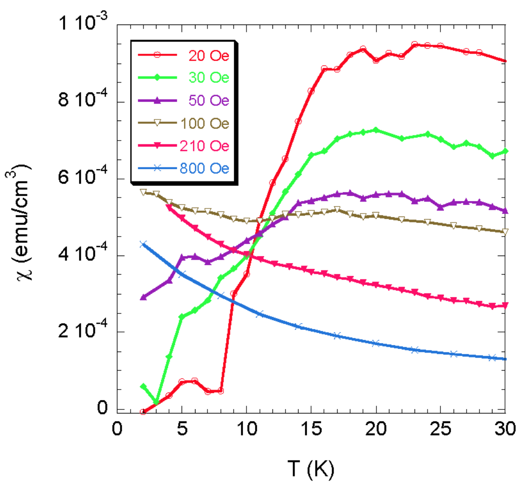

FIGURE 2. Field-cooled DC magnetic susceptibility χ vs temperature in the range of strong irreversibility.

strong irreversibility below the peak temperature and a weaker one at higher T (Fig. 1). The weak irreversibility reaches a maximum at $H \approx 100$ Oe. In the latter regime both ZFC and FC branches follow a CW dependence $\chi = \chi_0 + C/(T - \theta_{CW})$ with strongly H dependent parameters. For $H > 500$ Oe the hysteresis disappears and χ (T) obeys the CW dependence in the whole T range. The H dependence remains even in the paramagnetic state. Because ZFC and FC branches in the weak irreversible regime are close to each other, we have obtained the CW parameters in this T range using the reversible susceptibility $[\chi]_{rev} = (\chi_{ZFC} + \chi_{FC})/2$. It also follows a CW law (Fig. 3) of antiferromagnetic origin but with field dependent parameters.

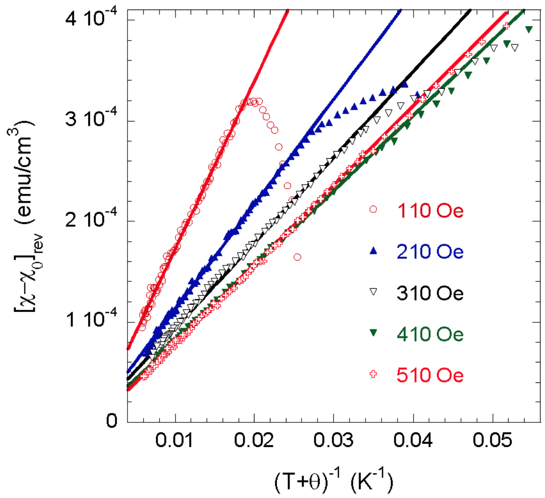

FIGURE 3 Curie-Weiss plot of reversible susceptibilityt for different applied fields. Solid lines are fits of the linear part

A CW dependence requires the existence of free moments in contrast to the history dependence. Therefore, we assume that frustration of the AFM order due to the long range Coulomb interaction creates a spin randomness envisaged as a cluster spin glass [3]. The superconductivity is weakened by the coexisting glassiness, hence, is very sensitive to H. Each cluster has an antiferromagnetically ordered kernel and an antidomain wall which collects the frustration. With increasing T, the cluster glass melts into a viscous ”liquid” of clusters floating in a “sea” of single ions and superconducting fluctuations. Therefore, the clusters behave as a superparamagnetic system up to their disintegration at high temperature.

ACKNOWLEDGMENTS

This research was supported by the National Science Foundation under Grant No. DMR-0406471 at KSU, the US Department of Energy under Grant No. DEFG02-04ER46105 at UCSD, and the Romanian NASR under the Projects CEEX 73 and MATNANTECH 260/2004 at NIMP.

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