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Field-induced antiferromagnetic order in $Pr_{2-x}Ce_xCuO_4$

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Abstract

μSR measurements of a superconducting $Pr_{2-x}Ce_xCuO_4$ single crystal show that a weak external magnetic field of only 91 Oe applied perpendicular to the CuO_2 planes is sufficient to induce long-range antiferromagnetic (AF) order below the superconducting transition temperature, T_c. The field-induced AF order extends throughout the volume of the sample, reflecting the close proximity of AF and superconducting phases in electron-doped cuprates.

Keywords: Magnetism; μSR

Experimentally, enhanced AF correlations have been observed in the superconducting state of *hole-doped* cuprates upon application of an external magnetic field [1–8]. These findings suggest that suppression of the superconducting order parameter by a magnetic field stabilizes the AF order characteristic of the undoped parent compounds. *Electron-doped* cuprates exhibit long-range AF order and superconductivity over much wider and narrower ranges of carrier concentration, respectively. Furthermore, unlike hole-doped cuprates, superconductivity appears at or near the doping concentration at which AF order disappears [9]. Consequently, there is reason to expect that superconductivity is more easily suppressed by magnetic field in the electron-doped systems.

Here we report μSR measurements on a single crystal of superconducting $Pr_{2-x}Ce_xCuO_4$ (PCCO), grown at the University of Maryland by a directional solidification method [10]. The plate-like crystal was 0.07 mm thick, with an a–b plane area of ~6.5 mm^2, a mass of 3.74 mg and a T_c value of approximately 16 K. The μSR measurements were performed at TRIUMF in Vancouver, Canada. We have determined that the implanted μ^+ resides within a radius of 1 Å from the O(2) site midway between CuO_2 planes. In zero-external field, measurements down to 2.3 K reveal an inhomogeneous distribution of quasi-static Cu moments, most likely arising from local variations in charge doping.

An external magnetic field H directed perpendicular to the CuO_2 layers is found to induce a magnetic moment on the Pr ions—identifiable above T_c as a negative μ^+ Knight shift. Fig. 1 shows the temperature dependence of the average local magnetic field at the μ^+ stopping site, B_0 and the bulk magnetic susceptibility, $\chi^\perp$, both measured under field-cooling conditions. The increase of B_0 indicates the onset of an additional source of local magnetic field, B^* in the superconducting state. From the dependence of the increase of B_0 below T_c on H, we have determined that B^* lies in the a–b plane at the μ^+ stopping site.

Fig. 2 shows two proposed magnetic structures for the Cu spins in Pr_2CuO_4. Canting of the Cu spins out of the a–b plane by an angle θ produces a net dipolar field

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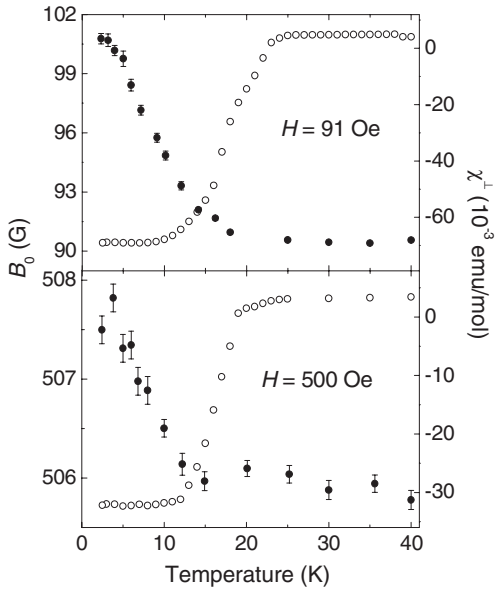

Fig. 1. Temperature dependence of B_0 (solid circles) and $\chi^{\perp}$ (open circles), at $H = 91$ Oe and 500 Oe directed perpendicular to the CuO_2 layers.

that has the same magnitude and lies in the *a–b* plane at all O(2) sites in Fig. 2(a) and (b). This is consistent with a single μ^+ site. Fig. 2(c) shows how the magnitude of the local field at the O(2) sites due to the dipolar fields of the Cu spins changes as a function of θ. Canting of less than 15° can account for the magnitude of B^*. We note that the noncollinear structure of Fig. 2(b) with Cu spins canted out of the *a–b* plane by ~20°, was proposed in an earlier μSR study of nonsuperconducting underdoped PCCO [12].

We have shown that the enhanced local magnetic field detected by μSR in the vortex state of PCCO arises from the onset of AF order of the Cu spins. The AF order is detectable throughout the sample, *i.e.* all muons see essentially the same field increase below T_c. We surmise that field-induced AF order in the vortex cores spreads into the surrounding regions because of sample inhomogeneity.

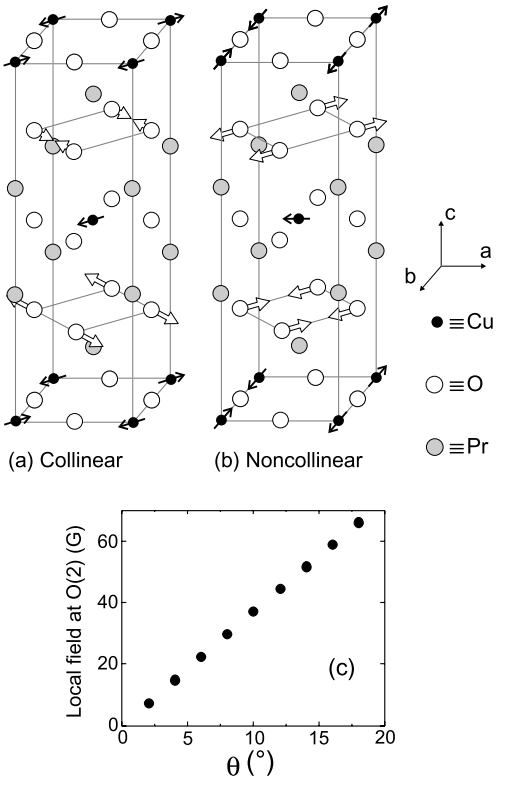

Fig. 2. Cu-spin structures with AF order in the CuO_2 layers. (a) Collinear La_2NiO_4-type structure, where the Cu spins are aligned parallel or anti-parallel to the [1 1 0] direction. (b) Noncollinear structure, where the Cu spins alternate along the [1 0 0] and [0 1 0] directions as one moves along the *c*-axis. (c) The magnitude of the local magnetic field at the O(2) sites (μ^+ stopping site) vs. θ. We have used the ordered Cu moment of $0.4\mu_B$ determined by neutron scattering in Pr_2CuO_4 [11]. The open arrows in (a) and (b) indicate the direction of the local field at each of the O(2) sites.

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