Experiment E1042

βNMR investigation of the magnetism near the surface of unconventional superconductors

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In contrast to the detailed experimental understanding of the hole-doped cuprate high temperature superconductors, less is known about the corresponding electron-doped materials. One key issue is the pairing symmetry in the superconducting state, with s- and d-wave order parameters being the most debated. The d-wave pairing symmetry is supported by phase-sensitive and angle-resolved photoemission experiments, while measurements of thermodynamic quantities showed more evidence of s-wave symmetry. One of the most studied electron-doped compounds is $Pr_{2-x}Ce_xCuO_4$ (PCCO), where recent measurements have reached inconsistent conclusions. Techniques such μSR, NMR, and small-angle neutron diffraction (SANS) measurements are often used to study the internal field variation within the vortex state (above the lower critical field). In this experiment, we performed the first βNMR study of the vortex state in superconducting PCCO films.

Using βNMR, we studied an optimally doped ($T_C \sim$ 20 K) sample of PCCO. A beam of $^8Li^+$ with kinetic energy $E = 3$ keV was implanted into a thin overlayer of Ag (400Å thick) on the PCCO film (3000Å thick). The measurements were carried out in the vortex state by applying a magnetic field $B_{ex} = 100$ G normal to the film (the crystalline c-axis). In this geometry, currents flowing in the ab planes determine the magnetic field profile both inside the crystal, *and* in the Ag layer. The field in the silver, however, will have little or no contribution from the intrinsic atomic magnetism in the PCCO (e.g. due to Pr^{3+}). Measurements of the temperature dependence of the βNMR resonance in the Ag showed a dramatic broadening in the vortex state (below T_C). The width of the line increases as temperature is decreased, while it is T-independent above the transition. Note that the data was collected in a newly developed and implemented mode of βNMR that employs pulsed RF field as well as pulsed beam. This mode allows a measurement of the lineshape free from many systematic effects found in continuous data acquisition modes.

In Fig. 1-a, we display the measured lineshape at four different temperatures. The spectrum, with a T-independent line width above the transition temperature T_C, broadens as we cool below T_C. The resulting lineshape is inconsistent with either the ideal triangular or square lattice arrangements, i.e. it is missing the characteristic high field tail and is too symmetric. This likely reflects a significant change of the vortex state in the thin film geometry. To quantify our measurements, we extracted the second moment, $\langle \Delta B^2 \rangle$, a measure of the line width. The second moment, plotted in Fig. 1-b, shows evidence of a flat temperature dependence at low temperatures, but better statistics are required to determine whether this T dependence can be used to discriminate between s and d wave states. We can tentatively extract, from $\langle \Delta B^2 \rangle$ an estimate of the low temperature magnetic penetration depth in PCCO, λ Normalizing to our results in the conventional superconductor $NbSe_2$ at similar fields, yields values of λ in PCCO between 250-300 nm, consistent with other results (180-300 nm).

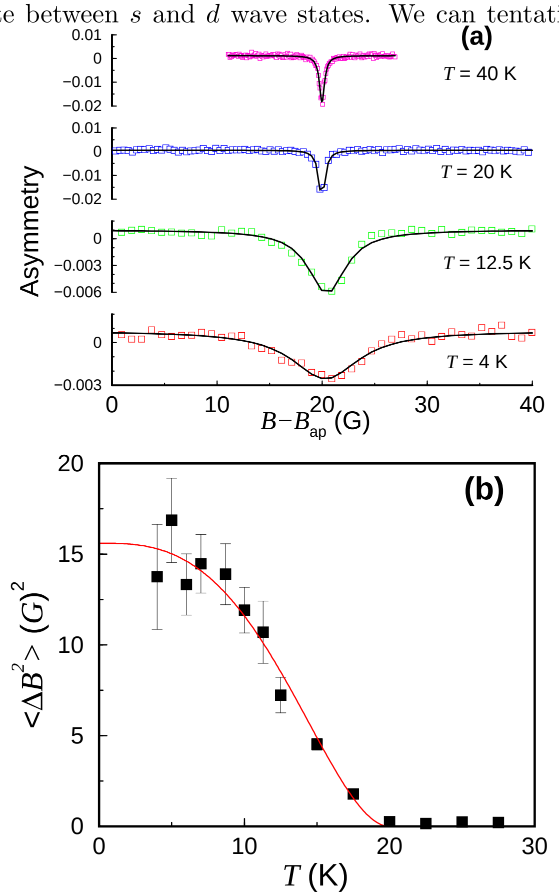

FIG. 1: (a) The asymmetry of $^8Li^+$ ions stopping in Ag/PCCO in $B_{\rm ap} = 100$ G. The solid line are Lorentzian fits. (b) The temperature dependence of the second moment is plotted. The solid line is a fit using $\langle \Delta B^2 \rangle(T) = \langle \Delta B^2 \rangle(0)(1-(T/T_C)^n)^2$. Best fit is found using $T_C = 20$ K and $n = 2.86$.

As the deceleration system is commissioned on the βNQR spectrometer, this experiment will focus there on measurements in PCCO and related materials, seeking signatures of interfacial magnetism.