Neutron Scattering Study of YBCO6.31: Nature of the Phase Just Below the Superconducting Phase

Z. Yamani [1], W.J.L. Buyers [1], R. Liang [2], D. Bonn [2], and W. N. Hardy [2]

[1] Canadian Neutron Beam Centre, National Research Council, Chalk River Laboratories, Chalk River, ON, Canada K0J 1J0

[2] Physics Department, University of British Columbia, Vancouver, BC, Canada V6T 1W5

The interplay between magnetism and superconductivity (SC) and how one phase is transformed to the other by doping, p, continues to be one of the most prominent questions in the physics of high-temperature superconductivity (HTSC). For the $YBa_2Cu_3O_{6+x}$ (YBCO6+x) family of superconductors, no studies have been made of whether the antiferromagnetic (AF) Néel phase is contiguous to the superconducting phase or whether a different phase such as the spin-glass phase of LaSrCuO separates them. A boson feature for $p < p_c$ (where p_c is the critical doping) seen in thermal conductivity, has been taken as evidence that the AF and SC phases are contiguous (see [1] and references therein). Only a neutron measurement can directly prove the existence of a long-ranged Néel state.

Previous neutron scattering experiments (polarized and unpolarized with thermal and cold neutrons) on YBCO6.353 and YBCO6.334 crystals (with T_c = 18 K and 8.4 K, respectively) have indicated [2-4] that superconductivity co-exists with quasielastic short-range AF correlations (central mode), but not with long-range antiferromagnetic order. In addition to the central mode, a damped excitation is also observed. The quasielastic spins are slowly dynamic, and are confined in finite-sized planar regions coupled weakly between planes. The spatial spin correlation length grows as doping is reduced but has not diverged even for the T_c = 8.4 K sample of YBCO6.334 (i.e. no 3D magnetic Bragg peaks were observed). In addition, only a continuous increase of central mode intensity is observed [2-4] on cooling to the lowest temperature, another indication that there is no transition but rather a cross-over to the low temperature limit without crossing a phase boundary. Thus studies on superconducting samples so far have shown that the long-range AF and SC phases do not coexist. Whether long-ranged AF and SC phases are separated by a novel phase remains unanswered. To resolve this question, we used thermal neutrons to measure elastic neutron scattering properties of a new crystal of YBCO6+x doped with x = 0.31. This gives a hole doping in the copper oxide planes of only 0.045 which is just below the critical doping, p_c = 0.052, for superconducting order.

The sample of YBCO6.31 consists of two co-aligned high quality single crystals grown at UBC with a total volume of ~ 2 cc that do not display a finite T_c. Nevertheless they remain in the orthorhombic phase, so that short oxygen chains are still available as a sink for holes. Neutron scattering measurements were performed at the C5 triple-axis spectrometer. A pyrolytic graphite (PG) vertically-focusing monochromator and a large flat analyzer were used at a fixed final neutron energy of E_f = 3.52 THz. Two PG filters were used in the scattered beam to suppress higher order contamination. The horizontal collimations were set to [none, 0.48°, 0.55°, 1.2°].

The neutron scattering from YBCO6.31 shows no evidence for 3D Bragg resolution limited AF peaks. Instead we find that AF correlations behave similarly to those in more highly doped samples but now with even larger correlation lengths (see Figure 1). Along the *c*-direction, which couples the planes the correlations are clearly of finite range (~ 70 Å) and thus exclude the existence of 3D Bragg peaks. Within the *ab*-plane the correlations are too long to be determined accurately with thermal neutrons. The absence of Bragg order is also confirmed by the temperature dependence of central mode, which shows only a smooth increase with decreasing temperature with no anomaly that might signal a transition below a sharp Néel temperature. The lack of 3D Bragg AF peaks as well as lack of evidence for a transition suggests that, similarly to very underdoped but superconducting samples, the spins are organized in a spin-glass phase. This is further supported by the fact that at very low temperatures a decrease in the peak intensity of the central mode is observed upon cooling below $T \sim 20$ K.

Compared to YBCO6.33 with T_c = 8.5 K, we find that the AF correlations are longer in YBCO6.31 but still remain finite. In addition in YBCO6.31, correlations start to grow at temperatures larger than for YBCO6.33. This study shows that there is an intermediate phase between the long range AF ordered and superconducting phases. The observed behaviour is consistent with a spin-glass phase. The absence of long range AF spin order does not require the presence of Goldstone spin-waves and renders the boson interpretation of thermal conductivity unlikely. Samples with even lower doping than YBCO6.31 will be required to access the long range AF ordered region of the phase diagram.

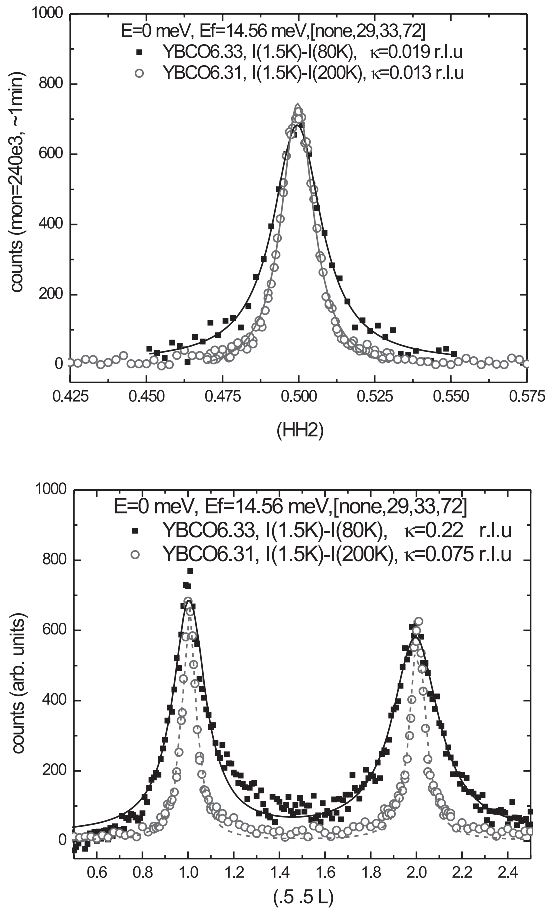

Fig. 1 *The background subtracted elastic data around the AF position (0.5 0.5 2) along [H H 2] and [0.5 0.5 L] directions in non-superconducting YBCO6.31 are compared to those in superconducting YBCO6.33 (T_c = 8.5 K). The fits to a Lorentzian form 1/(x^2 +κ^2/4) are shown. Although larger, correlations remain finite in YBCO6.31.*

References

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