Spin Dynamics in Underdoped YBCO6.33 Cuprate (T_c = 8.4 K)

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Since their discovery in 1986, high temperature superconductors (HTSC) have continued to challenge our understanding of condensed matter. Despite a large number of experimental and theoretical studies, an accepted microscopic theory for superconductivity in HTSC materials is still elusive. The phase diagram of these materials is rich and exhibits different states of matter such as superconductivity and antiferromagnetism close to one another. It has become quite clear that spin fluctuations play a fundamental role in HTSC. An understanding of the spin dynamics across the whole phase diagram is a key step towards a microscopic theory for HTSC.

The $YBa_2Cu_3O_{6+x}$ (YBCO6+x) family of HTSC cuprates is perhaps the most studied HTSC, however, the low-doped superconducting YBCO6+x materials close to the superconducting critical doping, p_c, have not been fully investigated. A magnetic excitation known as the "resonance" mode appears to be the most prominent spectral feature for optimally doped and lightly underdoped YBCO6+x (x ≥ 0.5) samples. This mode is observed [1-3] at the commensurate AF ordering wavevector **Q** = (0.5 0.5 L). The resonance energy is located in the saddle point of an hourglass-shaped dispersion observed for the magnetic excitations. For doping x ≥ 0.5, it appears that the resonance energy tracks the superconducting transition temperature, T_c, as one varies doping. A recent study on YBCO6.45 finds [4] that magnetic excitations are gapless and have a much broader resonance at this lower doping. Based on these results it is suggested [4] that the change in the magnetic excitations across x = 0.5 is related to the metal-to-insulator cross-over and the resonance therefore is a fundamental feature of the metallic ground state superconductors.

We have studied even lower doped YBCO6+x crystals. Our neutron scattering experiments on YBCO6.354 (T_c = 18 K) revealed that no long range AF phase exists at low temperatures [5]. Instead static short ranged AF correlations (central mode) set in gradually on cooling below 60-80 K and co-exist with superconductivity below T_c. The spin dynamics are relaxational at low energies having the form of modified Lorentzian with a relaxation rate of ~ 3 meV. In addition we found no resonant feature at higher energies. Our studies on even lower doped crystal YBCO6.334 (T_c = 8.4 K) revealed [6-8] qualitatively similar behaviour. We found that for this lower doped sample with a T_c of less than half that of YBCO6.35, the broad inelastic feature can also be described by a modified Lorentzian with a relaxation rate of about 4 meV. This observation rules out the possibility that the low energy broad feature is a remnant of the resonance at these very low doping that is now broadened and pushed to lower energies. If this were the case, we would have expected to see, as T_c decreases from 18 K in YBCO6.35 to 8.4 K in YBCO6.334, a reduction

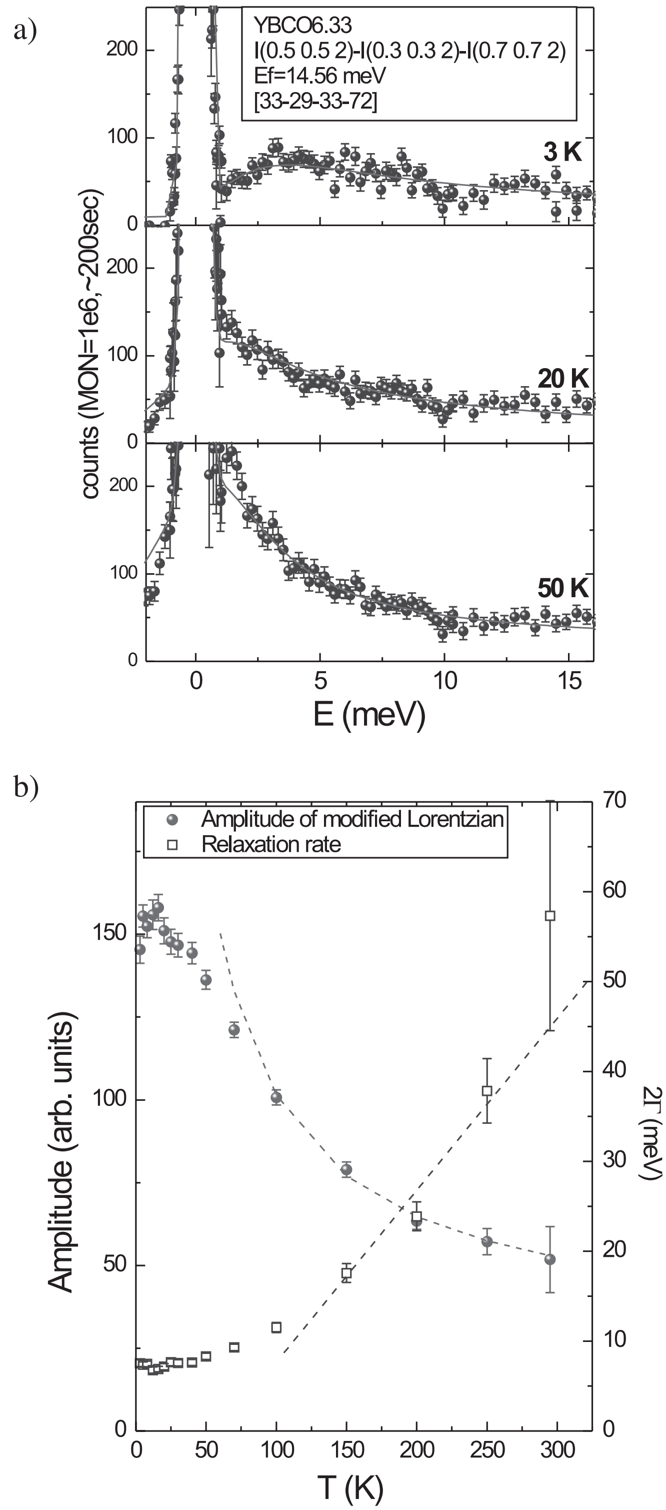

Fig 1. (a) Temperature dependence of inelastic intensity observed at the AF position (0.5 0.5 2). The solid lines are fits to a resolution-limited Lorentzian at zero energy and to a modified Lorentzian response with a relaxation rate. (b) The temperature dependence of the model parameters.

of the relaxation rate from 3 meV to < 2meV. Instead the spin relaxation rate has increased to 4 meV.

We have made more extensive measurements of the spin dynamics and its temperature dependence in YBCO6.334 from inelastic neutron scattering experiments at the C5 spectrometer. The sample and spectrometer configuration were previously described in Refs. [6-8]. Horizontal collimations of [33′, 29′, 33′, 72′] gave an energy resolution of ~ 1 meV.

The sample was aligned in the (HHL) plane and mounted in a closed cycle refrigerator (with exchange gas). Inelastic neutron scattering experiments were performed from room temperature down to 3 K.

The inelastic spectra at different temperatures are shown in Fig. 1(a) measured at (0.5 0.5 2). The average intensity at (0.3 0.3 2) and (0.7 0.7 2) is used for the background subtraction in the constant-Q scans. This method of background subtraction was verified by constant energy Q-scans at several energies and temperatures which gave the same intensity. The background corrected data is fitted with a resolution convoluted model containing two components, a narrow Lorentzian centered at zero energy and a modified Lorentzian (including the Bose-factor) characterized by the relaxation rate, Γ. The solid lines in Fig. 1(a) show that this model can fit the data reasonably well over large temperature and energy ranges. The fit parameters (amplitude and relaxation rate) for the modified Lorentzian as a function of temperature are shown in Fig. 1(b).

The relaxation rate decreases almost linearly on cooling and eventually saturates at its low temperature value of ~ 4 meV below 50 K. This saturation of the relaxation rate is accompanied by saturation of the observed amplitude for the modified Lorentzian. We find that the spin dynamics show no anomaly at the superconducting transition temperature T_c = 8.4 K. This behaviour is unlike what is observed for higher doped samples (x ≥ 0.4-0.5) where the intensity of excitations at the resonance energy further increases below T_c and the intensity of the lower energy excitations decreases indicating the opening of superconducting gap [2,3].

Similar to YBCO6.35, there is no evidence for a definable resonance or spectral feature at higher energy transfers in YBCO6.33. This together with the lack of any anomaly of the spin dynamics at T_c indicate that at the very low doping levels, close to the critical doping for superconductivity spin dynamics are fundamentally different from higher doping (x ≥ 0.4-0.5) region of the phase diagram. The spins are thus decoupled from the charges which undergo paring. Any microscopic theory for HTSC superconductivity must account for these observed properties of spin dynamics across the phase diagram.

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