Experimental Report

06/02/2014

Proposal: **4-01-1289** **Council:** 10/2012

Title: Influence of oxygen isotope exchange on the novel magnetic excitations in HgBa2CuO4+d

This proposal is a new proposal

Researh Area: Physics

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Samples: HgBa2CuO4

Instrument	Req. Days	All. Days	From	To
IN8	10	10	09/07/2013	19/07/2013

Abstract:

The pivotal issue in the study of the cuprates is to determine the bosonic glue that leads to superconductivity. In general, a mixing of the phononic and magnetic degrees of freedom is possible. Isotope shifts suggestive of phonon involvement have been observed in photoemission and tunneling measurements of the Bismuth-based compounds. Our recent inelastic neutron scattering work revealed well-defined (in energy) novel magnetic excitations in the pseudogap state in HgBa2CuO4+d (Hg1201) at similar energies. Although the magnetic nature of these modes at relatively low momentum transfers has been established from polarized neutron scattering, our latest results point toward a possible mixing of magnetic and lattice degrees of freedom at large momentum transfers. We propose to perform measurements on 18O isotope-exchanged Hg1201 samples to determine if there is an isotope shift of the mode energies.

Influence of oxygen isotope exchange on the novel magnetic excitations in $HgBa_2CuO_{4+d}$

Our previous inelastic neutron scattering results demonstrate the existence of novel magnetic excitations [1] that are likely related to the $\boldsymbol{q}=0$ pseudogap magnetic order [2-3]. Measurements of both under-doped ($Tc \approx 65\ K$; UD65) and nearly-optimally-doped ($Tc \approx 95\ K$; OP95) HgBa2CuO4+δ (Hg1201) reveal two weakly dispersive magnetic excitation branches throughout the entire Brillouin zone below the pseudogap temperature T^* [4] (#4-01-887). Polarized neutron scattering measurements on IN20 suggested magnetic nature of both branches [1] (#4-01-888, and #4-01-1005). Furthermore, the strength of the excitations is found to gradually decrease with increasing in-plane momentum transfer consistent with a magnetic form factor. However, our recent work performed on IN1 (#4-01-1217) showed that the dependence of the high-energy mode on *c*-axis momentum transfer is highly non-monotonic and hence cannot be explained by a conventional magnetic form factor. Comparison with STM results also show that the excitations occur at the same energies as the bosonic features in the bismuth-based cuprates. This raises the possibility of a magneto-structural coupling, and a shift of the excitation energy due to $^{16}O/^{18}O$ substitution is expected [5]. The goal of this new experiment was to determine if there is an isotope effect on the novel excitations, and thus to confirm the mixing of magnetic and lattice degrees of freedom in the cuprates.

The experiment was performed during 8 days. Approximately half a day was used to set up the spectrometer. Due to the lack of a Cu monochromater with which we can get a ~3meV resolution, we used PG (002) instead which reduced the resolution to ~8meV. One PG filter was used on k_f. Measurements were performed on our slightly underdoped ($Tc \approx 87\ K$) $^{16}O/^{18}O$ substituted sample.

Figure 1 shows both the previous work on IN8 with a nearly-optimally-doped sample (OP95) and our new results. The high-energy mode is measured by taking the temperature difference between energy scans at $T = 4K$ ($<< T^*$) and $T = 260K$ ($>\approx T^*$) at $\boldsymbol{Q} = (0,0,4.6)$, as shown in Fig. 1a. The Gaussian fitting of the peaks give peak center 52.55 (0.2) meV for the OP95 sample, and 53.56 (0.73) meV for the isotope exchanged sample, therefore the energy of the high-energy mode for the two samples have much smaller difference than what we expected (5-6%). Interestingly, although the high-energy plots show similar excitation modes, the lower energy background plots for these two samples are very different, which maybe a footprint of the isotope exchange effect or the result of slightly *Tc* shift, and further studies are needed for clear explanation. Fig. 1b demonstrates the lower energy mode measured at $\boldsymbol{Q} = (1.3,1.3,0)$by taking the same temperature difference, a hump is also presented at the same energy with previous results on OP95 [4].

During the remainder of the beamtime, we explored the temperature dependence of the mode intensity by taking three point scans (one at peak energy and two at background energies) of both modes. The intensities of the modes are calculated by subtracting the average of two background points from the peak point. Fig. 2a and 2b shows the temperature dependence of both modes at the same momentum transfer $\boldsymbol{Q} = (0,0,4.6)$. The high-energy-mode intensity decreases as temperature increases, and finally levels off at $T \approx 240K(24.5)$ ($\approx T^*$, numbers in parentheses is fitting error); while the low-energy-mode is not observable at this $\boldsymbol{Q}$ // ab plane, which is consistent with the previous work on the $\boldsymbol{Q}$-dependence of these modes. In Fig. 2c the low-energy-mode is measured at a different $\boldsymbol{Q}$ // c axis, where it levels off at $T \approx 94.4K(23.8)$.

The above results suggest that the $^{16}O/^{18}O$ exchange has no effect on the two excitations. However, due to the difficulties to exchange ^{18}O into the sample and limited time to prepare the sample, our sample may only be partly isotope exchanged. Figure 3 shows the Raman measurement of the oxygen phonon modes in Hg1201 sample, whose wavenumbers are theoretically predicted before [6] We found a significant difference of the results on the unpolished and polished surfaces. Taking into the limited penetration depth of Raman measurement, this could be explained by that the ^{18}O only exists near the surface of the sample, resulting in its effect is not observed in neutron scattering which is a bulk measurement. Regardless of that, our results provide meaningful data as a test, and more time needs to be invested into preparing and characterizing fully or mostly $^{16}O/^{18}O$ exchanged sample. Once we are able to achieve high quality samples, we expect to gain convincing data on resolving the isotope exchange effect problem, hence help us better understand the novel excitations.

References:

[1] Y. Li *et al.*, Nature **468** 283 (2010); Y. Li *et al.*, Nature Phys. **8**, 404 (2012).

[2] B. Fauqué *et al.*, Phys. Rev. Lett. **96**, 197001 (2006).

[3] Y. Li *et al.*, Nature **455**, 372 (2008); Y. Li *et al.*, Phys. Rev. B **84**, 224508 (2011).

[4] Y. Li et al., Nat. Phys. **8**, 404 (2012).

[5] J. Lee *et al.*, Nature **433**, 546-550 (2006)

[6] M.G. Stachiotti *et al.*, Physica C **243**: 207-213 (1995).

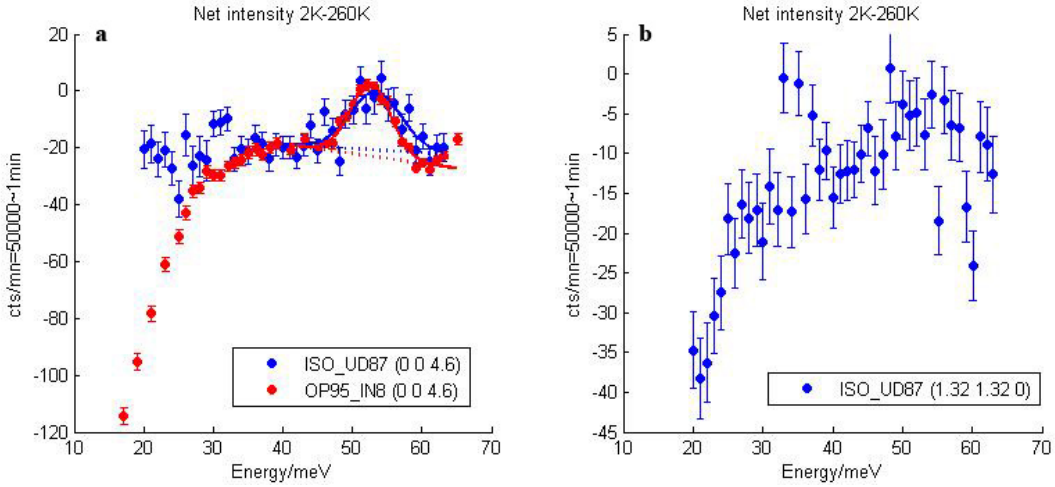

Figure 1: Full range energy scans of the pseudogap excitations. (a) Intensity difference between energy scans taken at T = 4 K (<< T*) and T = 230 K (≈ T*) at $\boldsymbol{Q}$ = *(0,0,4.6)* reveal the high-energy excitation. Red plots are previous result of OP95 sample on IN8, blue plots are data on ISO_UD87 sample taken in this experiment, and these data are shifted to have the same background level with red ones. The fitting Gaussian and linear background are solid and dashed lines with the same color for each set of data. (b) Intensity difference between energy scans taken at T = 4 K (<< T*) and T = 230 K (≈ T*) at $\boldsymbol{Q}$ = *(1.32,1.32,0)* reveal the low-energy excitation.

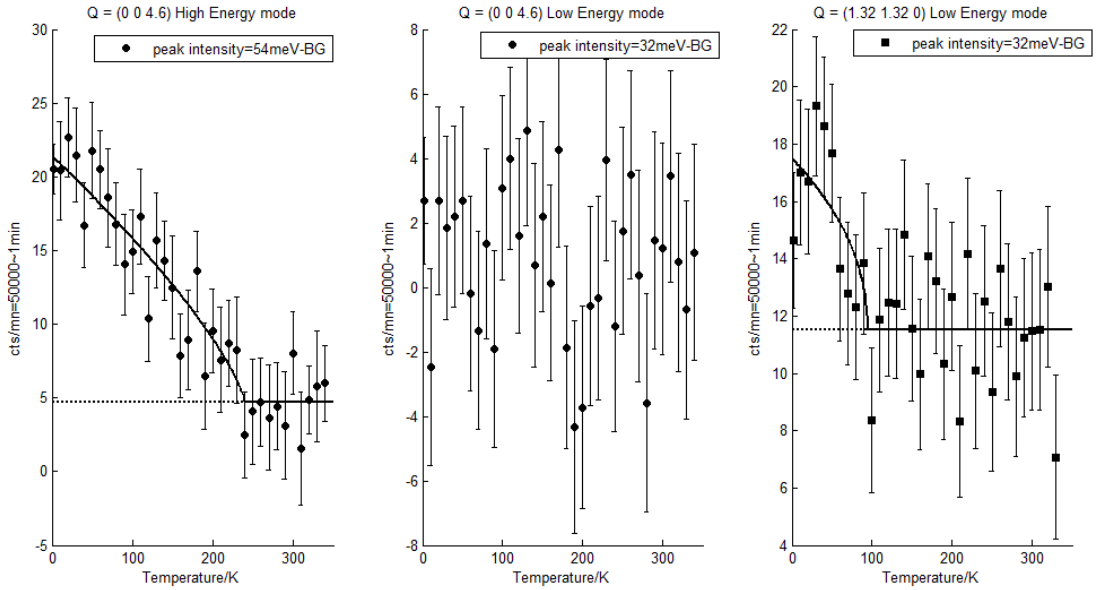

Figure 2: Temperature dependence of the novel excitations. The peak intensities are measured by 3 point energy scans, which is describe in main text. (a) High-energy-mode at $\boldsymbol{Q} = (0,0,4.6)$. (b) Low-energy-mode at $\boldsymbol{Q} = (0,0,4.6)$. (b) Low-energy-mode at $\boldsymbol{Q} = (1.32,1.32,0)$. The black solid lines are the powerlaw fits to the data, dash lines are the fitted baselines.

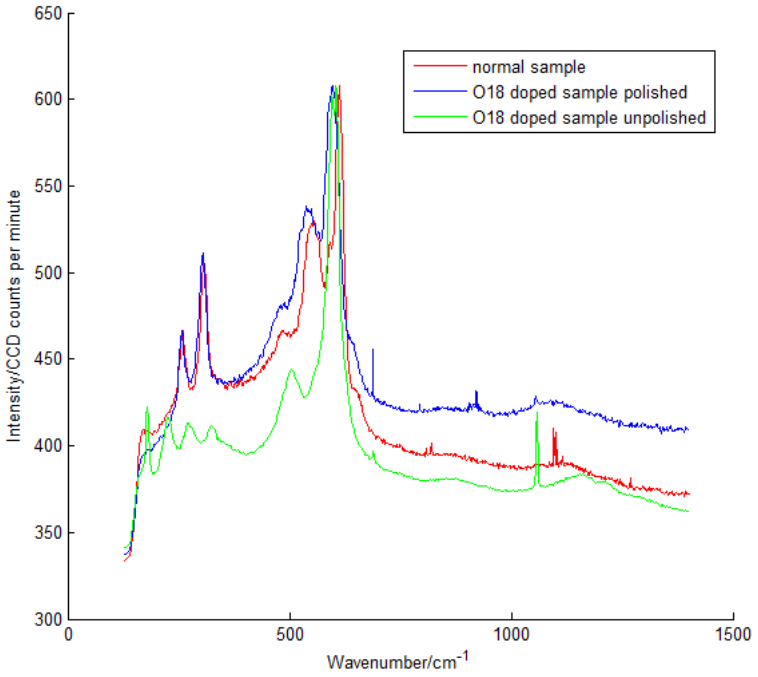

Figure 3: Raman spectrum of normal and isotope exchanged sample. Red: normal sample; Green: $^{16}O/^{18}O$ isotope exchanged sample, unpolished; Blue: $^{16}O/^{18}O$ isotope exchanged sample, polished. The surface of unpolished isotope exchanged sample shows different phonon patterns with the normal data, while the polished sample gives the same spectrum as the latter, suggesting that our sample is partly isotope exchanged, i.e. only the area near surface.