Experimental Report

01/04/2014

Proposal: **4-01-1244** **Council:** 10/2012

Title: Search for new low energy magneticexcitations in superconducting cuprates

This proposal is a new proposal

Researh Area: Physics

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Samples: YBa2Cu3O6.85

Instrument	Req. Days	All. Days	From	To
IN14 CPA	10	10	14/05/2013	24/05/2013

Abstract:

Using polarized neutron scattering diffraction, a new long range intra-unit-cell magnetic order has been recently discovered in the pseudogap state of high temperature superconducting cuprates. This phase has been reported for three cuprates and is likely to to be a genuine properties of superconducting cuprates. It could be associated with the spontaneous appearance of circulating current loops as proposed in the pseudogap theory of C. M. Varma. Within this theory, their fluctuations control the non-Fermi liquid properties in the normal state and superconducting pairing. We have recently observed new low energy magnetic response which could be related to these fluctuations and we would like to study their momentum, energy and temperature dependencies in detail.

ILL report on IN14 – may 2013
Search for new low energy magnetic excitations in superconducting cuprates
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Local contact: Paul Steffens

The phase diagram of high temperature superconductors is dominated by a pseudo-gap (PG) phase with highly unusual physical properties [1]. Many theories attribute its origin to the proximity of a competing state, but there is a wide disagreement about the nature of this state. Beyond usual charge or spin instability, it has been proposed that the PG phase involves circulating currents (CC) flowing around the CuO_2 square lattice with two (phase CC-Θ_{II}) circulating current loops per CuO_2 plaquette [2]. In the vicinity of each Cu site, current loops generate staggered orbital magnetic moments without breaking the lattice translation invariance. Such an intra-unit-cell (IUC) magnetic order can be detected by polarized neutron scattering technique. Using polarized neutron diffraction on the spectrometer 4F1 at Orphée Reactor at Saclay, we successfully reported the existence of a magnetic order in the PG state of three cuprates families: $YBa_2Cu_3O_{6+\delta}$ (Y123) [3-4], $HgBa_2CuO_{4+\delta}$ (Hg1201) [5], $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212) [6]. The change of the magnitude of the observed effect with different neutron polarization [7] demonstrates the magnetic nature of the phenomenon, and rules out an experimental artifact. The observed symmetry is consistent with the theoretically-predicted broken-symmetry state, CC-Θ_{II} phase [2]. The IUC order develops below a temperature T_{mag} that matches the PG temperature T* as defined by the resistivity measurement for those families of compounds. Our systematic study, carried on many single crystals with various hole doping demonstrates that the existence of an IUC magnetic state is a genuine properties of the PG phase of superconducting cuprates. Moreover, our polarized neutron scattering measurement suggests that the pseudogap is a symmetry breaking state, a conclusion which is now corroborated by ultrasound measurements [8].

Around optimal doping (p=0.16), where the SC transition is maximum, the magnetic critical temperature as well the magnetic intensity are reduced as one approaches the quantum critical doping [2,7] (p_c~0.2), where the PG state vanishes according to thermodynamic measurements. Even using polarized neutron diffraction, the observation of the static magnetic signal is difficult. In $YBa_2CuO_{6.85}$ (T_c=89 K, p~0.15), we have been recently able to observe the IUC magnetic order that develops in this sample at T_{mag}~180K (Fig. 1-A). Moving away from the Bragg reflection (1,0,0), we could observe for the first time low energy magnetic excitations. As shown in Fig.1-B, inelastic polarized neutron measurements performed at Q=(0.9,0,0) and -4meV reveal after polarization analysis a low energy magnetic signal. After correction from the detailed balance factor, the temperature dependence of the imaginary part of the magnetic susceptibility suggests a weak maximum around T_{mag} and the disappearance of the low energy fluctuations in the SC state (Fig.1-C)

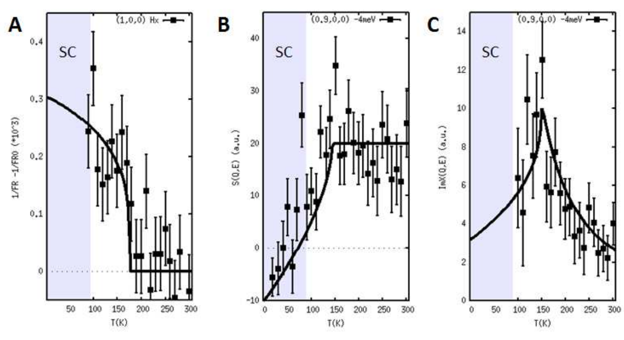

Figure 1. Polarized neutron data on optimally doped $YBa_2Cu_3O_{6.85}$ sample obtained on 4F1 in Saclay vs temperature. A) Inverse flipping ratio at Q=(1,0,0) for H_x. The polarization leakage $1/FR_0$ has been determined from measurements at Q=(2,0,0) and subtracted. B) Inelastic magnetic scattering at Q=(0.9,0,0) and -4 meV, deduced from polarization analysis. C) Imaginary part of the dynamical magnetic susceptibility, obtained from B) after correction from the detailed balance factor. In all figure, the blue area indicate the superconducting state (SC). Solid lines are guides to the eye.

In the CC-theory, the fluctuations associated with the broken symmetry are proposed to be responsible for the non-Fermi liquid properties reported in the normal state around optimal doping and are involved in the superconducting pairing. The observation and characterization of low energy magnetic excitations, likely associated with the IUC magnetic order, are to this respect of primary importance.

We have performed a 10-days experiment on IN14 in order to study the new magnetic excitations. The measurements were carried out at k_f=1.5 A^{-1}, we used a Heusler analyzer and CRYOPAD was necessary to improve the polarization measurements and to prevent us from depolarization of the neutron beam in the SC state. We used in addition the detector filter option which removes any count higher than 12 counts appearing in 0.3 second and recounts it. With this experimental set up, we studied temperature dependence of the newly observed low energy magnetic excitations at Q=(0.88,0,0) E=0meV. Unfortunately we were not able to study its energy dependence as planned because of a problem with the monochromator and as the measurements are time consuming (weak signal and slow spectrometer movements) we did not have time to study the momentum dependence. We were therefore able to observe a breaking slope for the three polarizations X, Y and Z (Fig. 2) around T~210K. The Y and Z spin-flip channels show a similar shape, although the X spin-flip channel seems to have a strange shaky shape, we can also detect a change in the behavior around 210K. This breaking slope is consistent with the appearance of a magnetic signal expected around T*. We did also temperature dependence of the non-spin-flip channel which seems to be flat but because of too big errorbars it is difficult to extract the behavior of the signal. The polarization analysis (2X-Y-Z) presents a shift in the negative intensities because of the too high background of the Y spin-flip channel and it is too shaky also to tell something, these data need to be improved and cross-checked.

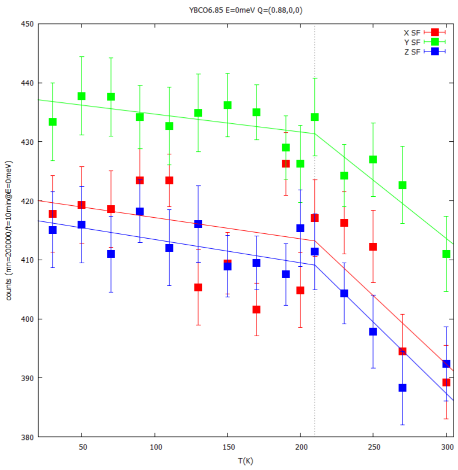

Figure 2. Temperature dependence of Spin-Flip channel of a $YBa_2Cu_3O_{6.85}$ optimally doped sample. The three polarizations X (red), Y (green) and Z (blue) present a breaking slope around T~210K.

References:

[1] M. R. Norman and C. Pepin, Rep. Prog. Phys. 60, 1547 (2003)
[2] C.M. Varma, Phys. Rev. B 73, 155113 (2006)
[3] B. Fauqué and al, Phys. Rev. Lett. 96, 197001 (2006)
[4] H. Mook and al, Phys. Rev. B 78, 020506 (2008)
[5] Y. Li and al, Nature 455, 372 (2008)
[6] S. De Almeida-Didry and al, Phys. Rev. B 86, 020504 (2012)
[7] P. Bourges and Y. Sidis, C. R. Physique 12, 461 (2011)
[8] A. Shekhter and al, Nature 497, 75 (2013)