Experimental Report

01/04/2014

Proposal: **5-53-234** **Council:** 10/2012

Title: Orbital moments in high-Tc cuprates

This proposal is continuation of: 5-42-297

Researh Area: Physics

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Samples: YBa2Cu3O6.85

Instrument	Req. Days	All. Days	From	To
D7	10	10	03/05/2013	13/05/2013

Abstract:

The phase diagram of high temperature copper oxides superconductors is dominated by a pseudo-gap phase with highly unusual
physical properties. In a serie of recent polarized neutron experiments at LLB-Saclay, we discovered a novel magnetic order specific
to that pseudogap state in various cuprate systems. The observations are consistent with the symmetry of microscopic circulating
currents creating orbitals moments as it has been theoritically proposed by C.M. Varma. In a previous expriment, we proved that this
experiment is also feasible on D7. We wish to take advantage of the higher flux of polarized neutrons of D7 to adress a few issues
discussed in the litterature. In particular, we have recently observed a magnetic diffuse scattering near the magnetic ordering temperature in the doping regime where the superconductivity is maximal (optimal doping). We ask for 10 days of beam time using the XYZ mode on a single crystal of YBa2Cu3O6.85 near optimal doping to map this magnetic diffuse

ILL report on D7 – may 2013

Orbital moments in high-Tc cuprates

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The phase diagram of high temperature superconductors is dominated by a pseudo-gap 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 pseudogap phase involves circulating currents (CC) flowing around the CuO_2 square lattice with two (phase 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 translation invariance of the lattice which should be observed by neutron diffraction. As this state conserves the lattice invariance, the magnetic scattering appears on top of nuclear Bragg peaks requiring polarized neutron diffraction experiments. Using polarized neutron diffraction on the spectrometer 4F1 at Orphée Reactor at Saclay, we successfully reported the existence of a magnetic order in the pseudogap state of the cuprate double-layer $YBa_2Cu_3O_{6+\delta}$ [3-4], in $HgBa_2CuO_{4+\delta}$ [5] and more recently in $Bi_2Sr_2CaCu_2O_{8+\delta}$ [6]. A large variety of samples from the underdoped part of the phase diagram of the high-T_c compound of those families have been studied, showing the reproducibility and the universal character of this magnetic order in high-T_c cuprates. The temperature dependencies of spin-flip scattering exhibits a magnetic scattering below a temperature T_{mag}, that matches well the pseudogap temperature T* as defined by the resistivity measurement for those families of compounds. 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 corresponds to the theoretically-predicted broken-symmetry state, Θ_{II}, consisting of circulating charge currents [2]. That suggests that the observed magnetism can be associated with orbital moments pointing along c*, perpendicular to the CuO_2 plane, the basal plane of the orthorhombic structure of $YBa_2Cu_3O_{6+\delta}$. Moreover, it has been recently confirmed by recent resonant ultrasound spectroscopy in $YBa_2Cu_3O_{6+\delta}$ [8] that there is a true phase transition at T*.

We performed a 10-days experiment on D7 on the $YBa_2Cu_3O_{6.85}$ optimally doped single crystal with polarized neutron using the multi-detector array with the XYZ polarization mode [9]. The magnetic scattering we are looking for is very weak (the ordered moment is typically around 0.1µB [7]). The major difficulty of this experiment is then that the magnetic scattering is much smaller than the nuclear scattering, a typical ratio is about 1/1000 for the Bragg peak Q=(100) which is the Bragg position where the observation is the easiest. In the spin-flip channel, the ”background” arising from the nuclear peak through the polarization leakage then dominates the magnetic intensity by a ratio 1000/R where R is the flipping ratio. A high flipping ratio is then requested. During this experiment we could obtain a flipping ratio which was about 20-25 and we succeed in observing new interesting effects. Moreover, we used the configuration with λ= 4.8A where the Bragg peak and the diffuse scattering is sampled out over a larger number of points.

We did measurements over a few rocking angles of the sample in order to map the diffuse scattering. To do so, we also achieved a full XYZ polarization analysis to separate the magnetic intensity from the large background [9]. To establish the critical behavior across T*, a few temperatures were also required.

In the one hand, we studied a few trajectories around different (1,0,L) Q-positions. The goal was to determine how the intensity evolves along L at H=1 for the three polarizations. The top right side of the figure shows this rocking map from L=-0.25 to L=3 for the Z spin-flip channel. One can notice that the signal seems to be intense along L, and between the maxima at each integer values of L some signal is remaining.

In the other hand, we chose to focus on a rocking angle of the sample which enabled us to go through the position Q=(0.9,0,0), we studied it at different temperature between 100K and 300K. The bottom left side of the figure gives the polarization analysis (2*I(H//x)-I(H//y)-I(H//z)) by integrating over a range of 10 detectors for each temperature to get magnetic intensity around Q=(0.9,0,0). It shows that the magnetic intensity exhibits a maximum around 190K which is the temperature of the appearance of the magnetic order that we expected from our previous experiment on 4F1(Orphée, Saclay). This cusp-like shape is characteristic of a critical scattering, we note a critical slowing down of magnetic fluctuations on both sides of the transition temperature. Moreover, we observed the shortening of the magnetic correlations (ξ~10-20a), (bottom right side of the figure) the signal persists away from the Bragg peak at low temperature meaning that the scattering remains short range even at temperature well below T*. All these new observations are consistent with our previous experiments and are in favor of the CC-Θ_{II} phase.

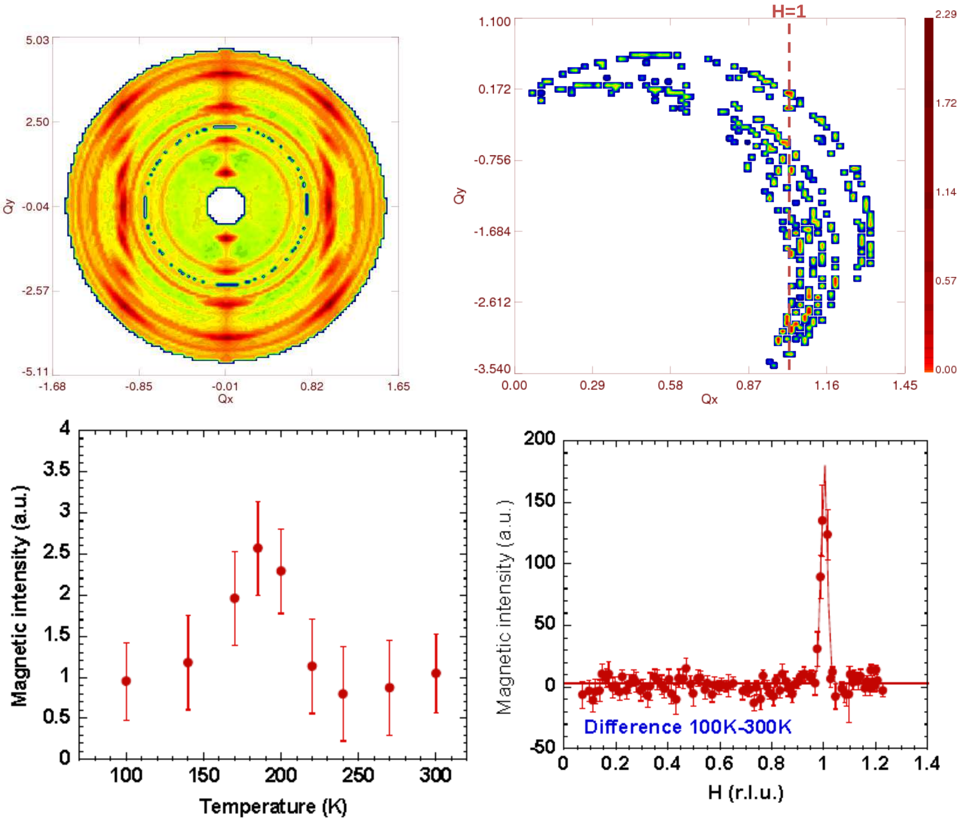

Figure. Rocking scans of a $YBa_2Cu_3O_{6.85}$ optimally doped sample. Top Left) Q-space map (non-spin-flip configuration) obtained by full sample rocking. Top Right) Temperature difference (100-300K) for the Z spin-flip channel at different rocking angles of the sample in order to get several (1,0,L) positions. Bottom Left) Polarization analysis given by 2*I(H//x)-I(H//y)-I(H//z) and by integrating over a range of 10 detectors for each temperature to get magnetic intensity around Q=(0.9,0,0). Bottom Right) Temperature difference (100-300K) for the rocking scan around Q=(0.9,0,0).

References:

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