NEUTRON SCATTERING FROM MAGNETIC EXCITATIONS IN $Bi_2Sr_2CaCu_2O_{8+d}$

H. F. Fong[1], P. Bourges[2], Y. Sidis[2], L. P. Regnault[3], A. Ivanov[4], G. D. Gu[5], N. Koshizuka[6] and B. Keimer[1,7]

[1] Department of Princeton University, Princeton, NJ 08544, USA.
[2] Laboratoire Léon Brillouin (CEA-CNRS)
[3] CEA Grenoble, DRFMC, 38054 Grenoble cedex 9, France.
[4] Institut Laue Langevin, 156X, 38042 Grenoble cedex 9, France.
[5] Department of Advanced Electronic Materials, University of New South Wales, Sydney 2052, Australia.
[6] SRL/ISTEC, 10-13, Shinomone 1-chome, Koto-ku, Tokyo 135, Japan.
[7] Max-Planck-Institut für Fertkörperforschung, 70569 Stuttgart, Germany.

Many of the physical properties of the copper oxides high-temperature superconductors appear to defy the conventional "one-electron" theory of metals. The development of alternative theories incorporating strong electron correlations is currently at the forefront of research in condensed matter physics. In this context inelastic neutron scattering can provide valuable insight into collective magnetic excitations in copper oxide superconductors and so guide these theoretical efforts.

For lack of suitably large single crystals, inelastic neutron scattering (INS) measurements have thus far proven possible for only two of the many families of high temperature superconductors, $YBa_2Cu_3O_{6+x}$ and $La_{2-x}Sr_xCuO_4$. While the magnetic spectra of both materials bear certain similarities, there are also pronounced differences that have hampered an unified description of the spin dynamics in the cuprates. In particular, the magnetic resonance peak that dominates the spectrum in the superconducting state of $YBa_2Cu_3O_{6+x}$, is not found in $La_{2-x}Sr_xCuO_4$.

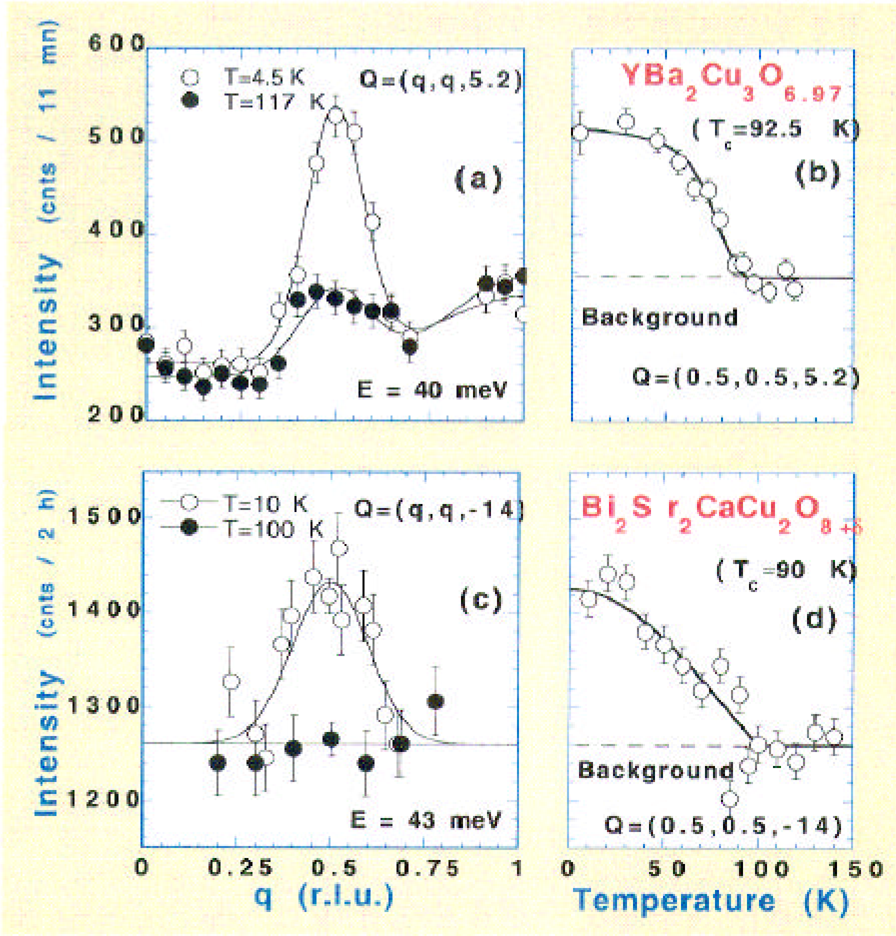
In the optimally doped $YBa_2Cu_3O_{6+x}$ (superconducting transition temperature T_c=93 K), the magnetic resonance peak is a sharp collective mode that occurs at 40 meV and at the two-dimensional wave vector (π/a, π/a), where a is the nearest neighbour Cu-Cu distance (Fig.a). Its intensity decreases continuously and vanishes above T_c (Fig.b). In the underdoped $YBa_2Cu_3O_{6+x}$, the mode energy decreases monotonically with decreasing hole concentration. Such a collective excitation mode has not been observed in conventional superconductors. Several microscopic models have been proposed, ranging from band structure singularities to interlayer pair tunnelling. In all these models, the interactions that give rise to the resonance mode are the same that cause pairing of electrons in the superconducting state, so that this phenomenon provides a direct clue to the mechanism of high-T_c superconductivity.

A very sensitive test of the disparate models is whether they are capable of providing a detailed description of both the INS results and those of angle resolved photoemission measurements (ARPES), a complementary momentum resolved experimental technique that primarily probes single electron excitations. By far the best ARPES data have been obtained in $Bi_2Sr_2CaCu_2O_{8+\delta}$, a material for which no INS data have been available for experimental difficulties ($Bi_2Sr_2CaCu_2O_{8+\delta}$ cleaves easily along CuO_2 layers, which facilitates surface sensitive techniques such as ARPES, but this property is also responsible for the lack of large single crystal required in INS measurements). This situation that has precluded a direct quantitative comparison of both techniques is remediated by the present study.

We have performed the first INS measurements on a 60 mm^3 single crystal of $Bi_2Sr_2CaCu_2O_{8+\delta}$ (T_c=91 K). Measurements have been carried out on the triple-axis spectrometers 2T located at the reactor Orphée at Saclay and IN8 located at Institut Laue Langevin at Grenoble (France)

The magnetic excitation spectra of $Bi_2Sr_2CaCu_2O_{8+\delta}$ and optimally doped $YBa_2Cu_3O_{6+x}$ exhibit an unmistakable similarity. In the superconducting state, the magnetic intensity is sharply concentrated around a single point in energy (~43 meV, with a width of ~10-15 meV) and wave vector (**Q**=(π/a, π/a)) (Fig.c). In the normal state, the intensity is either too broad or too weak to be observable above background. Fig. d shows the temperature dependence of the peak amplitude which vanishes above the superconducting transition temperature to within the experimental uncertainty. There is also no indication of magnetic intensity above the background level at other energies or wavevectors. In particular, an extensive search for magnetic excitations at 10 meV has thus far been fruitless in $Bi_2Sr_2CaCu_2O_{8+\delta}$.

In both $Bi_2Sr_2CaCu_2O_{8+\delta}$ and $YBa_2Cu_3O_7$, the magnetic resonance peak is thus by far the most predominant feature in the magnetic excitation spectrum.



Figures : *Resonance peaks in* $YBa_2Cu_3O_{6.97}$ *(a,b) [E=40 meV] and* $Bi_2Sr_2CaCu_2O_{8+d}$ *(c,d) [E=43 meV]. The resonance peak is centered at the antiferromagnetic wave vector q = 0.5 (in reciprocal lattice units* $2\pi/a$*). Its intensity vanishes above* T_c *(b,d)*

A further comparison between both compounds is made possible by a calibration of the absolute neutron cross-section against a vanadium standard. The energy integrated spectral weight of the resonance peak is $1.9\pm1\ \mu_B^2$, in close agreement with $1.6\ \mu_B^2$ found in $YBa_2Cu_3O_7$. The width of the resonance peak at the $(\pi/a,\ \pi/a)$ wavevector is much larger in $Bi_2Sr_2CaCu_2O_{8+\delta}$ (0.53 $Å^{-1}$, full width at half maximum) than in $YBa_2Cu_3O_7$ (0.25 $Å^{-1}$). If averaged over the Brillouin zone, in addition to integrating over energy, the resonant spectral weight is clearly larger in $Bi_2Sr_2CaCu_2O_{8+\delta}$ (0.23 μ_B^2) than in $YBa_2Cu_3O_7$ (0.043 μ_B^2).
Such a quantitative comparison between different materials are required for a microscopic, quantitative description of the origin of the magnetic resonance peak. In the framework of the models proposed for the resonance peak, it should be now possible to relate the different Q-width measured in $YBa_2Cu_3O_7$ and $Bi_2Sr_2CaCu_2O_{8+\delta}$ to their different Fermi surfaces as measured by ARPES.

Our study opens the way to a variety of further neutron experiments, in particular in the overdoped regime which is easily accessible in $Bi_2Sr_2CaCu_2O_{8+\delta}$ over a wide range of hole concentrations. It has also left open questions that can only be answered by neutron scattering work on other families of high-T_C superconductors. For instance, as both $YBa_2Cu_3O_{6+x}$ and $Bi_2Sr_2CaCu_2O_{8+\delta}$ are bilayer materials, the present study does not provide further insight into the role of interlayer interactions in the resonance peak. Most importantly, the observation of the resonance peak in $Bi_2Sr_2CaCu_2O_{8+\delta}$ rules out the possibility that this phenomenon is due to a conspiracy of structural and chemical parameters in $YBa_2Cu_3O_{6+x}$. It is in fact an intrinsic feature of copper oxides superconductors and an explanation of this feature needs to be an integral part of any theory of high-temperature superconductivity.

References:

H. F. Fong, P. Bourges, Y. Sidis, L. P. Regnault, A.Ivanov, G. D. Gu, N. Koshizuka et B. Keimer, Nature **398**, 588 (1999)