Neutron Scattering Study of the High-Temperature Superconductor $HgBa_2CuO_{4+\delta}$

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INTRODUCTION

Superconductivity, a phenomenon in which materials exhibit zero electrical resistance when cooled below a characteristic transition temperature, T_c, was discovered over 100 years ago. It wasn't until 1957 that a theory successfully described this phenomenon. Electrons are able to conduct with zero electrical resistance by binding into pairs, named Cooper pairs. In conventional superconductors (with T_c below ~30K), Cooper pairs are formed when the electrons interact with vibrations of the crystal lattice, phonons.

For high-temperature superconductors, with T_c values ranging up to 130K, the pairing mechanism for Cooper pairs is yet to be understood. A primary goal in the study of high-temperature superconductivity is to determine this pairing mechanism and to further understand the magnetic and electronic phases of these materials.

Neutron scattering was used to study magnetic excitations in the high-temperature superconductor $HgBa_2CuO_{4+\delta}$ (Hg1201). Such excitations are a candidate for the pairing mechanism. Hg1201 is of critical importance as it possesses one of the highest T_c values and is considered a model compound with a relatively simple structure.

METHODS

Inelastic neutron scattering was performed at the Spallation Neutron Source at Oak Ridge National Lab with a time-of-flight spectrometer as shown in figure 1. A large array of detectors measure the position of the scattered neutron, covering a large range of reciprocal space. The time between the initial pulse of incident neutrons and the arrival of the neutron determines energy loss of the neutron.

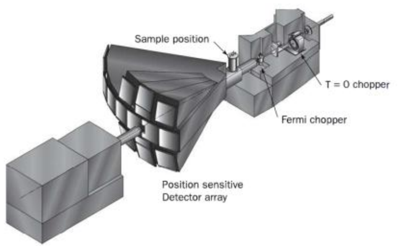

Figure 1: Time-of-flight spectrometer. Figure from [1].

Neutron scattering is a useful tool to study magnetism for several reasons:

1. Neutrons have a magnetic moment, allowing them to interact magnetically with the sample.
2. Neutrons are charge-neutral particles and therefore can penetrate deeply into the sample as they are not repelled by charged electrons and nuclei.
3. Thermal neutrons have kinetic energy on the order of most excitations of many materials.

Due to the small neutron scattering cross section, large high-quality crystal samples are required. The growth process of Hg1201 was optimized [2], resulting in several crystal samples to be measured with neutron scattering, shown in figure 2. This sample was prepared to low doping, with T_c of 45K.

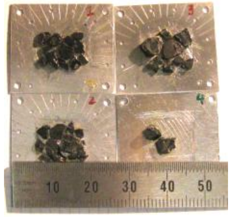

Figure 2: Several crystals mounted with their axes co-aligned in order to imitate one large crystal.

RESULTS

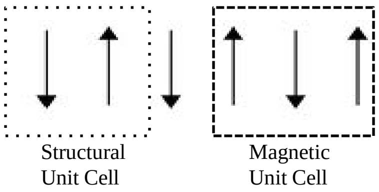

Figure 3: Structural and magnetic unit cell for AF ordering in Hg1201.

This neutron scattering study focused on magnetism near the antiferromagnetic (AF) wave-vector. Antiferromagnetism consists of magnetic moments (usually due to electron spin) pointing in opposite directions.

For AF order, the magnetic unit cell is twice as large as the structural unit cell in real space, as seen in figure 3. Doubling of the unit cell in real space corresponds to halving the unit cell in reciprocal space. The momentum transfer is represented in reciprocal space as (H,K). Thus, scattering of AF ordering will result in peaks at (1/2,1/2) in reciprocal lattice units.

It is necessary to measure two important qualities of excitations in order to compare results with other high-temperature superconductors:

- Energy Dependence
- Momentum Dependence

Shown in figure 4 is an example of data taken on the time-of-flight instrument. This experiment measured both energy transfer and momentum transfer from the neutron to the sample. The energy and momentum that is lost by the neutron upon scattering corresponds to the energy and momentum of excitations within the sample.

The data are analyzed by taking 1-dimensional cuts, shown in the right of figure 4. For lower energies, below approximately 40 meV, one peak at (1/2,1/2) is observed. For higher energies above 40 meV, the scattering begins to disperse and two peaks are observed around (1/2,1/2).

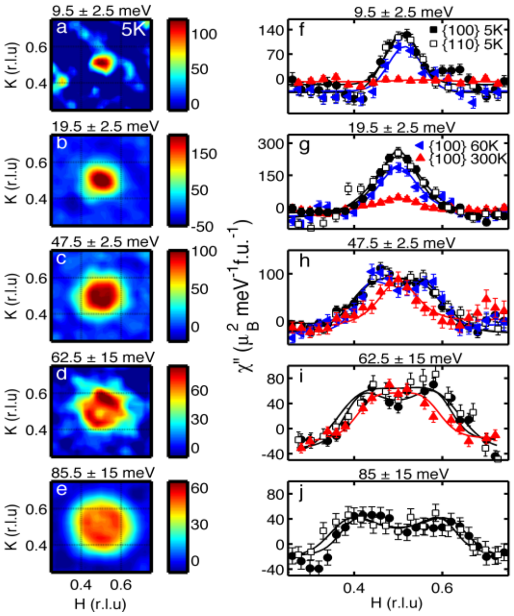

Figure 4: (left) Data slices taken on a time-of-flight spectrometer. These data were taken below Tc. (right) 1D cuts show that two peaks begin to form around the AF wave-vector at higher energies.

CONCLUSION

Results were compared to other high-temperature superconductors. Dispersive scattering near the AF wave-vector at high energies has been observed in several high-temperature superconductors, which is consistent with Hg1201. However, dispersive scattering is also seen at low energies for many high-temperature superconductors, which is inconsistent with Hg1201.

It is necessary to study this type of scattering in samples of Hg1201 at different doping levels to fully determine the relevance of these excitations to Cooper pairing and to comprehensively understand magnetic phases of this material.

This project was funded by the University of Minnesota's UROP program and by the Department of Energy, under my advisor, Martin Greven. These results are presently being written up for publication. [1] Neutron and X-ray Spectroscopy, F. Hippert et al. 2006 [2] X. Zhao *et al.* Advanced Materials **18,** 3243 (2006).