Low Temperature Heat Capacity Studies of $La_{1.92}Sr_{0.08}CuO_4$ at Magnetic Fields to 32T

Moir, C.; Kemper, J.B.; Boebinger, G.S. (FSU, Physics; NHMFL); Mandrus, D. (University of Tennessee, Knoxville)

Introduction -

Because superconductivity in the cuprates still does not have a satisfactory theoretical description, measurements investigating the electronic behavior of the cuprates continue to be of importance and interest. Specific heat measurements on $La_{2-x}Sr_xCuO_4$ in both the superconducting and resistive state seek to provide crucial insight into the scaling behavior of the electronic system in the d-wave superconducting state, as well as provide thermodynamic constraints on the proposed Fermi surfaces for these compounds. In this experiment we measured the heat capacity of under-doped $La_{2-x}Sr_xCuO_4$ as a function of temperature and field.

Experimental -

An $La_{1.92}Sr_{0.08}CuO_4$ single crystal with mass <10mg was measured at temperatures between 10K and 1.5K using a relaxation method heat capacity measurement optimized to maximize productivity during the limited time available for high-magnetic-field measurements. Square-wave heat pulses drive sample warming and cooling, and the rate of sample warming and cooling is measured to determine the specific heat of the sample.

Measurements were made at the NHMFL DC field facility in the cell 12 35 T magnet fitted with a VTI insert and magnetic fields were applied parallel to the c-axis of the samples. Most of the data were taken at a fixed field while sweeping the temperature. Some data were taken at a fixed temperature while stepping the magnetic field by small increments.

Results and Discussion -

Figure 1 shows the specific heat, C, data of $La_{1.92}Sr_{0.08}CuO_4$ at several magnetic fields ranging from 20T to 32 T, with C/T plotted versus T^2. The data are dominated by a roughly linear dependence when plotted on these axes, arising from the phonon contribution to specific heat. There is also an upturn at low temperatures due to a Schottky anomaly that, as expected, moves to higher temperatures as the magnetic field increases. *This Schottky anomaly, which arises from a two-level system in the sample, is removed during data analysis, as is the phonon term, leaving behind a nearly temperature independent term that is the electronic contribution to the specific heat.*

At magnetic fields sufficiently small that the sample remains superconducting, Wen et. al. [1] have reported an increase in the low temperature electronic specific heat that is expected for a d-wave superconductor, namely an electronic specific heat that increases as the square root of magnetic field in the zero temperature limit. Their measurements extend only to 12T however. Our data are taken at sufficiently high magnetic fields that the sample is in the resistive state, where the most striking feature of our data is the magnetic-field *independence* of the value of the electronic specific heat over a wide temperature range from T=7K (T^2=49K) down to the extrapolated value in the zero temperature limit *(once the Schottky term is removed).* This implies that the electronic specific heat is saturated in the resistive state. The magnitude of the high-field electronic specific heat compared to the smaller value at zero magnetic field will constrain the possible Fermi surfaces proposed for this underdoped cuprate. Measurements are continuing at other dopings to determine the Fermi surface evolution with doping.

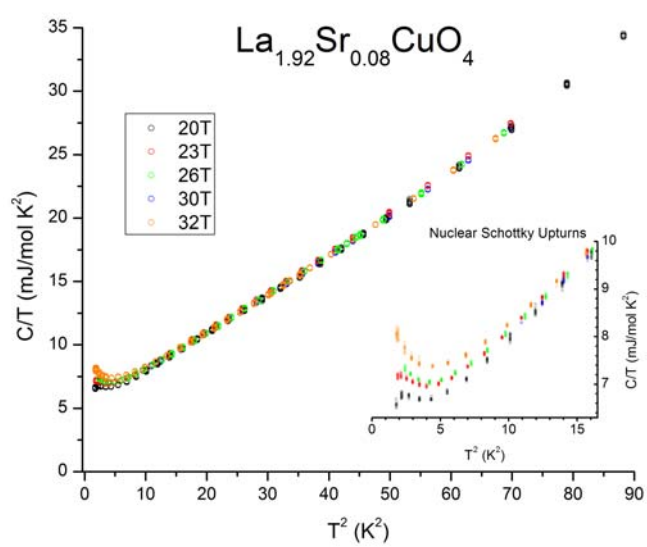

Fig.1 Specific Heat data for x = 0.08 at several fields. The inset shows in detail the Nuclear Schottky upturns at low temperature.

Acknowledgements

A portion of this work was performed at the National High Magnetic Field Laboratory, which is supported by National Science Foundation Cooperative Agreement No. DMR-1157490, the State of Florida, and the U.S. Department of Energy.

References

[1] Wen, H.H., *et al.*, Physics Review B, **70**, 214505-1-214505-12 (2004).