Magnetic Excitations of the 2-D Sm Spin Layers in Sm(La,Sr)CuO$_4$

F. Ronning$^a$, C. Capan$^a$, N.O. Moreno$^b$, J.D. Thompson$^a$, L.N. Bulaevskii$^a$, R. Movshovich$^a$, D. van der Marel$^c$

$^a$Los Alamos National Lab, Los Alamos, NM, 87545, USA
$^b$Departamento de Física, Universidade Federal de Sergipe, Sáo Cristóvão - SE CEP 49100-000, Brazil
$^c$DPMC-Geneva, 24, quai Ernest Ansermet, 1211 Geneva 4, Switzerland

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Abstract

We present specific heat and susceptibility data on Sm(La,Sr)CuO$_4$ in magnetic fields up to 9 T and temperatures down to 100 mK. We find a broad peak in specific heat which is insensitive to magnetic field at a temperature of 1.5 K with a value of 2.65 J/mol K. The magnetic susceptibility at 5 T continues to increase down to 2 K, the lowest temperature measured. The data suggest that the Sm spin system may be an ideal realization of the frustrated Heisenberg antiferromagnet on the square lattice.

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1. Introduction

The ideally frustrated 2-D Heisenberg antiferromagnet with first ($J_1$) and second ($J_2$) nearest neighbor interactions on the square lattice has been heavily studied theoretically,[1] but lacks few good examples in nature. For small $J_2/J_1$ the system orders into a Néel state, while for large $J_2/J_1$ one expects collinear order. At $J_2/J_1 \approx 0.5$ a spin liquid state whose properties are not well known is expected. Experimentally, the best examples of the spin 1/2 frustrated Heisenberg antiferromagnet on the square lattice occur in the vanadates, such as Li$_2$VO(Si,Ge)O$_4$,[2] VOMoO$_4$,[3] and Pb$_2$VO(PO$_4$)$_2$[4] where it is believed that $J_2/J_1 > 1$.

Here we report preliminary thermodynamic measurements on a single crystal cuprate Sm(La,Sr)CuO$_4$. By alternately stacking SmO and (La,Sr)CuO$_3$ layers this so called T$^*$ structure of the cuprates possesses 2-D Sm spin layers which are well isolated from one another.[5,6]

2. Results

Figure 1 presents raw specific heat data from a quasiadiabatic heat pulse method for Sm(La,Sr)CuO$_4$. At these temperatures the phonon contribution which becomes dominant above $\sim 10$ K is negligible. There is a peak at $T_{\text{max}} = 1.5$ K with a value of $C(T_{\text{max}}) = 2.65$ J/mol K. The low temperature ($T < 0.2$ K) specific heat is the sum of a magnetic contribution and a nuclear Schottky contribution. We subtract the nuclear Schottky contribution that we model as the sum of a constant quadrupolar term and a dipolar term subject to Zeeman splitting: $C_{\text{nuc}}(T, H) = (0.0041$ J K/mol + $1.3 \times 10^{-5}$ H$^2$ J K/mol T$^2$)/T$^2$. The resulting magnetic contribution to the specific heat is shown in figure 2. Note that there remains a low temperature upturn, which is suppressed with increasing magnetic field, but no clear long range magnetic order is observed down to 100 mK.

The zero field cooled susceptibility shows a superconducting transition at 15 K. By applying a field of 5 T in the ab-plane the evidence for superconductivity is suppressed, and the susceptibility continues to rise down to 2 K, the lowest temperature measured. A Curie-Weiss plus constant fit to room temperature allows us to extract a background paramagnetic contribution $\chi_0 = 2.4 \times 10^{-6}$ emu/gm. The remaining signal at low temperature is attributed to the susceptibility of the Sm spins and a Curie-Weiss fit below 10 K gives $\Theta_{\text{CW}} = -4.5$ K.

3. Discussion

In the absence of frustration, the magnetic susceptibility should show a peak at $0.935$ $J$[7] where $J$ can be deter-
specific heat

the presence of frustration. The small peak value of the

ingestion is playing a key role in the Sm spin dynamics. Know-

we have

determined by the low temperature Curie-Weiss fit. Therefore,

The solid line is a linear fit from 4 to 10 K.

Data plotted to extract the high temperature magnetic contri-

bution. After subtraction of the nuclear Schottky contribution in

zero and

2

$J_{2D} = (J_{1}^{2} + J_{2}^{2})^{1/2}$ and $R = 8.314 \text{ J/mol K}$. By assuming

that the phonon contribution to the specific heat varies as

$T^3$ up to 10 K, we can determine $J_{2D}$ by the $T=0$ linear

extrapolation from a plot of $CT^2$ versus $T^5$ as done in the

inset of figure 2. We find $J_{2D} \approx 2.4 \text{ K}$. This value is roughly

a factor of 2 too small for either graphical solution found

using the work of reference [8]. The graphical solution also

appears to over estimate $J_1$ and $J_2$ when considering that

the susceptibility also gives us $J_{1} + J_{2} = \Theta_{CW} = 4.5 \text{ K}$.

These small discrepancies might be reconciled if there is

an additional mechanism, aside from a simple frustration

model, that reduces the peak height in the specific heat.

The graphical solutions could then lean towards smaller $J_1$

and $J_2$, with $J_2/J_1 > 1$. Whether or not additional longer

range interactions, such as the RKKY interaction which

could be mediated through the CuO$_2$ conduction layers,

could achieve this remains to be seen.

The low temperature upturn in $C/T$ in figure 2 may

indicate the onset of ordering either from 3-D coupling or

an Ising like transition expected in the limit that $J_2/J_1$ is

large.

We should also caution that this system has the obvious

added complication of being embedded in a high tempera-

ture superconductor, with $T_c(H = 0) = 15 \text{ K}$ as determined from

a susceptibility measurement. While this fact could

be used to extract the magnetic spectrum via transport

measurements,[9] it may also have a significant effect on the

Sm-Sm exchange interaction as observed previously in sev-

eral other cuprates containing rare-earth elements within

the charge reservoir layers.[10]

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