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Magnetic Excitations of the 2-D Sm Spin Layers in $Sm(La,Sr)CuO_4$

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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 $Li_2VO(Si,Ge)O_4$,[2] $VOMoO_4$,[3] and $Pb_2VO(PO_4)_2$[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 $T^\star$ 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_{max} = 1.5 K with a value of $C(T_{max})$ = 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: $C_{nuc}(T,H) = (0.0041$ J K/mol $+ 1.3\ 10^{-5}H^2$ 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 $\chi_0 = 2.4\ 10^{-6}$ 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 Θ_{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-

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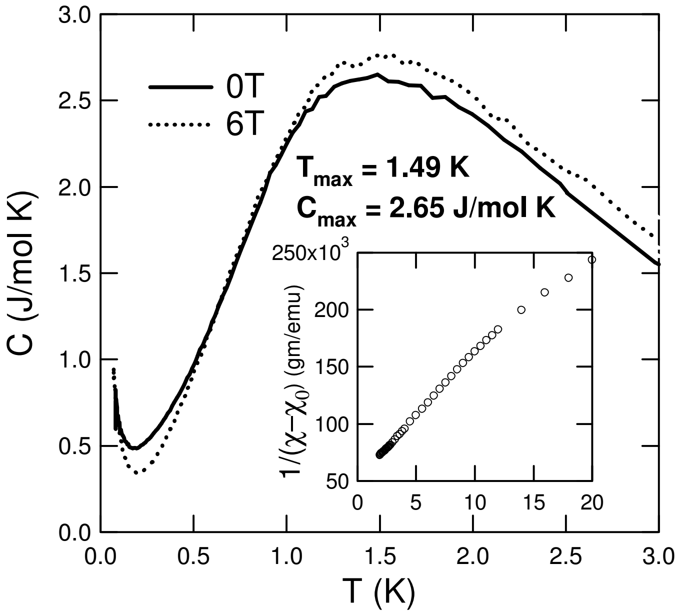

Fig. 1. Specific heat of $Sm(La,Sr)CuO_4$ in zero and applied magnetic field in the ab-plane. (inset) Inverse susceptibility at 5 T with field in the ab-plane.

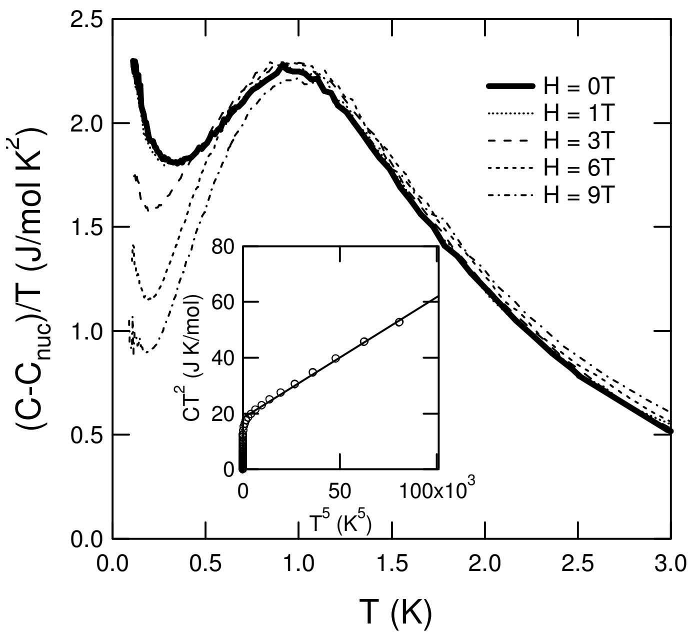

Fig. 2. Magnetic contribution to the specific heat of $Sm(La,Sr)CuO_4$ after subtraction of the nuclear Schottky contribution in zero and applied magnetic fields in the ab-plane. (inset) Zero field specific heat data plotted to extract the high temperature magnetic contribution. The solid line is a linear fit from 4 to 10 K.

mined by the low temperature Curie-Weiss fit. Therefore, we have $T^{\chi}_{max}/\Theta_{CW} < 0.45$ which is strong evidence for the presence of frustration. The small peak value of the specific heat $C(T_{max}) = 0.32$ R, also suggests that frustration is playing a key role in the Sm spin dynamics. Knowing $C(T_{max})$ and T_{max} we can use the work of Misguich, Bernu, and Pierre to solve graphically for J_1 and J_2.[8] The two solutions are $J_2/J_1 = 2.0$ K/4.8 K $= 0.42$ and $J_2/J_1 = 3$ K/3 K $= 1$, which indeed places this system very close to the spin liquid regime. Meanwhile, the high temperature expansion of the J_1-J_2 model predicts that the magnetic excitations should fall off as $C_{mag} \approx 3J^2_{2D}R/8T^2$ where $J_{2D} = (J_1^2 + J_2^2)^{1/2}$ and $R = 8.314$ 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 $J_{2D} \approx 2.4$ 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 $J_1 + J_2 = \Theta_{CW} = 4.5$ 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 temperature superconductor, with $T_c(H = 0) = 15$ 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 several other cuprates containing rare-earth elements within the charge reservoir layers.[10]

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References

[1] e.g. P. Chandra and B. Doucot, *Phys. Rev. B*, 38 (1988), p. 9335.
[2] R. Melzi, *et al.*, *Phys. Rev. Lett.* 85 (2000), p. 1318.
[3] P. Carretta, *et al.*, *Phys. Rev. B*, 66 (2002), p. 094420.
[4] E.E. Kaul, *et al.*, *J. of Magn. Magn. Mat.* 272 (2004), p. 922.
[5] Y. Tokura, *et al.*, *Phys. Rev. B*, 40 (1989), p. 2568.
[6] Z. Fisk, *et al.*, *Physica C*, 162-164 (1989), p. 1681.
[7] J.-Y. Kim and M. Troyer, *Phys. Rev. Lett.*, 80 (1998), p. 2705.
[8] G. Misguich, B. Bernu, and L. Pierre, *Phys. Rev. B*, 68 (2003), p. 113409.
[9] L.N. Bulaevskii, M. Hruska, and M.P. Maley, *Phys. Rev. Lett.* 95 (2005) p. 207002.
[10] See e.g. P. Allenspach and U. Gasser, *J. All. Comp.* 311 (2000) p. 1.