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Nano-Scale Correlations in Geometrically Frustrated Magnets

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Abstract – By studying the magnetic short range correlations in two frustrated magnets, namely the spin liquid, $Tb_2Ti_2O_7$ and the spin ice, $Ho_2Ti_2O_7$ we will show that magnetic correlations, on the nanometer length scale, dominate the spin system and determine the bulk magnetic properties. Neutron scattering on the parent and diluted compounds are complimented by susceptibility and specific heat measurements and these data are compared to theoretical predictions.

The study of geometrically frustrated magnetic systems has introduced important new concepts to condensed matter physics: order-by-disorder[1], spin ice[2-4], frustration driven distortion[5] and spin liquid states[6-8].

Co-operative paramagnetism where an interacting spin system remains dynamic as T → 0 K[6-7] was first introduced in the context of geometrically frustrated magnetism in the pyrochlore $Tb_2Ti_2O_7$[6], where despite a substantial antiferromagnetic Curie-Weiss temperature of 20 K, a large paramagnetic moment (9.4μ_B) and spin-spin correlations as high as 50 K, fluctuating spins have been measured at 17 mK[6,7].

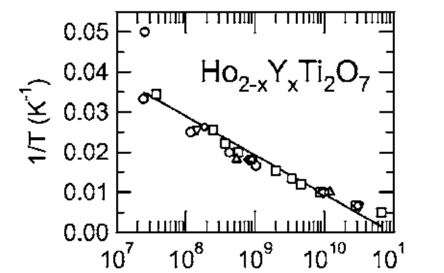

Figure 1: The temperature evolution of the relaxation times for six different samples x=1.8 (triangle), x=1.6 (diamond), x=1.15 (circle) and x=0 (square) revealing Arrhenius nature in the temperature range between 40 K and 200 K. The slope of the curve of the NSE data corresponds to a gap of 270 K.

Spin ice materials [2-4] are magnetic substances in which the magnetic moments obey the same ordering rules as the hydrogen atoms in ice, H_2O. This disordered structure results in residual entropy in the system and broad diffuse scattering, even deep in its frozen state. Experimental data is very accurately described by a dipolar spin ice model[8] the nearest neighbor spin ice model does quite well[2], indicating somewhat that nearest neighbour spin interactions on the ½ nm length scale dominate the gross features. In the data present→ed here, and summerised in figure 1, we experimentally confirm this by showing the relaxation processes in $Ho_{2-x}Y_xTi_2O_7$ are similar for all x. These neutron scattering data are consistent with a.c. susceptibility data. In perhaps a more surprising, and definitely less well understood, case of the co-operative paramagnet, figure 2 shows that the coarse features in the dynamical spin system are the same for all values of dilution. One would have expected the establishment of a frozen glass-like magnetic grounds state, as a consequence of introducing bond disorder in the system. However, for all amounts of dilution a dynamic groundstate was observed at 50 mK.

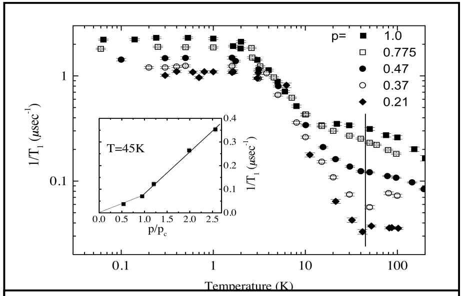

Figure 2: Spin relaxation measurements from a series of $(Tb_pY_{1-p})_2Ti_2O_7$ samples.

During my presentation, I will demonstrate through these two series of compounds that the bulk magnetic properties are governed by the spin-spin interactions on the nanometer scale. Neutron scattering, muon spin relaxation, specific heat and a.c. susceptibility data will demonstrate this fact and we will show that further neighbour, longer interactions onlt tweak the model slightly.

References

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