Geometric Frustration and Quantum Criticality in Heavy Electron Compounds

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We have studied a number of the R2T2X `221' compounds, where R=rare earth, T=transition metal, and X=main group element, where the R atoms sit on a geometrically frustrated Shastry-Sutherland lattice (SSL). Magnetically ordered or spin liquid phases, separated by a quantum critical point (QCP), can be realized in the system, depending on the relative strengths of the near neighbor J' and next neighbor J exchange interactions that couple the R moments. Ce_2Ge_2Mg and Yb_2Pt_2Pb order antiferromagnetically at 9.7 K and 2.05 K, respectively, while Ce_2Pt_2Pb appears to form very close to the QCP. Susceptibility measurements find that the magnetic susceptibilities of all three compounds display Curie-Weiss temperature dependencies, giving the full Hund's rule moment expected for Yb^{3+} or Ce^{3+}. Specific heat measurements confirm that the ground state is a magnetic doublet, well isolated from higher lying states in the crystal field manifold.

The magnetic ground state is constructed from pairs of neighboring moments, or dimers. Magnetic fields Zeeman split the excited dimer triplet state, and above a critical field HC1 it becomes the ground state. A further increase of the field increases the population of dimer triplets, driving a sequence of magnetic ally modulated states that are evidenced by steps in the magnetization. We observe these steps in Ce_2Ge_2Mg and in Yb_2Pt_2Pb, although they are much sharper and persist to higher temperatures in the former case, implying that fluctuations associated with both the finite temperature transition in Ce_2Ge_2Mg and the nearby QCP in Yb_2Pt_2Pb reduce the stability of these interaction driven modulated states. We have used specific heat and magnetocaloric effect measurements to map out a complicated phase diagram in Yb_2Pt_2Pb and Ce_2Ge_2Mg, where the field dependence of the in-plane order $T_N \sim (H-Hc1)^{\phi}$, where $\phi \sim 2/3$, which places this transition in the Bose-Einstein class, as in other quantum magnets. Clear evidence for quantum criticality is found in Ce_2Pt_2Pb, where $C/T \sim T^{1.4}$, $\rho \sim A-aT$, and $\chi \sim T^{-0.8}$.

This research was supported by the NSF under grant NSF-DMR-0405961.