Magnetic Quantum Phase Transition in an Anisotropic Kondo Lattice

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Introduction

Many heavy-fermion systems exhibit non-Fermi-liquid (NFL) behaviors in the vicinity of a continuous quantum phase transition (QPT) between an antiferromagnetic (AFM) metal and a paramagnetic (PM) metal. In the conventional theory for such QPTs, NFL properties arise from weak scattering of heavy quasiparticles by long-wavelength spin-density waves (SDWs). However, experiments on several systems (particularly CeCu$_{6-x}$Au$_x$) point instead to a strongly interacting QPT involving novel local physics [1]. Many of the deviations from the SDW theory can be explained if criticality in the magnetic ordering renders Kondo physics simultaneously critical, producing a “locally critical” QPT [2]. The present study [3] resolves an outstanding controversy as to whether the locally critical QPT proposed in Ref. 1 is continuous or is instead first-order.

Model and Results

Following Ref. 1, the starting model was the Kondo lattice model with Ising anisotropy in the RKKY exchange interactions between local moments. Zero-temperature solutions were obtained within extended dynamical mean-field theory using a recent extension of the numerical renormalization-group method. Fig. 1 shows the variation of three static quantities with $\delta = I/T_0$, where $I$ is the Fourier component of the RKKY interaction at the AFM ordering wave vector $Q$, and $T_0$ is the bare Kondo scale for $I = 0$. Both for magnetic fluctuations in 3D [Fig. 1(a)] and in 2D [Fig. 1(b)], the peak lattice susceptibility $\chi(Q,\omega = 0)$ diverges and the staggered magnetization $m_{\text{AFM}}$ vanishes continuously at the same value $\delta = \delta_c$ (to within numerical accuracy). For 3D fluctuations, the QPT is of the conventional SDW type. However, in the 2D case believed to be relevant for CeCu$_{6-x}$Au$_x$, the real part of the local susceptibility $\chi_{\text{loc}}(\omega)$ develops the logarithmically singular form $T_0 \chi'_{\text{loc}}(0) \sim (\alpha/2\delta^\alpha) \ln |1/\omega|$ expected at a locally critical QPT, with a value $\alpha = 0.78(4)$ consistent with the $\alpha \approx 0.75$ measured in inelastic neutron scattering from CeCu$_{6.9}$Au$_{0.1}$.

Conclusions

We have obtained nonperturbative, zero-temperature solutions of the Kondo lattice model, of great present interest in connection with heavy-fermion quantum criticality. For magnetic fluctuations both in two and three dimensions, our results point to a continuous QPT. In the 2D case, critical local-moment fluctuations are observed with an anomalous exponent $\alpha \approx 0.8$ in the dynamics that is in good agreement with the experimentally determined value for CeCu$_{6.9}$Au$_{0.1}$. This provides significant new evidence for local quantum criticality in strongly correlated systems.

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References