NUMERICAL RENORMALIZATION GROUP STUDY OF THE BOSE-FERMI KONDO MODEL

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Introduction

There is great current interest in the non-Fermi liquid physics arising near quantum critical points (QCPs) in strongly correlated electron systems. Recently, the Kondo lattice model of heavy fermions has been mapped[2] onto a self-consistently determined version of the Bose-Fermi Kondo model (BFKM), in which a local moment couples both to a fermionic band and a dissipative bath of vector bosons describing the fluctuating magnetic field generated by neighboring local moments. A perturbative renormalization group analysis[1] of the self-consistent BKFM predicts the existence of two types of QCP in the Kondo lattice: one of the usual spin-density-wave type,[2] the other a "local QCP,'' at which the destruction of the Kondo effect coincides with the divergence of the spatial correlation length, and the antiferromagnetic ordering transition is driven by local physics. Neutron scattering results on $CeCu_{5.9}Au_{0.1}$ appear to be well described within this local QCP picture. Since the solution relies on perturbative results, however, it is highly desirable to obtain a nonperturbative solution of the BFKM.

Results

We have extended the numerical renormalization group (NRG) approach to incorporate coupling of a magnetic impurity to delocalized fermions *and* bosons. As a first application, we have studied the QCP of the Ising-symmetry BFKM, described by the Hamiltonian $H = H_c + H_b + H_{\rm int}$, where

$H_c = \sum_{p,\sigma} \varepsilon_p c^\dagger_{p\sigma} c_{p\sigma}$ represents a noninteracting conduction band,

$H_b = \sum_q \omega_q \phi^\dagger_q \phi_q$ represents a bath of harmonic oscillators, and

$H_{\rm int} = J\vec{S}\cdot\vec{s}_c + gS_z \sum_q (\phi_q + \phi^\dagger_{-q})$ contains the interaction of the impurity spin $\vec{S}$ with both the conduction-band spin $\vec{s}_c$ at the impurity site and the "displacement'' of the oscillator bath. The band density of states is taken to be a constant ρ_0 over a half-bandwidth $\pm D$ about the Fermi energy, while the bath spectrum is assumed to be sub-Ohmic: $\sum_q \delta(\omega - \omega_q) = (K_0^2/\pi)(\omega/D)^s$ with $0 < s < 1$.

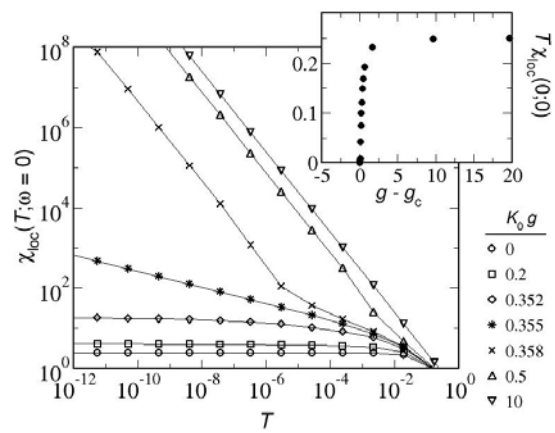

Fig. 1. Static local susceptibility for $s = 0.2$ and $\rho_0 J = 0.5$. Main figure: $\chi_{\rm loc}(T,\omega=0)$ *vs.* T for different bosonic couplings $K_0 g$ (see legend). Note the change in low-temperature slope at $K_0 g_c \approx 0.355$. Inset: $T\chi_{\rm loc}(T=0,\omega=0) \propto \langle S_z\rangle^2$ *vs.* $g - g_c$.

For fixed Kondo coupling J, a critical bosonic coupling g_c separates a Kondo-screened phase ($g < g_c$) from a bosonic phase ($g > g_c$). The impurity spin $\langle S_z \rangle$ acts as an order parameter for a continuous quantum phase transition at $g = g_c$. $\langle S_z \rangle$ and the local susceptibility $\chi_{\rm loc} = \partial\langle S_z\rangle/\partial h$ (where h is a magnetic field that couples only to the impurity) are characterized by a complete set of nontrivial critical exponents that obey hyperscaling. We also find that $\chi_{\rm loc}(\omega, T, g = g_c)$ exhibits ω/T scaling. These properties demonstrate that the Ising-symmetry BFKM has a fully interacting QCP. The numerical values of the critical exponents place this QCP in the same universality class as that of the sub-Ohmic spin-boson model. Extension to the *XY* and isotropic variants of the BFKM is ongoing.

Acknowledgements

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References

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