SPINLESS FERMION MODEL WITH QUANTUM CRITICALITY

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Introduction

Non-Fermi liquid (NFL) properties are observed in many heavy fermion systems and frequently attributed to a nearby quantum critical point (QCP). A QCP can arise by suppressing the transition temperature $T_c$ of a long-range ordered phase to zero. This can be accomplished by pressure, alloying (chemical pressure) or a magnetic field.

Model

The nesting of a Fermi surface (FS) in conjunction with the remaining interaction between the carriers after heavy fermions are formed, can give rise to long-range order. In most heavy fermion systems the long-range order is antiferromagnetism. Here, for simplicity, we consider spinless fermions yielding a charge density wave (CDW). The order is gradually suppressed by mismatching the nesting and a QCP is obtained as $T_c \rightarrow 0$.

Results

A renormalization group approach is used to sum the leading logarithmic contributions. A CDW instability, a $-T\ln(T)$-dependence of the specific heat and a quasi-linear $T$-dependence of the quasi-particle line-width have been obtained for the tuned QCP for two different situations of FS nesting: (a) two spherical pockets, one electron-like and one hole-like, and (b) two parallel FS sheets. Hence, the resistivity is essentially linear in $T$.

The enhancement of the electron-phonon coupling and the softening of the phonon with nesting wave-vector have also been investigated. Due to the nesting condition and the incipient CDW close to the QCP, the phonon energy corresponding to the nesting vector becomes soft as $T \rightarrow 0$. In other words the system is at the verge of a Peierls instability. Associated with the softening is a change in the Grüneisen parameter and the thermal expansion coefficient, which in the neighborhood of the QCP is proportional to $T^{1/2}$ (as expected from a mean-field approximation).

Conclusions

This simple model of spinless fermions with nested FS has many of the properties observed for heavy fermions at a QCP. These results are expected to remain valid if the fermions have a spin degree of freedom and give rise to itinerant antiferromagnetism rather than a CDW.

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References