Kondo Impurity in an attractive Hubbard Bath

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Abstract

In this work, we theoretically study the ground-state properties and out-of-equilibrium dynamics when a Kondo impurity couples with 1D and 2D attractive Hubbard bath. First, we find the ground state exhibits a singlet-doublet phase transition, and observe the competition between the Kondo correlation and the superconducting (SC) order. In particular, the SC gap on the two sides of the 1D chain exhibits a π phase shift when the Kondo singlet forms. Then we study the relaxation dynamics of the impurity coupled to a 2D bath and observe a fast buildup of Kondo correlation near the impurity, with a spin-wave emitted into the bath. The presence of the SC gap leads to an exponential decay of the spin-wave amplitude. Finally, we study the transport between two 1D chains connected by the impurity. By adding a bias voltage, we observe the Josephson effect in the weak-link regime and the ballistic charge transport when the Kondo singlet forms. The charge transport further dramatically influences the bath and the impurity state, leading to rich behaviors such as the dynamical breaking of the Kondo singlet.
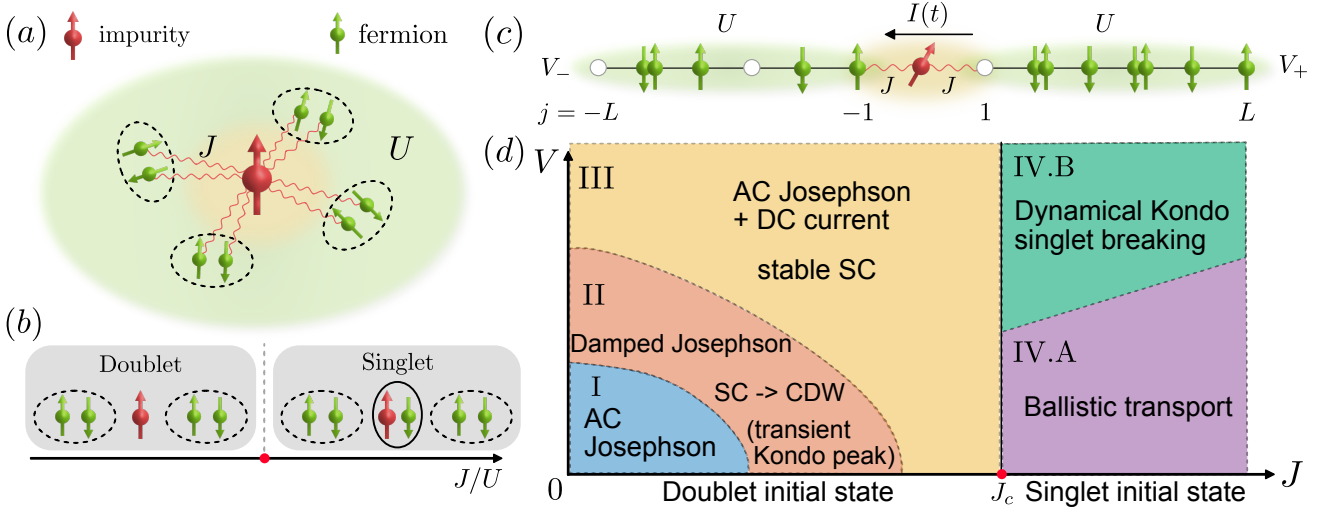
Figure: Ground-state and non-equilibrium physics of a Kondo impurity coupled to attractive Hubbard bath(s). (a) We consider a fermionic bath with attractive Hubbard interaction of strength U, such that the fermions with opposite spins can form Cooper pairs in the bath (denoted by the dashed ovals). A Kondo impurity is coupled to the bath via a spin-exchange interaction of strength J. (b) When $U \gg J$, the fermions tend to form Cooper pairs in the bath, with the impurity being close to a free spin, thus the system is in a doublet phase with total spin 1/2. When $U \ll J$, the Kondo impurity and one electron in the bath together form a Kondo singlet, thus the system is in the singlet phase with total spin 0. By tuning J and U, a first-order phase transition (denoted by the red dot) happens between the doublet and the singlet phase. (c) Consider two chains of Fermions with attractive Hubbard interaction connected by the Kondo impurity. By adding external bias voltages $V_\pm = \pm V/2$, we study the charge transport in this setup, such as the behavior of the charge current $I(t)$. (d) The transport properties of the setup in (c) shows five qualitatively different regimes (I,II,III,IV.A,IV.B).