Gate-dependent Kondo states in bilayer graphene

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One of the remarkable manifestations of cooperative phenomena in condensed matter physics is the many-body screening of a magnetic impurity placed in a metallic system, the *Kondo effect*. Although the physics underlying this effect in ordinary metals is well understood, microscopic symmetries can give rise to intricate features in the effective density of states of the host with profound consequences in the Kondo regime. Bilayer graphene (BLG) is an example of such a material with a gate-dependent gap and large pseudospin symmetry that provides an ample set of different microscopic environments for intercalated magnetic impurities. Combined to its easy tunability, BLG is an ideal material to study quantum phase transitions into various types of Kondo states.

We provide a full characterization of these transitions for a magnetic impurity intercalated in Bernal-stacked BLG and symmetrically coupled to carbon atoms on each layer, as a function of doping level of the system. Two factors determine the wealth of phases predicted: 1) the particular dispersion relation of BLG that gives rise to an interesting density of states with a discontinuity at the interlayer hopping energy; and 2) the properties of the microscopic coupling between the impurity and the layers that define different symmetries for the possible phases.

A multiband Anderson Hamiltonian that includes interaction and different hybridization environments describes the system. After an appropriate Schrieffer-Wolff transformation, we find the effective single-channel Kondo model with a strongly energy-dependent exchange coupling between conduction electron and impurity spins. This effective Kondo Hamiltonian reveals the possibility of driving the system through quantum phase transitions via changes in the chemical potential through gating or doping.

We use numerical renormalization group calculations to accurately describe the Kondo regime. Our calculations reveal zero-temperature transitions between local-moment and singlet strong-coupling phases under variation of band filling and/or energy of the impurity level. The latter show different regimes, such as conventional Kondo, pseudogap Kondo, and local-singlet ground states, distinguishable by their thermodynamic and spectral properties. We also obtain the Kondo temperature dependence with the chemical potential within the different regimes, which would be accessible via STM experiments.