Observation of a Quantum Phase Transition in a single-molecule Quantum Dot

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Quantum criticality is the intriguing possibility offered by the laws of quantum mechanics when the wave function of a many-particle physical system is forced to evolve continuously between two distinct, competing ground states. This phenomenon, often related to a zero-temperature magnetic phase transition, can be observed in several strongly correlated materials such as heavy fermion compounds or possibly high-temperature superconductors, and is believed to govern many of their fascinating, yet still unexplained properties. In contrast to these bulk materials with very complex electronic structure, artificial nanoscale devices could offer a new and simpler vista to the comprehension of quantum phase transitions. This long-sought possibility is demonstrated by our work in a fullerene molecular junction, where gate voltage induces a crossing of singlet and triplet spin states at zero magnetic field. Electronic tunneling from metallic contacts into the C_{60} quantum dot provides here the necessary many-body correlations to observe true quantum critical behavior. With our work, we demonstrate that C_{60} QDs in nanoscopic constrictions present the two key ingredients for observing quantum phase transitions : a gate-tuning of the singlet-triplet gap at zero magnetic field, and a single screening channel. This experiment constitutes thus a further step for the realization in Qds of fundamental many-body effects relevant for bulk correlated materials, and opens also new possibilities for the precise control of spin states in nanostructures containing few electrons. I will present a full experimental study of transport measurements on a C_{60} QD, as a function of bias voltage (V_b), gate voltage (V_g), temperature (35mK to 20K), and magnetic field (0 up to 8 Tesla). A scaling analysis of our conductance measurements reveals the nature of the quantum critical point, in the vicinity of which a surprisingly rich interplay of several Kondo effects occurs. These include the underscreening of a spin S = 1 state on the triplet ground state side, a fully developped inverse Kondo dip on the singlet ground state side, as well as complex non-equilibrium Kondo features on both sides of the transition.