Tunable Non-local Spin Control in a Coupled Quantum Dot System.

Authors: N. J. Craig, J. M. Taylor, E. A. Lester, C. M. Marcus, M. P. Hanson, A. C. Gossard.

Recommended and a Commentary by Elihu Abrahams, Rutgers University

Kondo physics - e.g., a localized spin interacting with a conduction electron sea in which it is embedded - has been a central theme in condensed matter physics for seven decades. The issue of the physics of many localized spins, perhaps on a lattice, interacting with each other as well as with the conduction electrons arose in connection with metallic spin glasses and heavy electron metals. It is then crucial to consider also the interaction among the localized spins, usually mediated by the conduction electrons (RKKY interactions). It is believed that the competition between the Kondo effect, which tends to screen out the local moments, and the RKKY interaction, which tends to produce long-range spin order among them, controls the unusual observed temperature dependences of thermodynamic and transport quantities in heavy-electron metals. This problem, the "Kondo lattice," is yet only partially understood and is a frontier issue in the physics of strongly correlated electrons. One way of approaching the Kondo lattice is to study the Kondo-RKKY competition in the minimal system of two localized spins in the conduction electron sea for which many theoretical results are already available

One of the very attractive things about the nanoscale devices known as quantum dots is that they can be designed as realizations of some problems of fundamental physics. Thus, an odd number of electrons on a dot coupled to leads acts like a localized spin 1/2 and the ensuing Kondo effect has been studied both experimentally and theoretically.

Craig et al have prepared a device with tunable parameters that directly realizes the two-spin Kondo-RKKY problem, heretofore not accessible experimentally. Two-dot situations have been studied earlier but only with direct tunneling between the two dots. Craig et al connected two small odd-occupancy dots to a larger central open dot. Each small dot has spin 1/2 and is susceptible to the Kondo effect, observed as a zero bias resonance peak in the conductance through the dot. In the experiments, the coupling of each small dot to the central dot could be adjusted. As the interaction between the dots, through the central dot, is increased, the Kondo resonance splits and its amplitude decreases. When these couplings are large, the electrons in the central dot couple the two small dots via an RKKY effect and the Kondo resonance signature disappears, indicating a mutual ordering of the two dots, probably into a spin-singlet state. The very strong interaction and the no-interaction cases are understood. The dependence of the initial splitting of the resonance on the couplings in the problem is of particular interest to study since this splitting may be the precursor of the formation of a heavy-electron band.

Thus, the high degree of control of experimental parameters will enable a detailed quantitative study of the Kondo-RKKY competition, the dependence on the sign of the RKKY interaction, and perhaps provide new insights into the heavy-electron lattice problem.