Transport through quantum dots attached to ferromagnetic leads: interaction-induced spin precession, spin-valve effect, and Kondo physics

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Electron transport through quantum dots is strongly affected by the Coulomb energy among the dot electrons. At low temperature, a phletora of effects arise, including Coulomb blockade, resonant tunneling, Kondo physics, spin-valve behavior, and spin precession. In this talk, we concentrate on quantum dots attached to ferromagnetic leads, and analyze the interplay of spin polarization in the leads and strong Coulomb interaction in the dot.

First, we give an introduction to a diagrammatic approach developed for a systematic classification and evaluation of different contributions to the transport current [1,2]. It is based on a real-time analysis of the time evolution of the reduced density matrix of the quantum-dot subsystem.

Then, we apply this technique to describe spin-dependent transport through an interacting quantum dot coupled to two ferromagnetic leads. The spin on the quantum dot and the current as a function of the relative angle θ between the leads' magnetization directions is derived to lowest order in the dot-lead coupling strength [3]. Due to the applied bias voltage, spin accumulates on the quantum dot, which leads to a spin-valve effect, i.e., a suppression of the transmission through the dot with increasing angle θ. For finite charging energy, the accumulated spin experiences a torque, resulting in spin precession. The latter leads to a non-trivial, interaction-dependent, θ-dependence of the linear conductance. In particular, we find that the spin-valve effect is reduced for all $\theta \neq \pi$.

We extend our theory into two directions. One is the nonlinear-response regime [4]. At finite bias voltage, the accumulated spin on the dot tends to align antiparallel to magnetization of the drain electrode. This leads to an increase of the spin-valve effect, detectable in a negative differential conductance. Furthermore, we generalize our theory to address the Coulomb blockade regime, where cotunneling dominates transport [5]. We predict a pronounced zero-bias anomaly associated with a reduction of spin accumulation.

At the end, we shortly address the question of how the finite spin polarization in the leads affects the Kondo effect for strong dot-lead coupling (see also talk by Jan Martinek). Based on a scaling approach [6] and a numerical-renormalization-group technique [7] we predict that for parallel alignment of the magnetizations in the leads the strong-coupling limit of the Kondo effect is reached at a finite value of the magnetic field.

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