COHERENT TRANSPORT AND SPIN EFFECTS IN QUANTUM DOTS

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The lecture is a review of recent results on coherent electronic transport in quantum dots, especially on a role of the spin. In macroscopic metallic systems, an introduction of magnetic impurities leads to the Kondo effect, which is a spin-flip process of a localized spin at the impurity caused by resonant interactions with spins of conducting electrons [1]. In the last decade the Kondo effect has been intensively investigated in nanostructures [2-5]. Electronic transport in such the systems shows different features than those in the macroscopic system, where the characteristic feature is an increase of the resistivity with lowering a temperature. The effect is due to an increase of the relaxation time, an increase a role of spin-flip processes. In contrast in the quantum dot, the conductance increases and reaches the value $2e^2/h$ at T=0, which means that electrons are then perfectly transmitted [6].

After the introduction of the Kondo resonance, we will consider more complex systems of quantum dots (QD), where the Fano resonance can occur as well. The examples

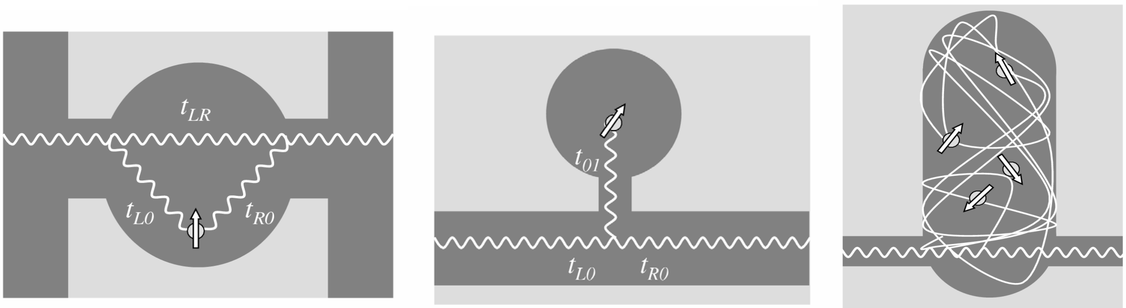

Fig.1 Schematic presentation of a QD dot strongly coupled with electrodes (left), a side-attached QD (center) and a large QD with many scatterers (right). In all these systems the Kondo-Fano resonance was observed.

are presented in Fig.1. The Fano resonance is a common quantum mechanical phenomenon and it is well known in various branches of condensed matter physics, as a special kind of interference process between a localized state and a subsystem of continuum of states. The combined Kondo-Fano effect was observed recently in transport through in various systems of QDs [7]. The experiments show that quantum interference and electronic correlations play

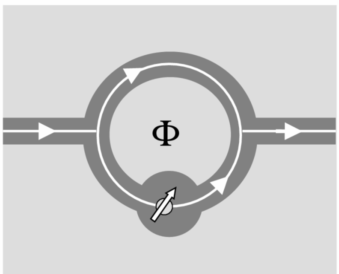

Fig.2 Metallic ring with a quantum dot, in which the Aharonov-Bohm effect as well as the Kondo resonance can be observed.

a crucial role in transport. The first experiment showing quantum interference in nanoscale was on a metallic ring, where the Aharonov-Bohm effect was observed. Advanced lithography technology enables to produce metallic rings with QDs. In such the system, there is interplay between the phase shift of the electronic waves traversing the arms of the ring and that one caused y the Kondo effect.

We will present a theoretical description of electrical transport in these systems as well [8]. Only essential elements will be shown, technical details interesting for theorists one can find in references or/and discuss them later after the lecture.

In the second part of the lecture we consider the influence of accumulated electrons on the conductance through a two quantum dot (2QD) system. Such a system is the simplest realization of a qubit, an electronic device based on coherently coupled quantum dots. Much experimental effort has been undertaken to construct a 2QD connected with the source and drain electrodes either parallel [9] or in series [10]. The problem is more complex, because one can have two electrons and the single and triplet states have to be taken into account. A coherent coupling of these states with conducting electrons leads to the Kondo resonance [2] involving both the orbital and spin degrees of freedom of electrons [11]. The 2QD system can be considered as two Kondo impurities and described by the two impurity Anderson model [12, 13]. Depending on the relation of the inter-dot coupling J_{AF} to the dot–electrode coupling J_K, one can expect two different ground states. For the strong inter-dot coupling, the ground state is antiferromagnetic the singlet state formed by electrons at two neighboring quantum dots), while in the opposite case, for the strong coupling between the dots and the electrodes, two Kondo singlets are formed between conducting electrons and those localized at the dots [12]. There is a competition between the two configurations, which can be controlled by the interdot coupling. We will show theoretical studies of the transition between these states [14], the role of charge fluctuations and many body excitations, and their influence on the electronic transport.

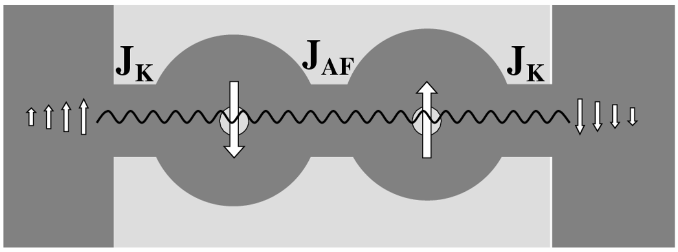

Fig.3 System of two coupled quantum dots with competition between an antiferromagnetic ordering of the magnetic moments localized at the quantum dots and formation of the Kondo singlet (between the localized moments and spins of conducting electrons in the electrodes). Effective coupling parameters are denoted as J_{AF} and J_K.

Acknowledgements

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