Theory of Quantum Transport

Quantum dots coupled to additional degrees of freedom

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The ongoing miniaturization of electronic devices reinforces the interest for investigations of electronic transport in the quantum régime, where the phase coherence of the propagating electrons is maintained on lengths and times that are non-negligible as compared to the scales of the system. The resulting quantum effects in the transport properties are of prominent interest from a fundamental point of view and can be crucial for possible applications.

Among the quantum effects in transport, the Coulomb blockade is paradigmatic. It is due to the quantization of the electron charge combined with repulsive interactions among electrons, and leads to radical modifications in the low-temperature transport through quantum dots (small conducting islands connected to electrodes via tunnel barriers). The Coulomb blockade leads to very interesting features in the transport properties like oscillations of the conductance as a function of a gate voltage and can for example be used to add electrons one by one to the quantum dot.

Though the transport properties of standard metallic quantum dots are nowadays quite well understood, recent experiments at the IPCMS and elsewhere have revealed interesting and surprising new features in the transport properties of more complex setups. One interesting example involves quantum dots that are coupled to mechanical degrees of freedom like for example in the case of a carbon nanotube suspended between the electrodes [1]. Another intriguing situation appears in samples investigated experimentally at the IPCMS, where one of the crucial new features might be the ferroelectric character of the islands [2].

Motivated by the hitherto unexplained results of those experiments, we propose in this work to elaborate and to study models describing quantum dots with couplings to additional degrees of freedom, with a particular focus on the cases of a ferroelectric polarization and mechanical vibrations. We will explore theoretically the effect of those couplings on the electronic transport properties of the quantum dots and also the effect of an electric current on the additional degrees of freedom using both, analytic and numerical methods. The results could then be compared to the experimentally observed behaviors.

The theoretical tools and concepts to be used in this study are the basic ones of quantum transport through mesoscopic systems. Both analytical and numerical calculations using an effective Langevin approach [3] will be used to tackle this problem.

The student will work in the Theoretical Mesoscopic Physics Team at IPCMS, in close contact with experimentalist teams.

[1] A. Eichler, J. Chaste, J. Moser, A. Bachtold, Nano Lett. 11, 2699 (2011)
[2] D. Halley *et al.,* preprint (2012).
[3] G. Weick, F. Pistolesi, E. Mariani, F. von Oppen, Phys. Rev. B 81, 121409(R) (2010); G. Weick, F. von Oppen, F. Pistolesi, Phys. Rev. B 83, 035420 (2011); G. Weick, D. M.-A. Meyer, Phys. Rev. B 84, 125454 (2011); J. Brüggemann, G. Weick, F. Pistolesi, F. von Oppen, Phys. Rev. B 85, 125441 (2012)