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Tunneling transport through molecules and coupled quantum dots

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While early studies of electron transport through mesoscopic systems such as quantum dots or molecular systems concentrated on the current, more recent activities, both experimental and theoretical, include the analysis of shot noise. The latter provides additional insight into the quantum transport properties and plays an important role for the characterization of quantum information and nanomechanical systems, as well as molecular devices.

We study the charge transport through coupled quantum dots ("artificial molecules"), that are weakly coupled to metallic electrodes. The current-voltage characteristics as well as the current noise (S) are calculated within first-order perturbation theory in the coupling strengths (Γ). We explicitly account for intra- and inter-dot Coulomb interactions of the electrons on the dots. In Fig. 1 a sketch of a system of three coupled quantum dots is shown.

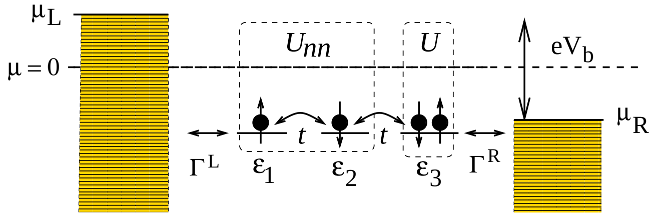

Fig. 1: Model of three coupled quantum dots with onsite energies ϵ_i, hopping strength t, local Coulomb interactions U and non-local (nearest neighbor) Coulomb interactions U_{nn}. The metallic leads are denoted by the chemical potential $\mu_{L,R}$.

Transport through these systems shows Coulomb blockade behavior and is strongly influenced by the energy level structure of the dot system. In the case of two coupled quantum dots various sources of asymmetry such as non-resonant dots ($\epsilon_1 \neq \epsilon_2$) or asymmetric couplings lead to a current suppression and negative differential conductance (NDC). The current shot noise becomes super-Poissonian in this regime implying Fano factors $F = S/2eI$

greater than unity, which signals correlated electron transport.

In contrast, the three dot system displays interesting super-Poissonian behavior even in fully symmetric situations due to a complex spin-related mechanism. The origin of this lies in a competition of “slow” and “fast” transport channels that are formed due to the differing non-local wave functions and total spin of the states participating in transport. Fano factors may thus be largely enhanced up to values of 100. Such strong enhancement should allow direct experimental detection of shot noise in lateral quantum dot experiments.

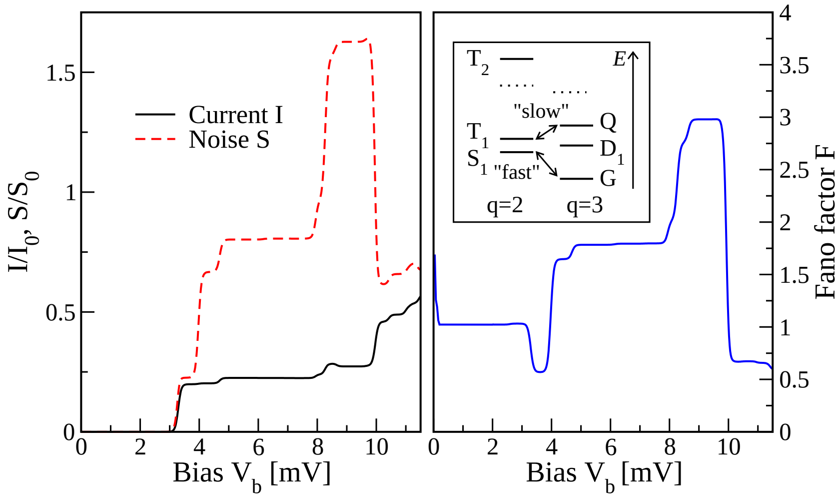

Fig. 2: Normalized current I, noise S and and Fano factor F for a system of three coupled quantum dots with strong non-local Coulomb interactions ($U_{nn}/t >> 1$). Inset: part of the eigenspectrum of the three dot system, displaying the duplet ground state G, D, the singlet S, the triplet T and the quadruplet Q states participating in transport.

References

[1] J. Aghassi, A. Thielmann, M.H. Hettler, and G. Schön, cond-mat/0505345, J. Aghassi, A. Thielmann, M.H. Hettler, and G. Schön, cond-mat/0602261.

[2] *'Mesoscopic Electron Transport'*, eds. L. L. Sohn, L. P. Kouwenhoven, and G. Schön, NATO ASI Series Vol. 345, (Kluwer Academic Publishers, 1997).

[3] W.G. van der Wiel, S. de Franceschi, J. M. Elzerman, T. Fujisawa, S. Tarucha, and L. P. Kouwenhoven, Rev. Mod. Phys. **75**, 1 (2003).

[4] S. S. Safonov, A. K. Savchenko, D. A. Bagrets, O. N. Jouravlev, Y. V. Nazarov, E. H. Linfield, and D. A. Ritchie, Phys. Rev. Lett. **91**, 136801 (2003).

[5] A. Nauen, F. Hohls, N. Maire, K. Pierz and R. J. Haug, Phys. Rev. B **70**, 033305 (2004).

[6] S. W. Jung, T. Fujisawa, Y. Hirayama and Y.H. Jeong, Appl. Phys. Lett. **85**, 768 (2004).