Shot noise in strongly correlated double quantum dots

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In a quantum conductor out of equilibrium, electronic current noise originates from the dynamical fluctuations of the current away from its average value due to both thermal and quantum fluctuations. In particular, measurements of the zero frequency noise out of equilibrium ($\mathcal{S}$) called shot noise [1] allow us to obtain valuable information not available in conventional dc transport experiments. For uncorrelated carriers, described by a Poissonian distribution, one finds Schottky's result $\mathcal{S} = 2qI$ where q is the charge of the carrier (the *full* shot noise or the Poissonian noise). Deviations from the Poissonian noise appear due to correlations between carriers. Quantum statistics or the way carriers scatter and interact within a sample strongly affect noise. The Fano factor (γ), which is defined as the ratio between the actual shot noise $\mathcal{S}$ and the *full* shot noise [1]: $\gamma \equiv \frac{\mathcal{S}}{2qI}$, quantifies the deviation of the actual shot noise from the *full* shot noise. Theoretical and experimental works focusing on the shot noise in strongly correlated electron systems are scarce [1]. This motivates our study of shot noise in double quantum dots (DQD's) exhibiting Kondo effect [2] . If only spin fluctuations are important, this system can be regarded as an artificial version of the two-impurity Kondo problem [two Kondo impurities coupled to conduction electrons and coupled to each other through an antiferromagnetic (AF) exchange coupling]. Indeed, we find an abundance of regimes in the Fano factor directly reflecting the physics of the two-impurity Kondo problem in an out-of-equilibrium situation. The relevant parameters governing the different regimes are: $\tau \equiv t_C/\Gamma$ (t_C is the interdot tunneling coupling and Γ is the coupling to the leads), the AF exchange constant between dots J and the Kondo temperature T_K. In particular, the ratio $(J/T_K)_c \sim 2$ determines the transition from a Kondo state (KS) to an AF spin singlet state in the two-impurity Kondo problem. Our results are based on a strong-coupling approximation, the so-called slave-boson mean-field theory , which is known to capture the main physics in the Kondo regime [3]. The main conclusions of our study are summarized in Fig. 1(a) [serial dots with $\tau < 1$ showing the transition from Kondo state $(J/T_K) > (J/T_K)_c$ to an AF state $(J/T_K) < (J/T_K)_c$] and Fig. 2(a) [parallel dots with $(J/T_K) > (J/T_K)_c$] and Fig. 2(b) [parallel dots with $(J/T_K) < (J/T_K)_c$]. The variety of behaviors of the Fano factors, as a function of the applied dc voltage, for the different configurations of double quantum dots are noteworthy [4]. For the serial case, at low dc bias voltages, the Fano factor changes non-monotonically with J/T_K [see Fig. 1(a)] . By increasing the ratio J/T_K, the Fano factor first decreases until the value $\gamma = 0$ is reached for $(J/T_K)_c$. For $(J/T_K) > (J/T_K)_c$, γ grows. A vanishing Fano factor as one reduces the Kondo temperature (by lowering the gate voltage), for fixed $\tau < 1$, would thus be an unambiguous experimental evidence of a KS$\rightarrow$AF transition in a serial DQD. For parallel DQD's (Fig. 2) there is a completely different behavior of the Fano factor depending on the ratio J/T_K. For $(J/T_K) < (J/T_K)_c$, both QD's are decoupled and we recover the physics of a single Kondo impurity. A very different physical scenario is found when J/T_K is above the critical value. In this case, there is a perfect singlet formation

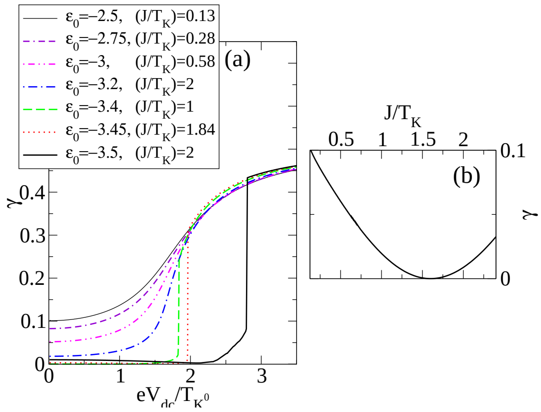

Figure 1: *Serial Double quantum dot* with $U = 4 \times 10^2$ ($J = 0.036$), $\varepsilon_0 = -3.5$ and fixed $\tau = 0.6$: (a) γ vs. $eV_{\rm dc}/T_K^0$ for several ratios of J/T_K (b) γ vs. J/T_K ($eV_{\rm dc} = 0.01T_K^0$). (All energies are in units of Γ).

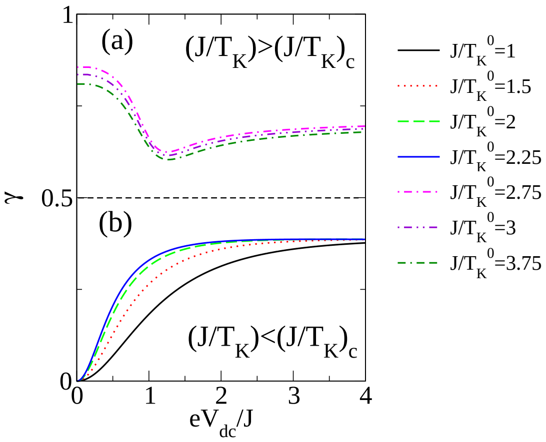

Figure 2: *Parallel double quantum dot* (a) γ–$eV_{\rm dc}/J$ when $(J/T_K) > (J/T_K)_c$ and (b) when $(J/T_K) < (J/T_K)_c$.

and $\mathcal{G}(0) \to 0$ leading to $\gamma \to 1$ as $V_{\rm dc} \to 0$. As one increases $V_{\rm dc}$ the Fano factor decreases until we reach the voltage at which transport is optimized, $eV_{\rm dc} = J$, where γ has a kink. At large voltages, one recovers the limit $\gamma \to 0.5$ (symmetric structure). In closing we have shown that shot noise is a very useful tool to measure the transition from a KS to an AF spin singlet state. In addition this transition manifests itself in a different manner in serial DQD's than in parallel ones. Whereas for serial DQD's the transition occurs when γ vanishes, in the parallel case occurs when γ goes from zero to a $\gamma \to 1$ abruptly.

References

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