Nonlinear Fluctuation Relations in a Spin Diode System

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The linear fluctuation dissipation theorem (Kubo formula) and Onsager's reciprocity relation have been useful tools in analyzing linear transport of mesoscopic systems. For steady state transport, there have been several attempts to extend the linear relations into higher-order relations when a mesoscopic system is driven out of equilibrium. In order to derive such a nonlinear fluctuation relation, one of those attempts extends the microreversibility principle even into a nonequilibrium regime [1], while the other theoretical approach employs the microreversibility principle only at equilibrium [2]. It has been shown that two approaches yield the same results when the system under consideration respects the microreversibility. It is thus quite interesting to investigate the nonlinear fluctuation relations in the situation when the mircoreversibility is broken.

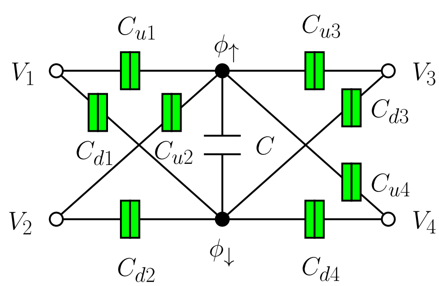

Fig. 1 Capacitively coupled model representation of a spin diode.

When the microreversibility is explicitly broken, the nonlinear fluctuation relations were theoretically tested using mesoscopic Coulomb drag effects [3]. But, a study for the relations in the presence of a magnetic field is still missing. In this work, we examine the nonlinear relations in the absence of the microreversibility and in the presence of a magnetic field. We study a quantum dot coupled to normal and ferromagnetic leads (spin diode). In order to break the microreversibility, we introduce incoherent spin-flip relaxation dynamics between up and down spins in a quantum dot. Also, to ensure gauge invariance we consider a capacitively coupled model shown in Fig. 1. Using full counting statistics [4] and Markovian master equation, the higher-order transport coefficients with respect to the bias voltage are then analyzed.

First, we check the linear fluctuation relations and verify they are exactly satisfied. Next, we proceed to examine second-order relations. Figure 2 shows second-order current and first-order noise transport coefficients with respect to the bias voltage as a function of incoherent spin-flip relation rate γ_{sf} and left lead polarization p_L in the presence of a magnetic field. We observe that the green and red lines perfectively overlap and this implies a second-order fluctuation is exactly satisfied for various parameters. It can be proven that our model system is an irreversible Markov chain and this means the microreversibility is broken. Our result confirms that there exist higher-order fluctuation relations even when the microreversibility is broken in the presence of a magnetic field.

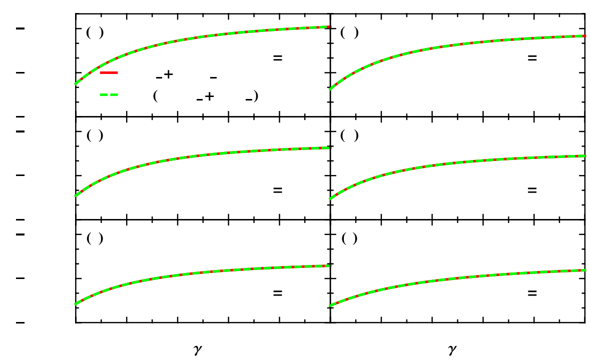

Fig. 2. Second-order fluctuation relations in the presence of a magnetic field.

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