Nonequilibrium Steady States and Current Fluctuation in an AB ring with a Quantum Dot

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Abstract

本研究では、量子ドットと Aharonov-Bohm リングを組み合わせた複合系における非平衡定常状態での Fano 効果、電流ゆらぎの振る舞いを理論的に調べた。系を流れる電流を導出する際に C* 代数の方法を用い、伝導電子の漸近場を導出し演算子の時間発展を調べ、それを $t \to \infty$ とすることで非平衡定常状態を厳密に構成した。結果として、我々は Fano 効果、電流ゆらぎが外部バイアス電圧に強く依存することを示し、更に電流を議論する際には見られなかった干渉効果が電流ゆらぎにおいて重要になることを指摘した。

Exact nonequilibrium steady states for a noninteracting system of an Aharonov-Bohm (AB) ring with a quantum dot (QD) are explicitly constructed with the aid of the C* algebraic method. In addition to Fano resonances and AB oscillations, current fluctuations are shown to strongly depend on the bias voltage. Furthermore, the interference effect contributes to the current fluctuation, even when it can not be seen in the average current.

Fano effect is well known to come from a coupling between resonant and nonresonant states [1]. Asymmetric resonance peaks induced by the interference between them appear when electrons transport coherently through mesoscopic systems such as quantum dots (QDs) embedded in an Aharonov-Bohm (AB) ring [2]. The shape of the resonance peak depends on the magnetic flux enclosed with the two paths and the conductance oscillates due to the interference effect (AB oscillation). We investigate how these features and current fluctuation appear at far-from-equilibrium states with the aid of the C* algebraic method [3]. Nonequilibrium steady states (NESS) are constructed for a noninteracting model of an AB ring with a QD [4]. We then examine the bias-voltage-dependence of the Fano shapes and AB oscillation as well as the current fluctuation. Here, we focus on the magnetic-flux-dependence of the current fluctuation at far-from-equilibrium regime.

The exact NESS for the model is constructed as follows. Initially, the two electrodes are prepared to be equilibrium with the different temperatures and the chemical potentials. Then the system evolves according to the total Hamiltonian and the NESS can be obtained as $t \to \infty$-limit. So-obtained NESS satisfies Wick's theorem and characterized by the two-point function with respect to the asymptotic incoming field operators of conduction electrons. Then the steady-states current and its fluctuation are obtained by using the asymptotic field operators.

The wave-like behavior of electrons causes Fano resonances. On the other hand, their particle-like behaviors can be seen in the shot noise. In order to see their interplay at far-from-equilibrium regime, the relative current that indicates the particle profile is investigated in Fig.1 and Fig.2. As is shown in Fig.1, the relative current fluctuation is dependent on the magnetic flux. In the low bias regime, when

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the current takes its minimum value due to the destructive interference, the noise is almost Poissonian and when the current takes the maximum value due to the constructive interference, the fluctuation is suppressed. With increasing the bias voltage, the relative current fluctuation dose not show the peak-and-dip structures and it seems not to depend on the magnetic flux. This indicates that the contribution of the transfer through the QD becomes small compared to the low bias voltage.

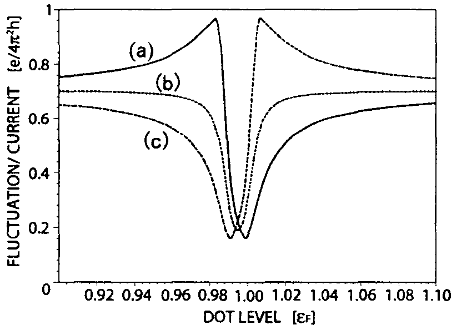

Fig.1. Relative fluctuation at low bias voltage V ($eV/\epsilon_F = 0.01$. ϵ_F: Fermi energy at $eV = 0$) (a) magnetic flux $\varphi = \pi$, (b) $\varphi = \pi/2$, (c) $\varphi = 0$

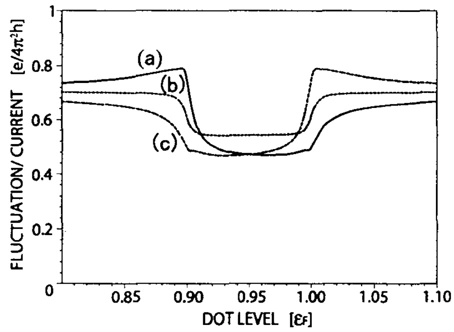

Fig.2. Relative fluctuation at high bias voltage V ($eV/\epsilon_F = 0.1$) (a) $\varphi = \pi$, (b) $\varphi = \pi/2$, (c) $\varphi = 0$

In summary, we investigate the current fluctuation for the noninteracting model of a QD embedded in an AB ring. The current fluctuation is calculated by using the asymptotic in-coming field operators. The magnetic-flux-dependence of the relative fluctuation is shown and the different profiles appear between the equilibrium and nonequilibrium states.

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