Electron Waiting Times in Mesoscopic Conductors

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Electron Waiting Times

Investigations of electrical noise and fluctuations in mesoscopic conductors have traditionally involved measurements of the shot noise and the full counting statistics of transferred charge [1], [2]. Recently, the distribution of waiting times between consecutive electrons has been suggested as a complementary view on the quantum transport in sub-micron conductors [3]–[8], [10]. In this talk, I provide an overview of our Geneva efforts to evaluate the electronic waiting time distributions (WTDs) for several types of quantum conductors. In addition, I provide an outlook on future work and identify possible avenues for further developments.

Theory

The electronic WTD is denoted as $\mathcal{W}(\tau)$ with τ being the waiting time between subsequent electron transfers in a nano-scale conductor. The WTD can be related to the idle time probability $\Pi(t, t_0)$, i. e., the probability of observing *no* electrons in the time interval $[t_0, t_0 + t]$. For stationary processes, it depends only on the length of the interval t, such that $\Pi(t, t_0) = \Pi(t)$. Simple considerations then lead to the following expression for the WTD [5]:

$$\mathcal{W}(\tau) = \langle\tau\rangle \frac{d^2}{d\tau^2}\Pi(\tau). \qquad (1)$$

Here, $\langle\tau\rangle = \int_0^\infty d\tau\tau\mathcal{W}(\tau)$ is the mean waiting time, which can be obtained as $\langle\tau\rangle = -1/\partial_\tau\Pi(\tau)|_{\tau\to 0}$. For periodically driven systems, a generalization of Eq. (1) can be formulated [8], [9].

The central task is to evaluate the idle time probability to obtain the WTD using Eq. (1). For quantum-coherent conductors the WTD can obtained from scattering theory [5], [8]. For open quantum systems, it can be found using (non-Markovian) generalized master equations [3], [4], [6]. The WTD can also be evaluated exactly for non-interacting fermions on a tight-binding chain [10].

Results

Figure 1 depicts schematically a quantum point contact (QPC) connected to voltage-biased electrodes. Figure 2 shows the WTD of a QPC calculated using scattering theory. Figure 3 shows results for the WTD of a dissipative double quantum dot obtained using a generalized master equation.

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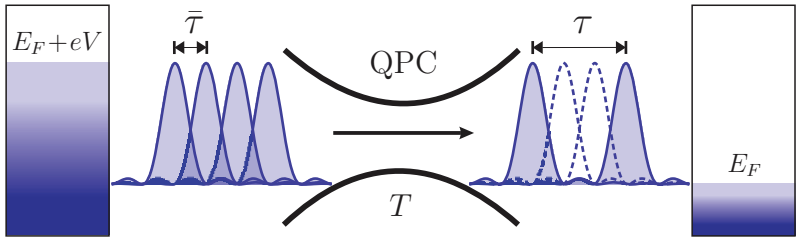

Fig. 1. Quantum point contact (QPC) connected to voltage-biased electrodes. The transmission is denoted as T, the Fermi energy is E_F, and V is the applied voltage. The average time between the in-coming electrons is $\bar{\tau} = h/eV$. The distribution of waiting times τ between transmitted electrons is determined by the many-body state of the in-coming electrons as well as the QPC which may cause electrons to reflect back. Reflected (missing) electrons are indicated by dashed lines. The figure is adapted from Ref. [5]

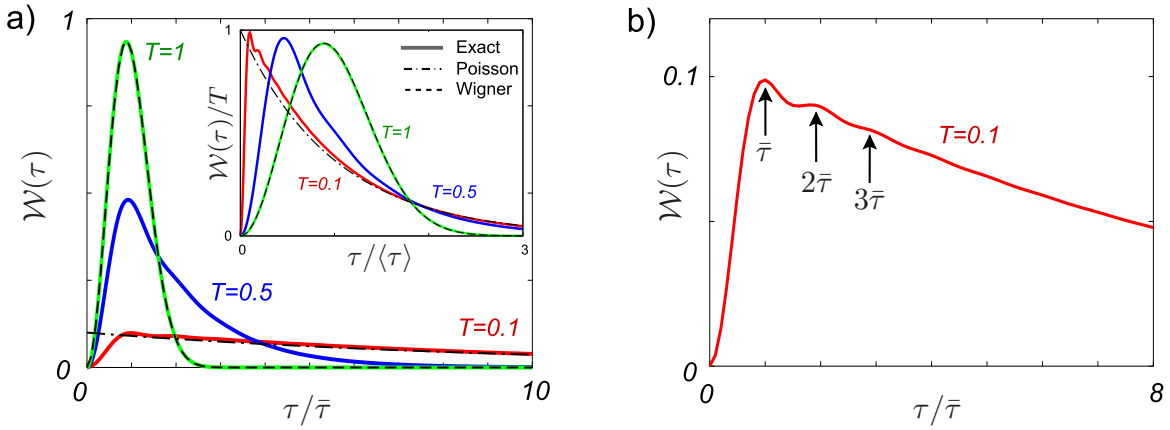

Fig. 2. Electronic WTDs for a quantum point contact with different transmission probabilities T. **a)** The waiting time τ is given in units of $\bar{\tau} = h/eV$ or $\langle\tau\rangle = \bar{\tau}/T$ (inset), where V is the applied voltage. Together with the results for full transmission ($T = 1$) we show a Wigner–Dyson distribution (dashed curve). Together with the results for $T = 0.1$, we show an exponential distribution (dotted-dashed curve). **b)** The electronic WTD in the low-transmission regime ($T = 0.1$). The arrows indicate small oscillations with period $\bar{\tau}$. The figure is adapted from Ref. [5].

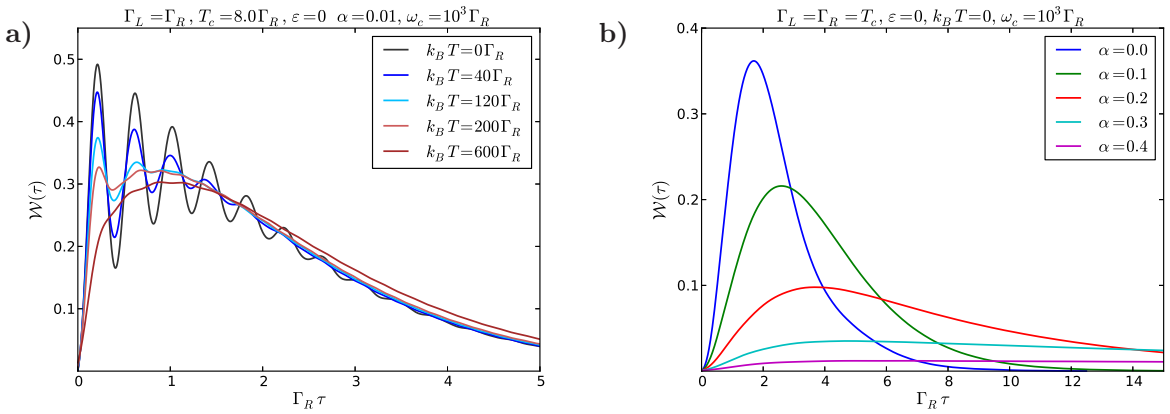

Fig. 3. Electronic WTDs for transport through a double quantum dot coupled to a heat bath. **a)** Weak coupling results ($\alpha = 0.01$). Coherent oscillations between the quantum dots are washed out by an increasing bath temperature T. **b)** Electronic WTDs with increasing coupling (α) to the heat bath. The figure is adapted from Ref. [6].