Effect of intrinsic noise on the conductance of open quantum dots

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Outline

Introduction

- Noise-induced transport in quantum dots
- Motivation

Model & Technique

- Model
- Semiclassical approach

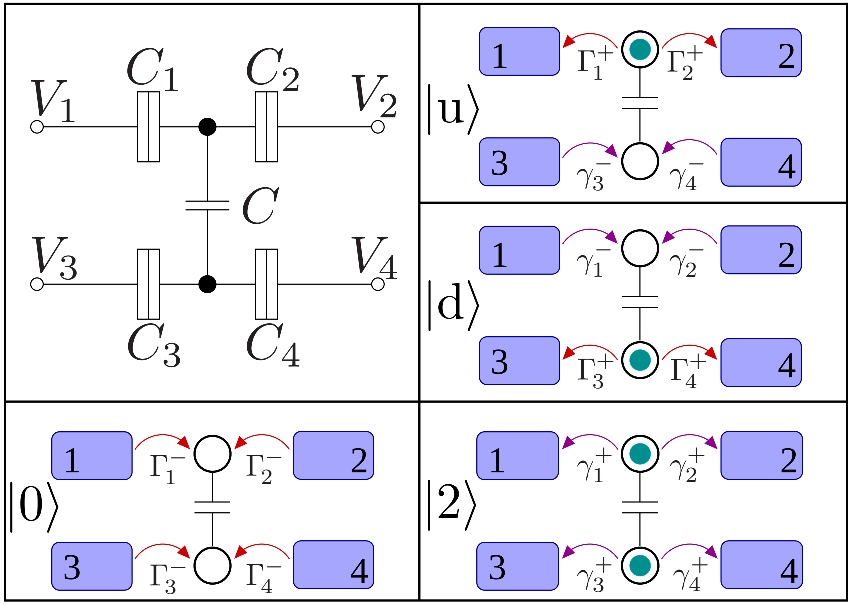
Results

- I-V characteristics of single cavity
- Double cavity: Current from hot spots

Summary & Outlook

Noise-induced transport in quantum dots

Sánchez, López, Sánchez, Büttiker, PRL 2010



- Double quantum dot with four contacts
- Coulomb blockade regime
- Energy-dependent, asymmetric tunneling rates: $\Gamma_1^+\Gamma_2^- \neq \Gamma_1^-\Gamma_2^+$
- Nonequilibrium noise of driven dot induces current through undriven dot: Coulomb drag

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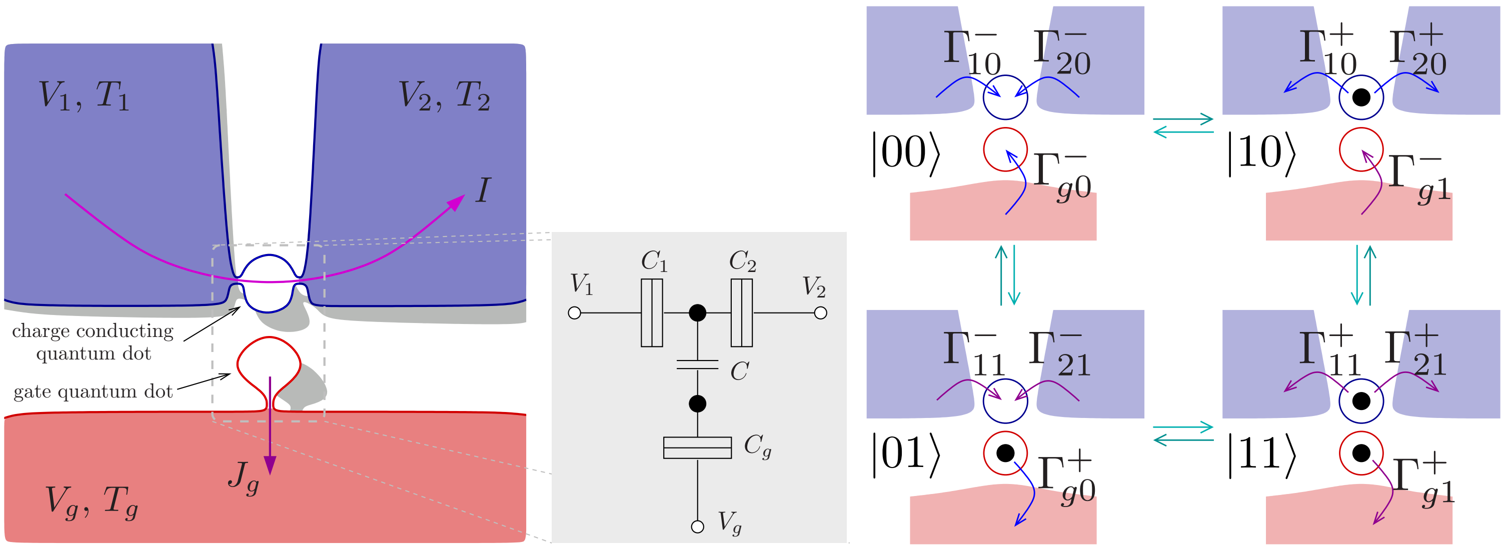
Noise-induced transport in quantum dots

Sánchez, Büttiker, PRB 2011



- Three-terminal setup
- Thermal fluctuations of gate dot occupancy
- Optimal heat to charge conversion
- One energy quantum of the bath transfers one charge quantum

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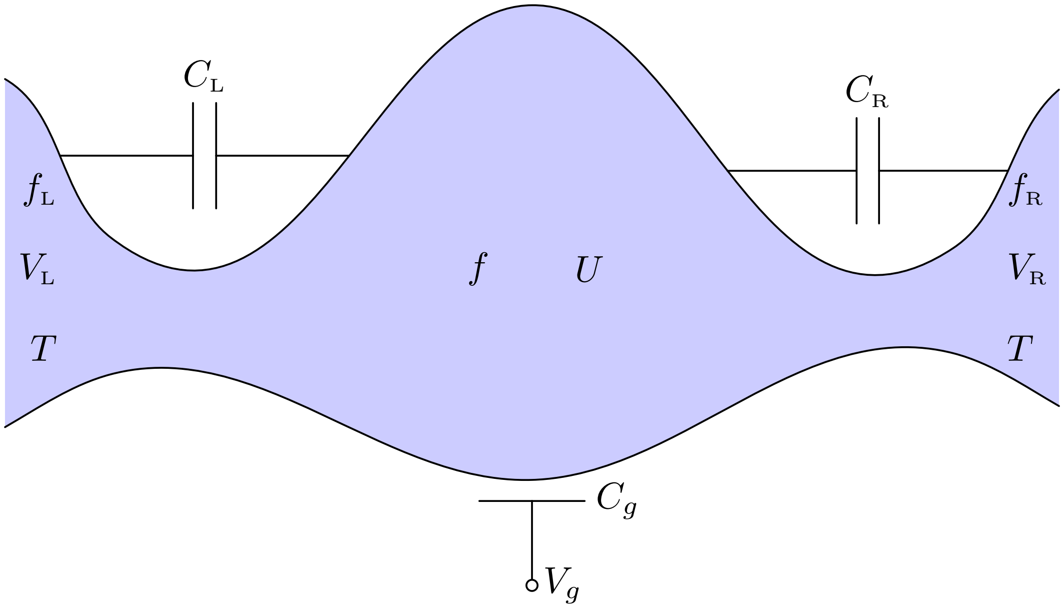
Motivation

Consider transport through open quantum dots!

- Very small currents in Coulomb-blockade system
- Not optimal for applications
- How do effects scale with the system size?

Model



- Cavity coupled to 2 leads via quantum point contacts
- Chaotic cavity subject to potential fluctuations δU
- Energy-dependent transmissions $T_r = T_r^0 - eT_r'\delta U$
- Large channel number $\Rightarrow$ Semiclassical approach

Theoretical description

Kinetic equation for distribution function $f = \sum_r \frac{T_r}{T_\Sigma} f_r + \delta f$

$$\frac{df}{dt} = \frac{\partial f}{\partial U}\dot{U} + \frac{1}{h\nu_{\mathsf{F}}}\sum_r T_r(f_r - f) + \frac{1}{e\nu_{\mathsf{F}}}\delta i_\Sigma$$

Charge inside cavity

$$Q_c = e\nu_{\mathsf{F}} \sum_r \int dE f - e^2\nu_{\mathsf{F}} U,$$

$$Q_c = C_\Sigma U - \sum_r C_r V_r - C_g V_g$$

Relation between fluctuations of distribution function δf and potential δU

$$\int dE \delta f = e\left(\frac{C_\Sigma}{C_\mu} + \frac{\chi}{e^2\nu_{\mathsf{F}}}\right)\delta U + \frac{\chi}{\nu_{\mathsf{F}}}\frac{T'_\Sigma}{T^0_\Sigma}(\delta U)^2$$

where $\chi = e^3\nu_{\mathsf{F}} \frac{T'_r T^0_{\bar{r}} - T'_{\bar{r}} T^0_r}{(T^0_\Sigma)^2}(V_r - V_{\bar{r}})$

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Theoretical description

Eliminate δf from kinetic equation

$\Rightarrow$ Nonlinear Langevin equation determining the potential fluctuations δU

$$C_\Sigma \delta\dot{U} = -\frac{e^2}{h} T_\Sigma^0 \left(\frac{C_\Sigma}{C_\mu} + \frac{\chi}{e^2 \nu_{\mathsf{F}}} \right) \delta U + \frac{e^3}{h} T'_\Sigma \frac{C_\Sigma}{C_\mu} (\delta U)^2 + \delta I_\Sigma$$

- Diffusion coefficients $\langle \delta I_r(t) \delta I_r(t') \rangle = D_r \delta(t - t')$ depend on δU!
- Noise term has to be interpreted according to Klimontovich prescription Klimontovich, Phys. A, 1990
- Convert Langevin equation into Fokker-Planck equation
- Determine fluctuations

Equilibrium: $$\langle \delta U \rangle^{(0)} = 0, \quad \langle (\delta U)^2 \rangle^{(0)} = \frac{2 C_\mu k_{\mathsf{B}} T}{C_\Sigma^2}$$

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Theoretical description

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Linear voltage:

$$\langle (\delta U)^2 \rangle^{(1)} = \frac{T^0_\Sigma}{e T'_\Sigma} \langle \delta U \rangle^{(1)} = -\frac{C_\mu^2}{e^2 \nu_\mathsf{F} C_\Sigma} \frac{2 k_\mathsf{B} T (T^0_\Sigma)^2 \chi}{C_\Sigma^2 (T^0_\Sigma)^2 + 4 e^2 C_\mu (T'_\Sigma)^2 k_\mathsf{B} T}$$

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I-V characteristics

Current

$$I_r = \frac{e}{h} \int dE \, T_r (f_r - f) + \delta I_r$$

Zeroth order in bias voltage:

$$\langle I_r \rangle^{(0)} = \frac{e^3}{h} \frac{C_\Sigma}{C_\mu} T'_r \langle (\delta U)^2 \rangle^{(0)} + \frac{D_{1r}^{(0)}}{2C_\Sigma} = 0$$

- No current in equilibrium!

I-V characteristics

Linear voltage:

$$\langle I_r \rangle^{(1)} = \frac{e^2}{h} \left[\frac{T_r^0 T_{\bar{r}}^0}{T_\Sigma^0} (V_r - V_{\bar{r}}) + e \frac{C_\Sigma}{C_\mu} \frac{T_r' T_{\bar{r}}^0 - T_{\bar{r}}' T_r^0}{T_\Sigma^0} \langle (\delta U)^2 \rangle^{(1)} \right]$$

- First term: Standard current through cavity
- Second term: New contribution due to energy-dependent transmissions and potential fluctuations

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I-V characteristics

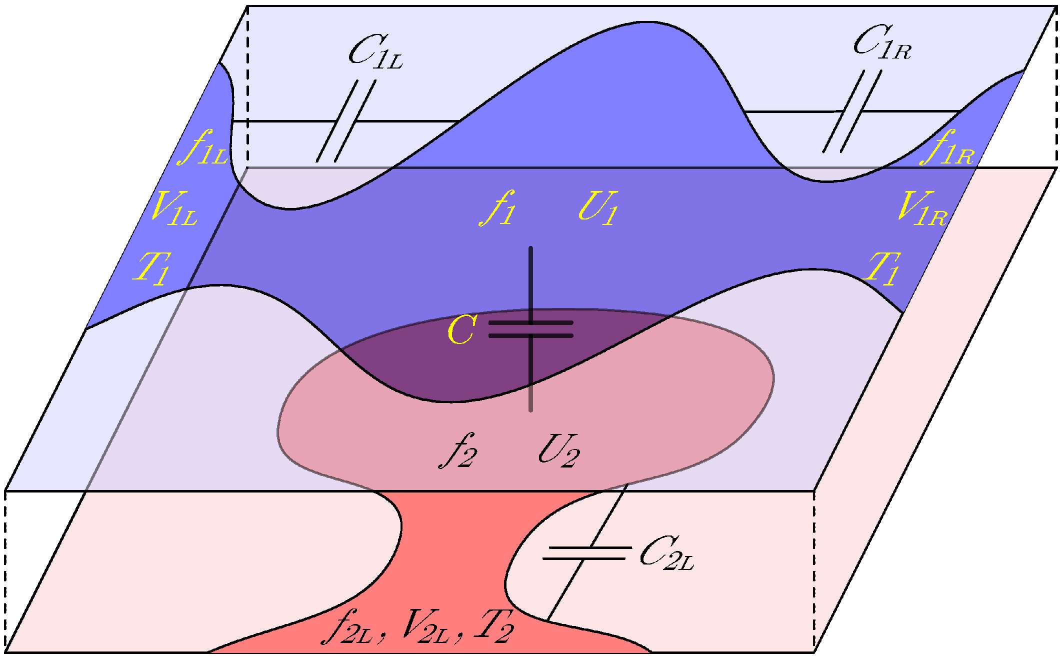
Quadratic voltage:

$$\langle I_r \rangle^{(2)} = -\frac{e^3}{h} \frac{T_r^0 T_{\bar{r}}'}{T_\Sigma^0} \langle \delta U \rangle^{(1)} (V_r - V_{\bar{r}}) - \frac{e^2}{h} \frac{C_\Sigma}{C_\mu} \left(T_r^0 \langle \delta U \rangle^{(2)} - e T_r' \langle (\delta U)^2 \rangle^{(2)} \right)$$

$$+ \frac{D_{1r}^{(2)} + 2 D_{2r}^{(1)} \langle \delta U \rangle^{(1)}}{2 C_\Sigma}$$

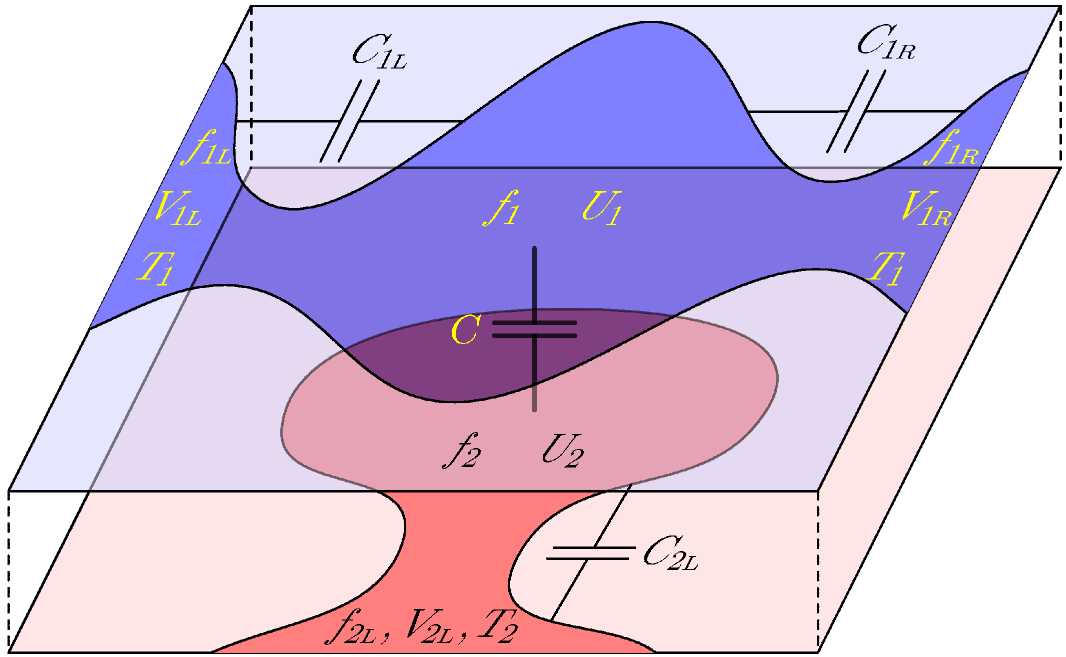
- Nonlinear current contributions due to energy-dependent transmissions and potential fluctuations
- Potentially useful for rectification

Double cavity



- Two capacitively coupled cavities
- Hot gate reservoir
- Investigate heat to current conversion

Double cavity



- Set up kinetic equations for distributions f_1 and f_2
- Charge in cavity sensitive to capacitive dot coupling C
- Determine $\langle \delta U_1 \rangle$, $\langle (\delta U_1)^2 \rangle$, $\langle \delta U_2 \rangle$, $\langle (\delta U_2)^2 \rangle$, $\langle \delta U_1 \delta U_2 \rangle$

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Double cavity

Current:

- Finite current from hotspot requires energy-dependent transmissions of cavity 1
- Finite current from hotspot requires asymmetric transmissions of cavity 1
- Hotspot current depends linearly on temperature difference $T_1 - T_2$
- For symmetric capacitances $C_{1\Sigma} = C_{2\Sigma} = C_\Sigma$ and densities of state $\nu_{1\mathrm{F}} = \nu_{2\mathrm{F}} = \nu_\mathrm{F}$:

$$\langle I_{1r} \rangle = \frac{2e^3}{h} \frac{C_\mu C^2}{C_\Sigma^2} \frac{T_{1\Sigma}^0 T_{2\Sigma}^0}{T_{1\Sigma}^0 + T_{2\Sigma}^0} \frac{T_{1r}^0 T'_{1\bar{r}} - T_{1\bar{r}}^0 T'_{1r}}{C_\Sigma^2 (T_{1\Sigma}^0)^2 + 4e^2 (T'_{1\Sigma})^2 C_\mu k_\mathrm{B} T_1} k_\mathrm{B} (T_1 - T_2) + \mathcal{O}(C^3)$$

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Summary & Outlook

- I-V characteristics of cavity subject to potential fluctuations
- New contributions to linear conductance
- Nonlinear terms in the I-V characteristics
- Noise?
- Double cavity: Current from hot spots