From Equilibrium- to Non-Equilibrium Interaction in Coupled Quantum Dot Devices

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• few electron serial **triple quantum dot**

• **backaction** of a quantum point contact charge detector

• **counterflow** in 2 quantum point contacts
electrostatically defined quantum dots (QDs)
transport through a serial double QD

current flows on **triple points** of the stability diagram
charge spectroscopy using a quantum point contact (QPC) in its tunneling regime

\[ G_T = \frac{dI_{QPC}}{dU_{gL}} \]

has extrema on charging lines of the double QD.
a serial few-electron triple quantum dot

3 QDs ↔ 3 main slopes of charging lines

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triple quantum dot stability diagram
**bistable region – telegraph noise**

(a) bistable region

\[ \frac{dI_{QPC}}{dV_R} \text{ (a.u.)} \]
\[ V_{QPC} = -0.3 \text{ mV} \]

(011) is the ground state!
boundaries of telegraph noise

what is the non-equilibrium energy source?
bistable region in a DQD

arXiv:0801.4002, in cooperation with M. Pioro-Ladriere & A. Sachrajda (CIAR)
multiple bistable regions in a DQD

\[ V_L, V_C, QPC \]

molecular states at triple points

\[ dI_{QPC}/dV_R \text{ (a.u.)} \]

\[ V_{QPC} = -1.0 \text{ mV} \]
the driven QPC is the energy source

- position of charging line is always determined by $\Gamma_{in} = \Gamma_{out}$;  $\left(\Gamma_{in} \gg \Gamma_{out}\right)$ ⇒ QD is permanently charged
- equilibrium:  $\Gamma_{in} = \Gamma_{out}$ at resonance condition
- non-equilibrium energy source:  $\Gamma_{in} \neq \Gamma_{out}$ at resonance condition possible

the nearby QPC used as charge detector provides non-equilibrium energy!
transition between atomic and molecular behavior

gap for $\Gamma_{\text{in}} = \Gamma_{\text{out}}$ smaller than Lock-In frequency
noise spectroscopy of excited states

Γ_{in} and Γ_{out} change at interdot resonances

$\text{arXiv:0801.4002, in cooperation with M. Pioro-Ladriere & A. Sachrajda (CIAR)}$
• a driven QPC always provides energy and causes telegraph noise (fluctuations between charge configurations) in coupled QDs

• the noise will limit the coherence time of a qubit

• the fluctuations can be directly observed only if slow enough!

is the energy mediated by phonons or by photons?
interaction between two electrically separated QPCs

the two QPCs are electrically separated: \textit{no leakage current}!
counterflow current $I_{CF}$ flows through the detector QPC in the opposite direction than $I_{DRIVE}$. 

$V_{drive} = 4.0 \text{ mV}$

$G_{drive} / G_0$

$V_3 (V)$

$V_8 (V)$

**PRL 99, 096803 (2007)**
counterflow current as a function of $G_{\text{det}}$

g_{\text{cf}} \equiv \frac{dI_{\text{cf}}}{dV_{\text{drive}}}$

detector QPC:

maximal effect for $G_{\text{det}}$ between plateaus
counterflow current in the pinch-off regime ($G_{\text{det}} = 0$)

$g_{\text{CF}}$ is enhanced compared to $4T_0 (1-T_0)$ even in the pinch-off regime of the detector QPC → hot electrons ($E-E_F \sim 0.5 \text{ meV}$)

Transmission function: $4 T_0 (1-T_0) \equiv \frac{G_{\text{det}}}{G_0} \left| 1 - \frac{G_{\text{det}}}{G_0} \right|$
model in terms of asymmetric phonon based heating

1.) hot electrons \((E-E_F \sim 4 \text{ meV})\) scatter with Fermi-see \((E_F \sim 8 \text{ meV})\) only in the right lead of the drive-QPC

2.) hot electrons emit phonons with maximal momentum of \(2k_e \rightarrow \text{maximal } E_{ph} \sim 0.5 \text{ meV}\)

3.) acoustic phonons are absorbed in the detector circuit by exciting electron-hole pairs with max. \(E_e \sim 0.5 \text{ meV}\)

4.) the resulting hot electrons pass the detector-QPC, but the “cold” holes are reflected \(\rightarrow\) counterflow current
• full control of charge states in few electrons triple QDs achieved
  → triple QDs provide rich spectrum of physics going beyond that of double QDs (e.g. QCA-processes,...)

• bounded (bistable) regions of telegraph noise observed in triple and double QDs
  → quantum point contact acts as non-equilibrium energy source
  → noise is always present, but usually too fast for charge detection
  → consequence: switch off charge detector during qubit operation for longer coherence times

• counterflow through quantum point contacts
  → strongly driven quantum point contact provides phonons

thank you!!
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