Charge fluctuation effects in superconductor-quantum dot hybrid systems

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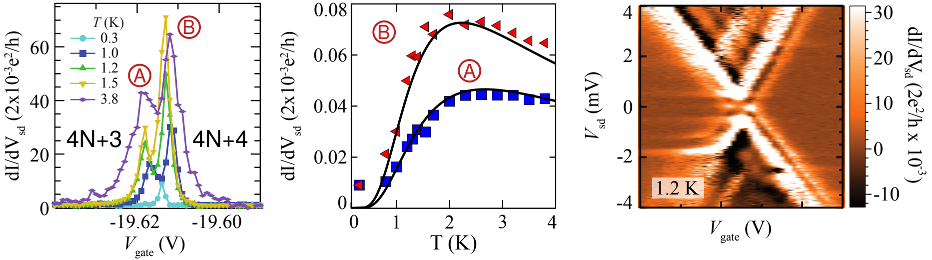
Motivation



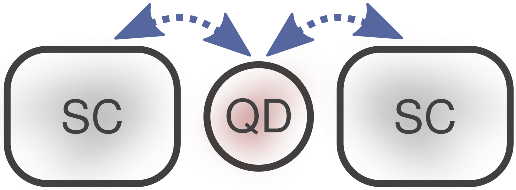
- Basic experimental features[1] explained by 2nd order theory[1, 2]
- Broadening not captured
- Application of the dressed second order theory[3] (DSO) to the case of superconducting contacts

[1] M. Gaass, S.Pfaller *et al. PRB 89, 241405(R) (2014)*

[2] S. Pfaller *et al. PRB 87,155439(2013)*

[3] J. Kern *et al. Eur. Phys. J. B (2013) 86: 384*

Model



$$\hat{H} = \hat{H}_S + \hat{H}_L + \hat{H}_T$$

Electron number conserving Bogoliubov transformation:

$$\hat{\mathrm{c}}^\dagger_{\eta k\sigma} = \hat{\gamma}^\dagger_{\eta k\sigma} + \mathrm{sgn}\,\sigma\,\hat{\gamma}_{\eta k\sigma}\hat{\mathrm{S}}^\dagger_\eta$$

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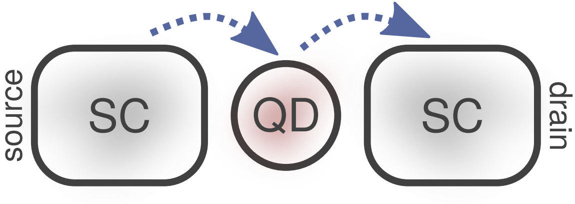

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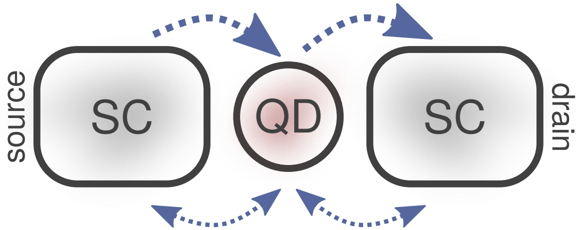

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Transport theory

Exact master equation for RDM:

$$\dot{\hat{\rho}}_\infty = 0 = \mathcal{L}_S \hat{\rho}_\infty + \lim_{\lambda \to 0} \mathcal{K}(\lambda) \hat{\rho}_\infty$$

Kernel in Laplace space can be expressed in a diagramatic language:

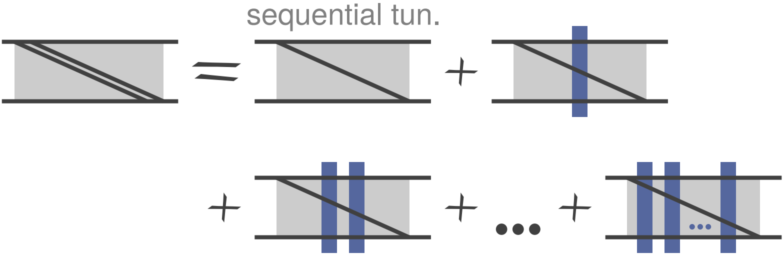
$$\mathcal{K}(0) = \sum \left(\text{irreducible diagrams} \right)$$

irreducible

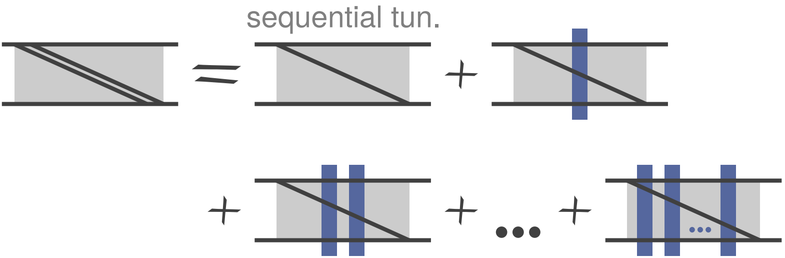
reducible

In the following we consider an infinite subset of irreducible diagrams that can be resummed

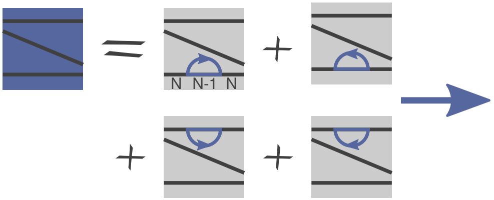
Resummation



Resummation

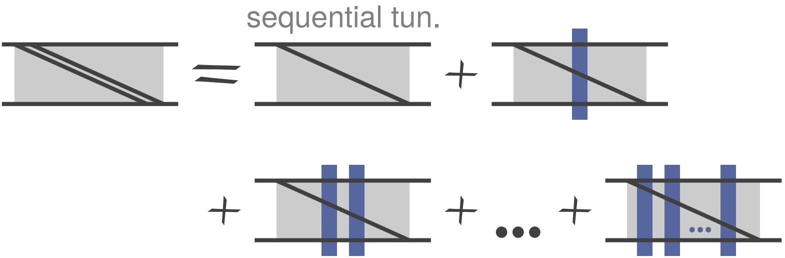


Self energy like contributions in the DSO approximation:



charge fluctuations within one tunneling event

Resummation



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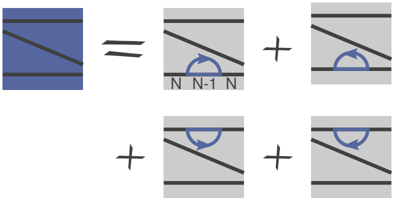
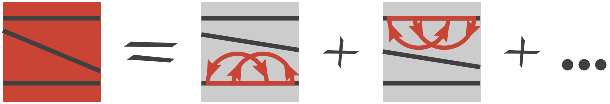


we consider **only** fluctuations between **neighboring** particle numbers on the dot

$$= \mathcal{O}(\Gamma)$$

What about the Cooper pairs?

Contribution of Cooper pair fluctuations to the self energy:



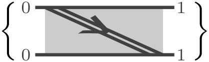
$= \mathcal{O}(\Gamma^2)$

neglected in the DSO approximation

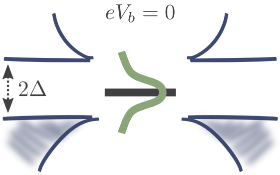
- Derivation along the lines of normal conducting leads[3]
- Energy dependent quasi particle density of states

[3] J. Kern *et al.* *Eur. Phys. J. B (2013) 86: 384*

Single non-degenerate level

$\Gamma_l^{1\to 0} = 2\,\mathrm{Re}\Big\{$  $\Big\}$

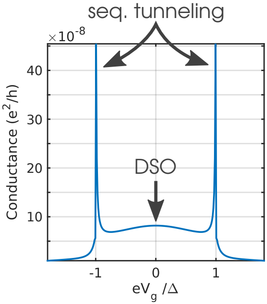
$$= 2\,\mathrm{Re}\left\{\frac{i}{\hbar}\Gamma\int_{-\infty}^{\infty} dE\,\frac{f^{-}(E)G(E)}{E+\mu_l-E_{10}-\Sigma_{dso}}\right\}$$



Zero bias conductance:

$$\left.\frac{dI}{dV}\right|_{V_b=0} = \frac{4e^2}{h}\int_{-\infty}^{\infty} dE_0\,\frac{\pi\Gamma G(E_0)}{\left(E_0-E_{10}\right)^2+4\big(\pi\Gamma G(E_0)\big)^2}$$

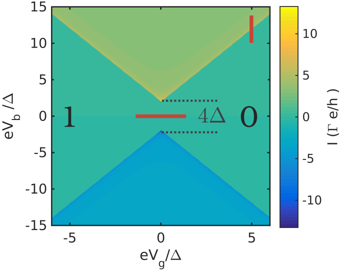
$$\times\left(\frac{1}{k_BT}\,\frac{\pi\Gamma G(E_0)}{4\cosh^2\left(\frac{E_0}{2k_BT}\right)} - \pi\Gamma G'(E_0)\big(f^{+}(E_0)\rho_0 - f^{-}(E_0)\rho_1\big)\right)$$

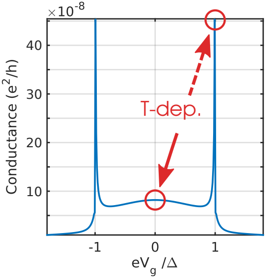


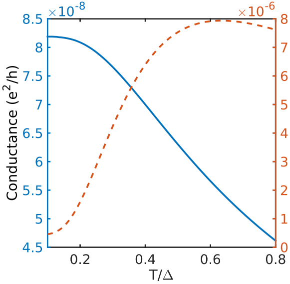
comparable to the resonant tunneling regime of Levy Yeyati *et al.*[4]

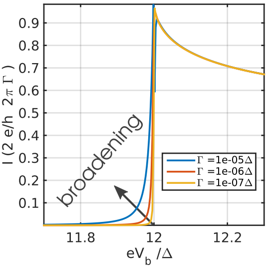
[4] A. Levy Yeyati *et al.* PRB 55, R6137(R)(1997)

Transport characteristics





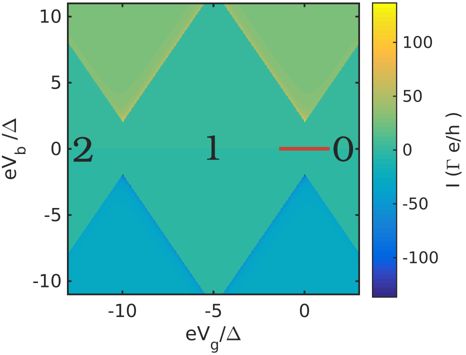


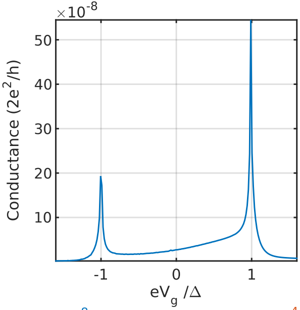


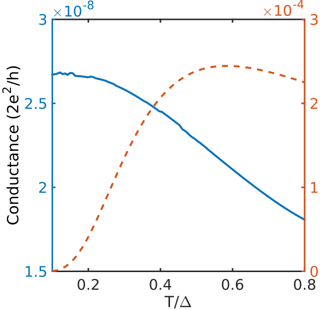
Main features:

- zero bias conductance peak
- grows with decreasing T
- broadening of the current

Single impurity Anderson model







- similar features as for the spinless level
- zero bias conductance independent of the spin

Summary and Outlook

- Application of the dressed 2nd order theory to the case of superconducting leads
- Scalability to quantum dot molecules
- New features due to charge fluctuations induced broadening

- Self energy beyond DSO approximation
- Inclusion of Cooper pair transport