Series of scientific works

Quantum Effects of Interaction in Nanosystems

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KEY FEATURES OF SINGLE-ELECTRON TRANSPORT IN QUANTUM DOTS

Basic theoretical idea on sigle-electron charge transport in nano-sized granules: ***"A quantitative theory in terms of rate equations describing the transport through a blockaded quantum dot or metal grain at*** $G << e^2/2\pi\hbar$ ***was formulated in Refs. [1,2], and was generalized to systems with a controllable gate in Ref.[3]."*** **– from the Review article by: I.L. Aleiner, P.W. Brouwer, L.I. Glazman in:** ***Physics Reports, V. 358, No.5-6, 2002, Pp. 309-440.***

$eV, T << E_C \propto e^2/D$	[1] R.I. Shekhter — Sov. Phys. JETP, 36, 747, (1973).
$eV_g \approx E_C$	[2] I.O. Kulik, R.I. Shekhter — Sov. Phys. JETP, 41,308 (1975).
	[3] D.V. Averin, K.K. Likharev — J. Low Temp. Phys. 62, 345 (1986).

Size quantization in nanotubes: $\Delta E \propto \hbar v_{F(N)}/L >> eV, T$	**Possibility of electron transport through a single quantum level in nanotubes:** $D \propto L$	$E_C/\Delta E \propto e^2/\hbar v_{F(N)} \propto 1$

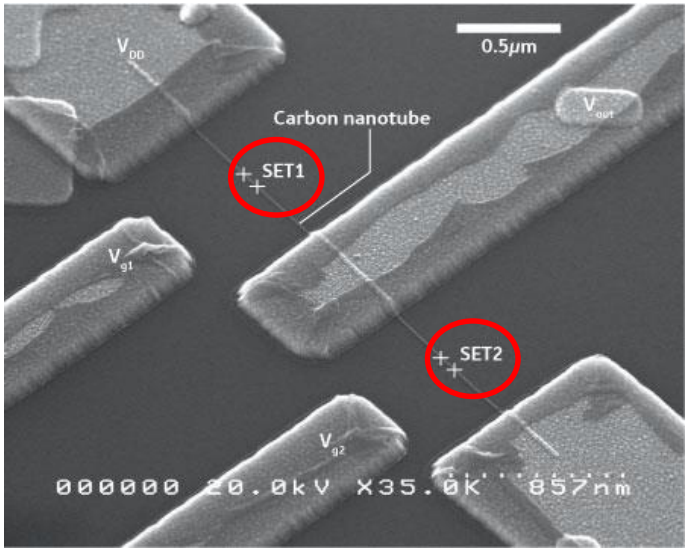
Example of experimental design of nanotube-based single-electron transistor:

Typical values of main characteristic parameters for single-electron transistors, as relevant nanosystems :

Characteristic energies and differences between chemical potentials of the leads (bias voltages) in such systems: < 100 meV

Characteristic temperatures: < 100 mK

Characteristic scale of a system: 10-100 nm

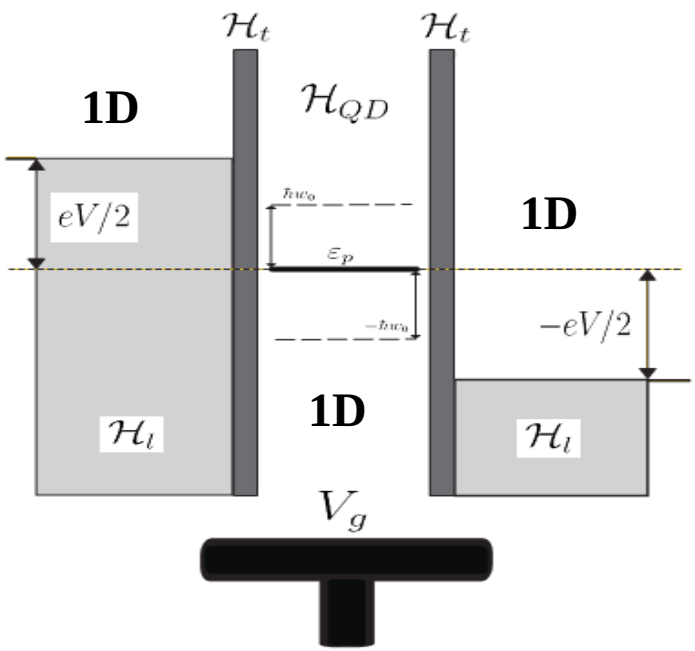


K. Ishibashi et al., ADL, RIKEN, Japan, 2003.

1. INTERPLAY OF QUANTUM-VIBRATIONAL AND LUTTINGER LIQUID EFFECTS IN ELECTRON TRANSPORT THROUGH SINGLE-LEVEL QUANTUM DOT. Model.

G.A.Skorobagatko , I.V.Krive , *Low Temp. Phys. 34, 858 (2008).*

Model of a single-electron molecular transistor with Luttinger liquid leads and quantum vibrating quantum dot:



Total Hamiltonian of the system:

$$\mathcal{H} = \mathcal{H}_{LL} + \mathcal{H}_{QD} + \mathcal{H}_T$$

$$\mathcal{H}_{LL} = \sum_{j=L,R} \mathcal{H}_l^{(j)}$$

- Hamiltonian of Luttinger liquid leads in bosonic representation («charge» sector):

$$\mathcal{H}_l^{L(R)} = \mathcal{H}_l = \hbar v_c \int_0^\infty a_k^+ a_k k dk$$

Hamiltonian of quantum vibrating quantum dot with electron-vibron interaction:

$$\mathcal{H}_{QD} = \varepsilon_0 f^+ f + \varepsilon_i (b^+ + b) f^+ f + \hbar w_0 b^+ b$$

Tunnel Hamiltonian:

$$\mathcal{H}_T = \sum_{j=L,R} \{ t_j f^+ \Psi(j) + h.c. \}$$

Connection between fermionic and bosonic operators in the leads

$$\Psi(L(R)) = \sqrt{\frac{2}{\pi\alpha}} \cdot \exp\left[\int_0^\infty dk \frac{e^{-\alpha k/2}}{\sqrt{2K_\rho k}} \cdot (a_k - a_k^+) \right]$$

Luttinger liquid correlation parameter:

$$g = (1 + U/2\pi v_F)^{-1/2}$$

$$K_\rho = (2/g - 1)^{-1}$$

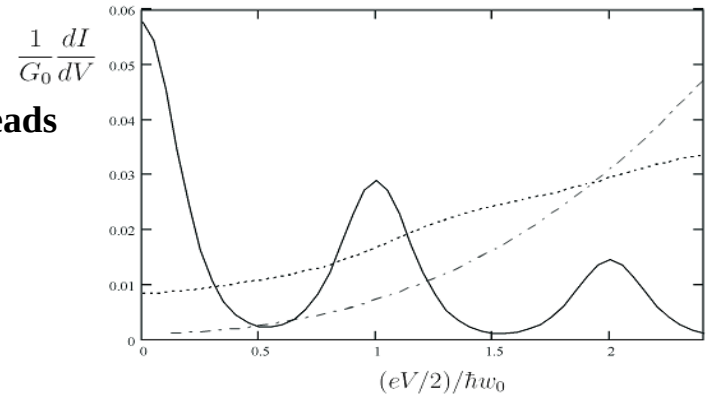
1. INTERPLAY OF QUANTUM-VIBRATIONAL AND LUTTINGER LIQUID EFFECTS IN ELECTRON TRANSPORT THROUGH SINGLE-LEVEL QUANTUM DOT. Results.

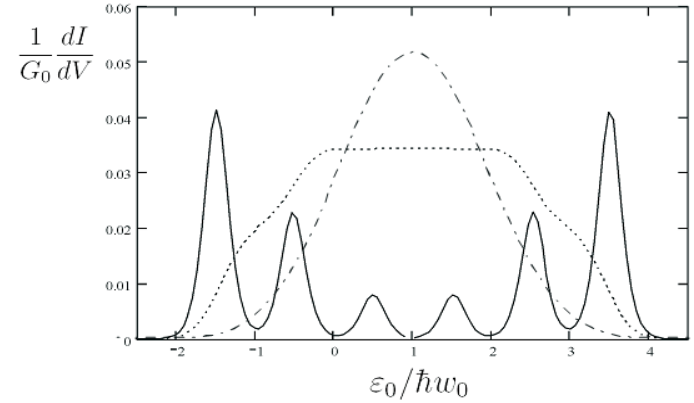
G.A.Skorobagatko , I.V.Krive , *Low Temp. Phys. 34, 858 (2008).*

Differential conductance: $G(V) = dI/dV$ **in the non-linear regime on bias voltage**

Strong electron-electron repulsion in the leads

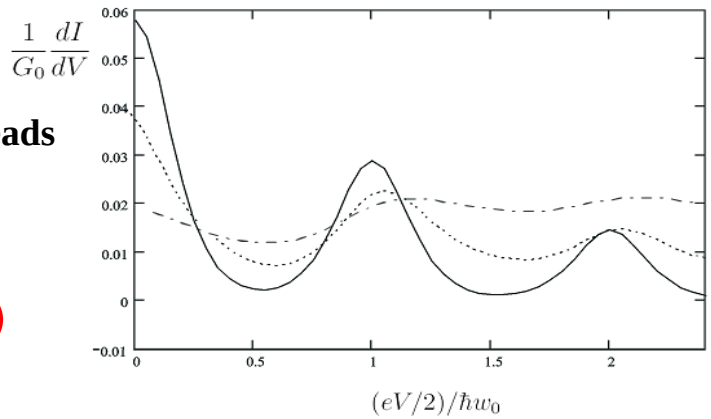
$g < 1/2$

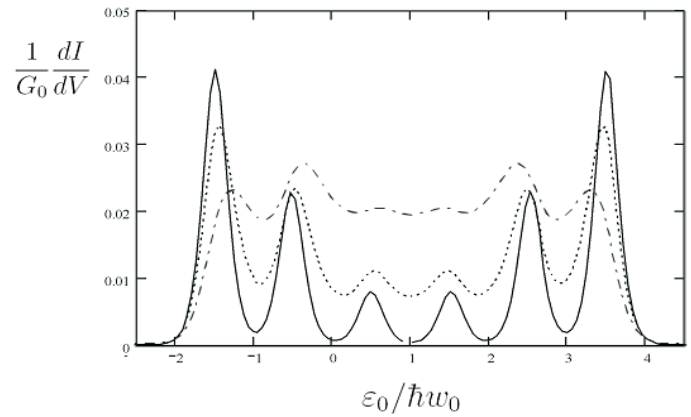




Weak electron-electron repulsion in the leads

$1/2 \leq g < 1$



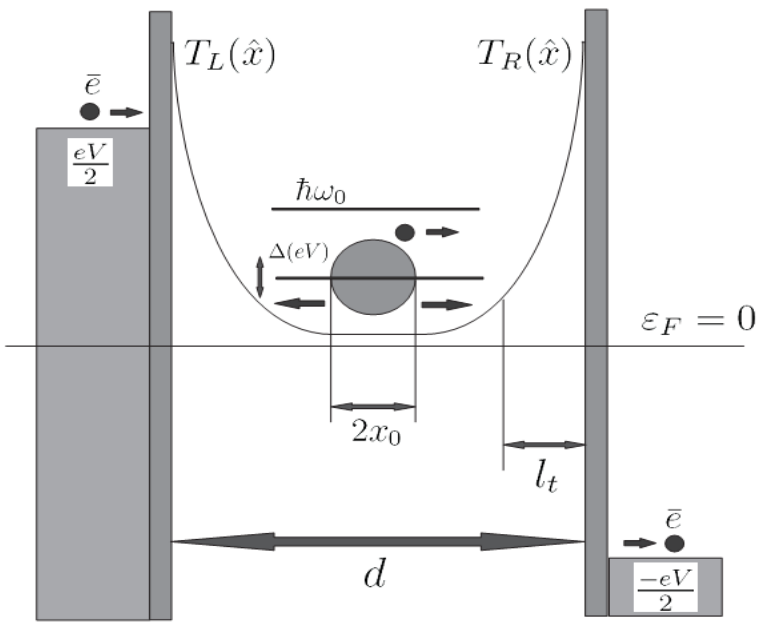


If: $eV/\hbar w_0 \gg (1/g - 2)$ **then:** $G(V) \simeq 4\pi G_0 \frac{\Gamma_\lambda}{\Lambda} \cdot \left[\frac{1}{(n-1)!}\right] \cdot \left(\frac{eV}{2\Lambda}\right)^{n-2}$

2. POLARONIC EFFECTS IN THE EMERGENT SHUTTLE INSTABILITY OF QUANTUM DOT CLASSICAL MOTION. Model.

G.A.Skorobagatko, I.V.Krive, R.I.Shekhter , Low Temp. Phys. 35, 949 (2009).

Model of single-electron transistor with vibrational degree of freedom:
(see e.g. L.Y.Gorelik, R.I.Shekhter et al., Phys.Rev.Lett. -1998. –V.80, No. 20. -P. 4526.)



$$\lambda = \frac{\sqrt{2}\varepsilon_i}{\hbar\omega_0} = r_d \frac{eV}{2\hbar\omega_0} \qquad \frac{\hat{X}_{c.m.}}{x_0} = \hat{X} = \frac{1}{\sqrt{2}}\left(\hat{b}^+ + \hat{b}\right)$$

$$r_d = \frac{2x_0}{d} \ll 1 \qquad x_0 = \sqrt{\hbar/M\omega_0}$$

Total Hamiltonian of the model:

$$\hat{H} = \sum_{j=L,R} \hat{H}_l^{(j)} + \hat{H}_d + \sum_{j=L,R} \hat{H}_t^{(j)}$$

Hamiltonian of Fermi-liquid lead :

$$\hat{H}_l^{(j)} = \sum_k (\varepsilon_k - \mu_j)\hat{a}_{kj}^+ \hat{a}_{kj}$$

Hamiltonian of quantum dot with electron-vibron interaction:

$$\hat{H}_d = \varepsilon_0 \hat{c}^+\hat{c} - \varepsilon_i(\hat{b}^+ + \hat{b})\hat{c}^+\hat{c} + \hbar\omega_0 \hat{b}^+\hat{b}$$

Tunnel Hamiltonian:

$$\hat{H}_t^{(j)} = \sum_k \left[\hat{t}_j(\hat{X}_{c.m.})\hat{a}_{kj}^+\hat{c} + h.c.\right]$$

$$\hat{t}_j(\hat{X}) = t_{0j}\exp(j\lambda_t \hat{X})$$

$$\lambda_t \equiv x_0/l_t \qquad j = (L,R) \equiv (-,+)$$

2. POLARONIC EFFECTS IN THE EMERGENT SHUTTLE INSTABILITY OF QUANTUM DOT CLASSICAL MOTION. Quantum equations of motion.

G.A.Skorobagatko, I.V.Krive, R.I.Shekhter , Low Temp. Phys. 35, 949 (2009).

Applying first-principles quantum equation of motion (QEOM) method in the regime of electron sequential tunneling :

$$T \gg \Gamma$$

$$\Gamma = \Gamma_{0L} + \Gamma_{0R}$$

$$\Gamma_{0j} = 2\pi\rho_j|\bar{t}_{0j}|^2$$

- One can obtain following «classical» equation of motion for the average coordinate of molecular shuttle center-of-mass displacement, with the averaged «quantum» force y in the r.h.s. of equation:

$$\frac{d^2}{dt^2}\left[\bar{x}(t) + \lambda N\{\bar{x}(t)\}\right] + \omega_0^2\bar{x}(t) = -\frac{\omega_0\lambda_t}{\hbar}\sum_{j=^{-/L}_{+/R}} jH_j\left\{\bar{x}(t)\right\}$$

- See similar calculation in: D.Fedorets , Phys.Rev. B. V. 68, No. 3,P. 033106 (2003)

$$N\{\bar{x}(t)\} = \langle\hat{c}^+(t)\hat{c}(t)\rangle \qquad H_j\left\{\bar{x}(t)\right\} = \langle\hat{H}_j(\hat{X},\hat{p})\rangle$$

Linearizing above equation with respect to small parameters: $\lambda\bar{x}(t) \ll 1 \qquad \lambda_t\bar{x}(t) \ll 1$

searching its solution in the form:

$$\bar{x}(t) = A_0 e^{r_s t}\sin(t)$$

one obtains following shuttle instability increment:

$$r_s = \sum_{j=^{-/L}_{+/R}} \frac{\bar{\Gamma}_{0j}}{8}\sum_{l=-\infty}^{+\infty} F_{lj}(\beta)\left\{(\lambda - j\lambda_t)^2 f_j(\Delta - l + 1) - (\lambda + j\lambda_t)^2 f_j(\Delta - l - 1)\right\}$$

Where:

$$\bar{\Gamma}_{0j} = \Gamma_{0j}\exp(j\lambda\lambda_t)$$

$$F_{lj}(\beta) = \exp[-(\lambda^2 - \lambda_t^2)(1 + 2n_b)]\left|\frac{\lambda + j\lambda_t}{\lambda - j\lambda_t}\right|^l I_l(2|\lambda^2 - \lambda_t^2|\sqrt{n_b(1 + n_b)})e^{-\beta l/2}$$

2. POLARONIC EFFECTS IN THE EMERGENT SHUTTLE INSTABILITY OF QUANTUM DOT CLASSICAL MOTION. Results.

G.A.Skorobagatko, I.V.Krive, R.I.Shekhter , Low Temp. Phys. 35, 949 (2009).

Low-temperature shuttle instability increment as the function of applied bias voltage:

$$T \ll \hbar\omega_0, \quad T \gg \Gamma.$$

$$r_s = \frac{\Gamma\lambda\lambda_t}{2}\exp(-\lambda^2+\lambda_t^2-\lambda\lambda_t)\sum_{l=0}^{l_m-1}\frac{(\lambda+\lambda_t)^{2l}}{l!}$$

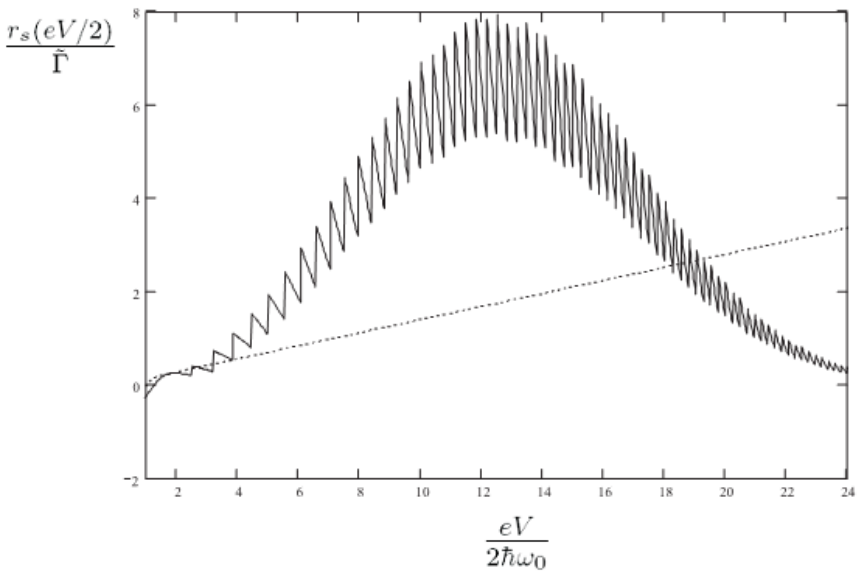
$$l_m = \left[\frac{eV}{2} - \left(\varepsilon_0 - \frac{\lambda^2}{2}\right) - 1\right]$$

Shuttle instability «window» with respect to bias voltage: $eV_c/2 < eV/2 \leq 2r_d^{-2}$

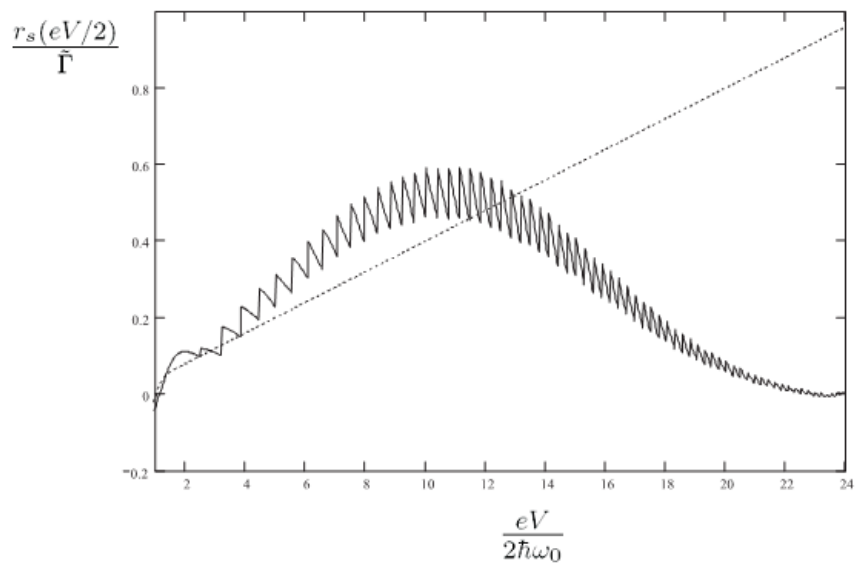
The maximum of increment is achieved for: $eV \sim r_d^{-2}$

$$V_c = 2(\varepsilon_0 - \lambda^2(V_c)/2 + 1) \qquad r_d = 2x_0/d$$

$\lambda_t = 0,7 > r_d$ $\qquad r_d = 0,2$



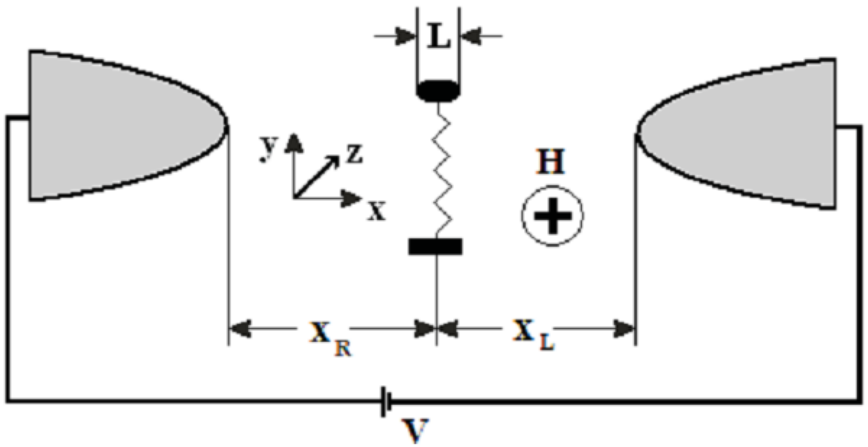
$\lambda_t = r_d = 0,2$ $\qquad \lambda_t \equiv x_0/l_t$



3. ROLE OF MAGNETIC PHASE QUANTUM FLUCTUATIONS IN SEQUENTIAL ELECTRON TUNNELING THROUGH VIBRATING QUANTUM DOT. Model.

G.A. Skorobagatko , S.I. Kulinich , I.V. Krive , R.I. Shekhter , M. Jonson, Low Temp. Phys., 35, (2011).

Model of single-electron molecular transistor with quantum vibrational degree of freedom in the transverse magnetic field



$$t_j(\hat{y}) = t_{0j} \exp\left(-\sqrt{x_j^2 + \hat{y}^2}/l_t\right)$$

$$l_0 = \sqrt{\hbar/m\omega_0} \qquad \hat{y} = (b^\dagger + b)\, l_0/\sqrt{2}$$

$$[b, b^\dagger] = 1$$

d - **Characteristic size (diameter) of quantum dot**

Total Hamiltonian of the model:

$$\hat{H} = \sum_{j=L,R} (H_j^{(l)} + H_j^{(t)}) + H_D$$

Hamiltonian of Fermi-liquid lead:

$$H_j^{(l)} = \sum_k (\varepsilon_{k,j} - \mu_j) a_{k,j}^\dagger a_{k,j}$$

Hamiltonian of vibrating quantum dot :

$$H_D = \varepsilon_0 c^\dagger c + \hbar\omega_0 b^\dagger b$$

Tunnel Hamiltonian:

$$H_j^{(t)} = t_j(\hat{y}) \exp(-ij\hat{\phi}) a_{k,j} c^\dagger + H.c.$$
$$j = (L, R) \equiv (-, +)$$

$$\hat{\phi} = eH d\hat{y}/\hbar c$$

-Aharonov-Bohm magnetic phase of tunneling electron, in the case of quantum fluctuations of quantum dot coordinate along y-axis

3. ROLE OF MAGNETIC PHASE QUANTUM FLUCTUATIONS IN SEQUENTIAL ELECTRON TUNNELING THROUGH VIBRATING QUANTUM DOT. Results.

G.A. Skorobagatko , S.I. Kulinich , I.V. Krive , R.I. Shekhter , M. Jonson, Low Temp. Phys., 35, (2011).

Results: **magneto-polaronic blockade; anomalous temperature dependence of the conductance; "excess" (inelastic) part of average current.**

1. Conductance : $\Gamma \ll T$

$$G(0) = G_0(\pi/2)(\Gamma/T)$$

$$\frac{G(H)}{G(0)} \simeq \begin{cases} \exp(-\phi^2), & \Gamma \ll T \ll \hbar\omega_0 \\ 1 - \phi^2 \frac{\hbar\omega_0}{2T}, & T \gg \phi^2 \hbar\omega_0 \end{cases}$$

2. Average current: $eV \gg \Gamma$

де: $J_0 = e\Gamma/\hbar \quad n_m = [eV/\hbar\omega_0]$

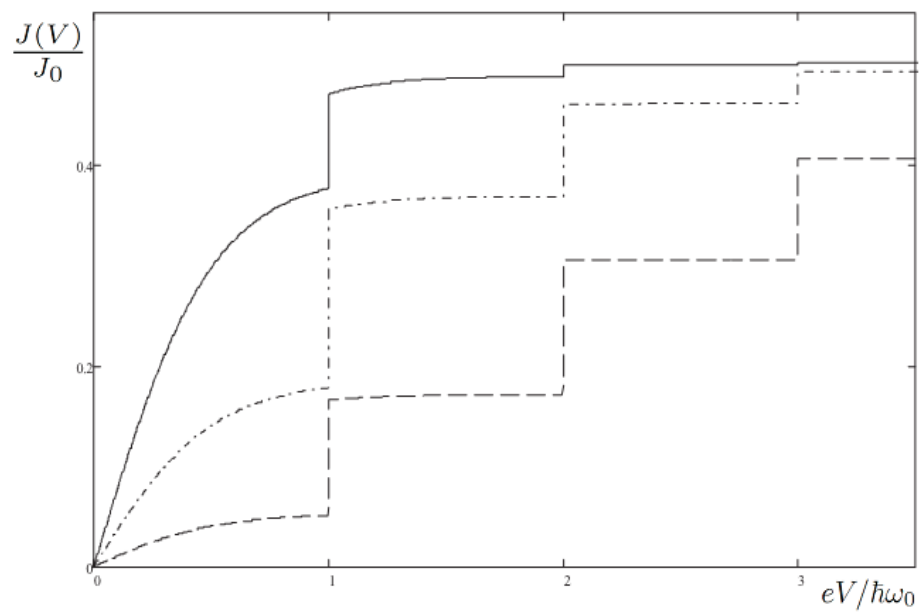
$$J(V;\phi) = J_0 \exp(-\phi^2) \sum_{n=0}^{n_m} \frac{\phi^{2n}}{n!}$$

3. «Franck- Condon» factors:

$$\Delta J_n = J_{n+1} - J_n = J_0 e^{-\phi^2} \frac{\phi^{2n}}{n!}$$

4. «Excess» (inelastic) average current:

$$\delta J = J_0\{1 - \exp(-\phi^2)\}$$



4. ANDREEV-TYPE RESONANT POLARONIC TUNNELING OF STRONGLY INTERACTING ELECTRONS THROUGH VIBRATING QUANTUM DOT. Model.

G.A.Skorobagatko *Phys. Rev. B 85, 075310 (2012).*

Total Hamiltonian of the system:

$$\hat{H} = \sum_{j=L,R} \hat{H}_l^{(j)} + \hat{H}_d + \sum_{j=L,R} \hat{H}_t^{(j)}$$

where: $\hbar v_g = \hbar v_F / g = 1$

Tunnel Hamiltonian:

$$\hat{H}_t^{(j)} = (\gamma_j \hat{d}^+ \hat{\Psi}_j(0) + h.c.)$$

where: $\hat{\Psi}_j(x) = \exp(i\Phi_j(x)/\sqrt{g})/\sqrt{2\pi a_0}$

Hamiltonian of Luttinger liquid lead with interacting electrons in its bosonic representation:

$$\hat{H}_l^{(j)} = 1/4\pi \int dx (\partial_x \Phi_j(x))^2 \quad (j = L, R)$$

Hamiltonian of quantum dot with electron-vibron- and fixed Coulomb interactions:

$$\hat{H}_d = \{\Delta \hat{d}^+ \hat{d} + \lambda_C \hat{d}^+ \hat{d} \sum_{j=L,R} \hat{\Psi}_j^+(0) \hat{\Psi}_j(0)\} + \\ + \hbar\omega_0 \{\frac{1}{2}(\hat{p}^2 + \hat{x}^2) + \lambda \hat{x} \hat{d}^+ \hat{d}\}$$

$$\hat{\Psi}_j(0) = (\hat{\Psi}_j(0^-) + \hat{\Psi}_j(0^+))/2$$

Chiral charge-density bosonic operator in the leads:

$$\hat{\rho}_j(x) = \hat{\Psi}_j^+(x) \hat{\Psi}_j(x) \\ = \partial_x \Phi_j(x)/2\pi\sqrt{g}.$$

Bosonization and re-fermionization: $\Phi_\pm(x) = (\Phi_L(x) \pm \Phi_R(x))/2,$

$$\hat{U}_f = \exp[-i(\hat{d}^+ \hat{d} - 1/2)\Phi_+(0)/\sqrt{2g}]$$

$$\hat{U}_b = \exp(-i\lambda \hat{p} \hat{d}^+ \hat{d})$$

$g = 1/2$ и $\lambda_C = 2\pi$

Transformed tunnel Hamiltonian:

$$\hat{\tilde{H}}_t = \hat{d}^+ \hat{X}^+ [\gamma_L \hat{\Psi}_-(0) + \gamma_R \hat{\Psi}_-^+(0)] + \\ + [\gamma_L \hat{\Psi}_-^+(0) + \gamma_R \hat{\Psi}_-(0)] \hat{X} \hat{d}.$$

$$\hat{\Psi}_\pm(x) = \exp(i\Phi_\pm(x))/\sqrt{2\pi a_0},$$

$$\hat{X} = \exp(i\lambda \hat{p})$$

4. ANDREEV-TYPE RESONANT POLARONIC TUNNELING OF STRONGLY INTERACTING ELECTRONS THROUGH VIBRATING QUANTUM DOT . Results.

G.A.Skorobagatko ***Phys. Rev. B 85, 075310 (2012)*.**

In the case of symmetric tunnel barriers, where : $\gamma_L = \gamma_R$

$$R_S(\varepsilon) = \frac{1}{1 + (S(\varepsilon))^{-2}}$$

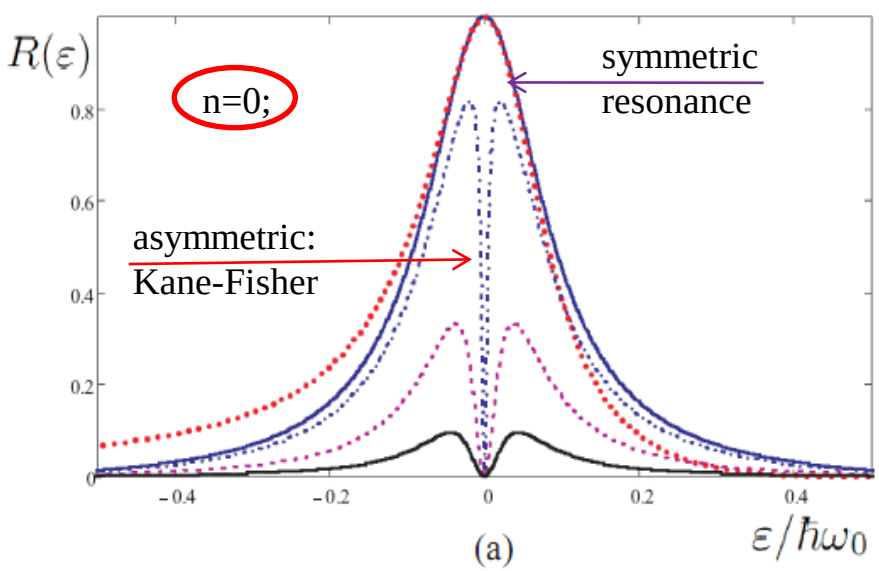
$$S(\varepsilon) = \sum_{l=-\infty}^{+\infty} \frac{\varepsilon \Gamma_0 F_l(\beta)}{\Delta_l^2 - \varepsilon^2}$$

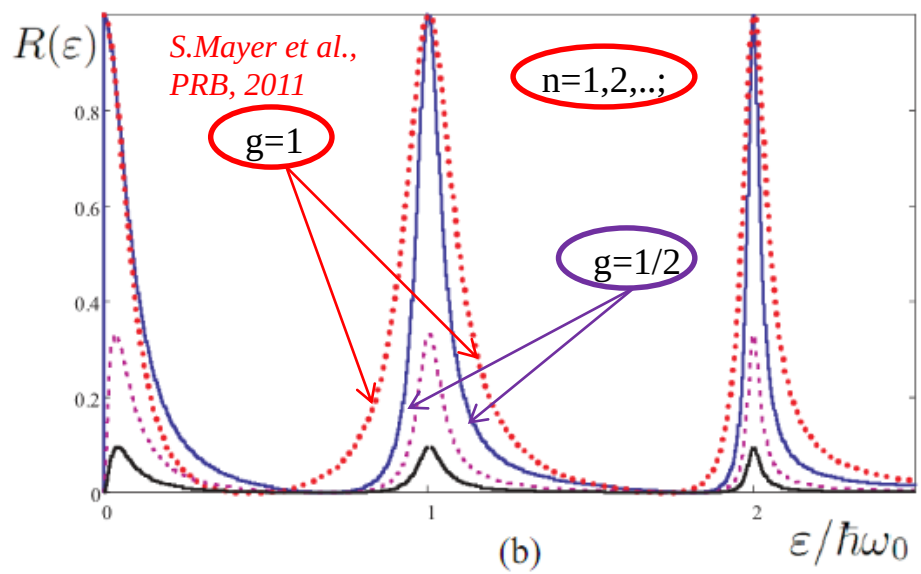
$$F_l(\beta) = e^{-\lambda^2(1+2n_b)} I_l(\lambda^2 \sqrt{n_b(1+n_b)}) e^{-\beta l/2}$$

$$\Delta_l = \tilde{\Delta} - \hbar\omega_0 l \qquad \Gamma_0 = \gamma_L^2 + \gamma_R^2$$

$$n_b(\beta) = (\exp(\beta) - 1)^{-1} \qquad \beta = \hbar\omega_0/T$$

Effective transmission coefficient in the model, as function of energy of incident electron:

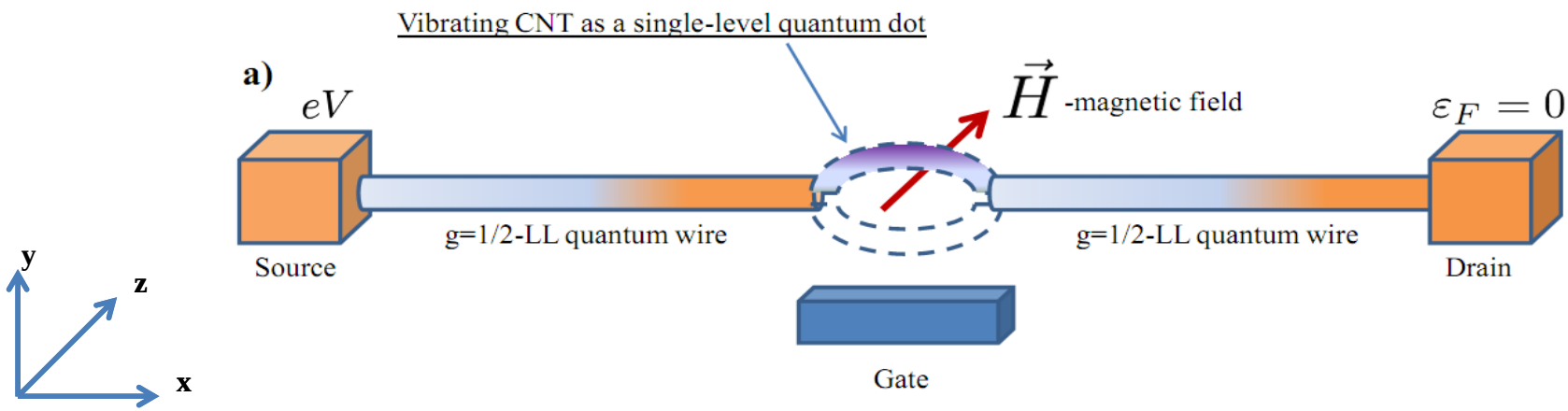




5. Magnetopolaronic Majorana-resonant level (M-MRL-) model

G.Skorobagatko, Cond.Mat.Phys., 21(2), 23703, (2018)

Schematic picture of tunnel junction with vibrating CNT as quantum dot in the magnetopolaronic g=1/2 - case:



Total Hamiltonian of the system :

$$\hat{H} = \hat{H}_l + \hat{H}_d + \hat{H}_t$$

Hamiltonian of quantum dot (QD) in the presence of quantum vibrations of QD (with Coulomb interaction in QD (λ_C -term)

$$\hat{H}_d = [\Delta - \lambda_C \partial_x \theta_+(0)] d^+ d + \frac{\hbar\omega_0}{2}\{\hat{p}_y^2 + \hat{y}^2\}$$

$$\hat{H}_t = \{d^+(\gamma_L \hat{X}_L^+ \hat{\Psi}_L + \gamma_R \hat{X}_R^+ \hat{\Psi}_R) + h.c.\}$$

Tunnel Hamiltonian with "magnetopolaron-dressed" tunnel amplitudes

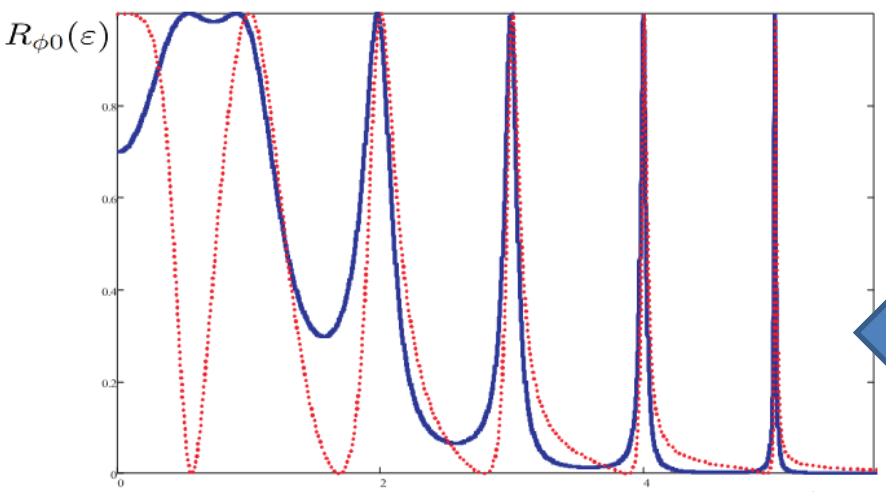
$$\begin{cases} \hat{X}_L = \exp(-i\phi\hat{y}) \\ \hat{X}_R = \exp(i\phi\hat{y}) \end{cases}$$

$$\hat{H}_l = 1/4\pi \sum_{j=L,R} \int_{-\infty}^{+\infty} dx (\partial_x \theta_j(x))^2$$

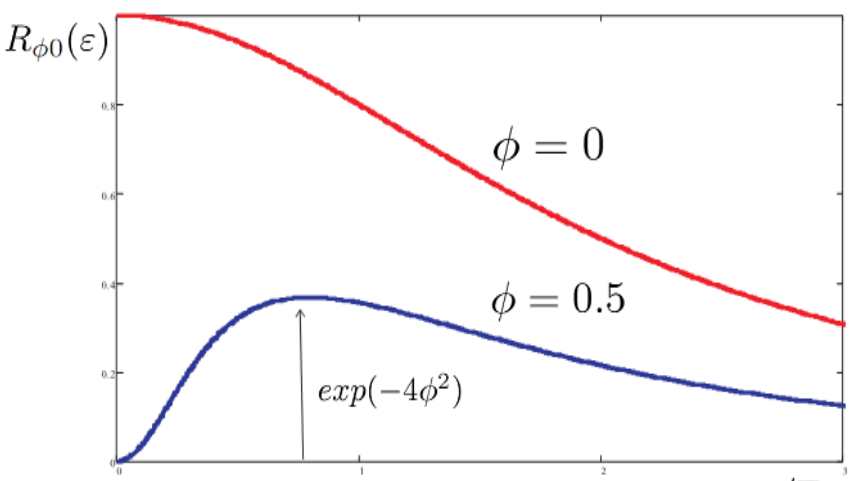
$$\phi = \Phi/\sqrt{2}\Phi_0 = e y_0 D_0 H/\sqrt{2}\hbar c$$

5. Results of the paper: *G.Skorobagatko, Cond.Mat.Phys., 21(2), 23703, (2018):*

Both constructive and destructive interference between different virtual vibronic channels of resonant magnetopolaronic tunneling – manifestation of the anomalous magneto-polaronic (or "Aharonov-Bohm") blockade effect



$a)\ \Gamma_0 \ll \hbar\omega_0$



$b)\ \Gamma_0 \gg \hbar\omega_0 \to 0$

$$\left(\hat{X}_{L(R)} \Leftrightarrow \hat{X}_{R(L)}\right) = (\hat{y} \Leftrightarrow -\hat{y})$$

$$\hat{X}^{+}_{L(R)} = \hat{X}_{R(L)}$$

$$R_{\phi 0}(\varepsilon) = \frac{(2\tilde{\Gamma}_\phi)^2}{1 + 2(\tilde{\Gamma}_N^2 + \tilde{\Gamma}_\phi^2) + (\tilde{\Gamma}_N^2 - \tilde{\Gamma}_\phi^2)^2}$$

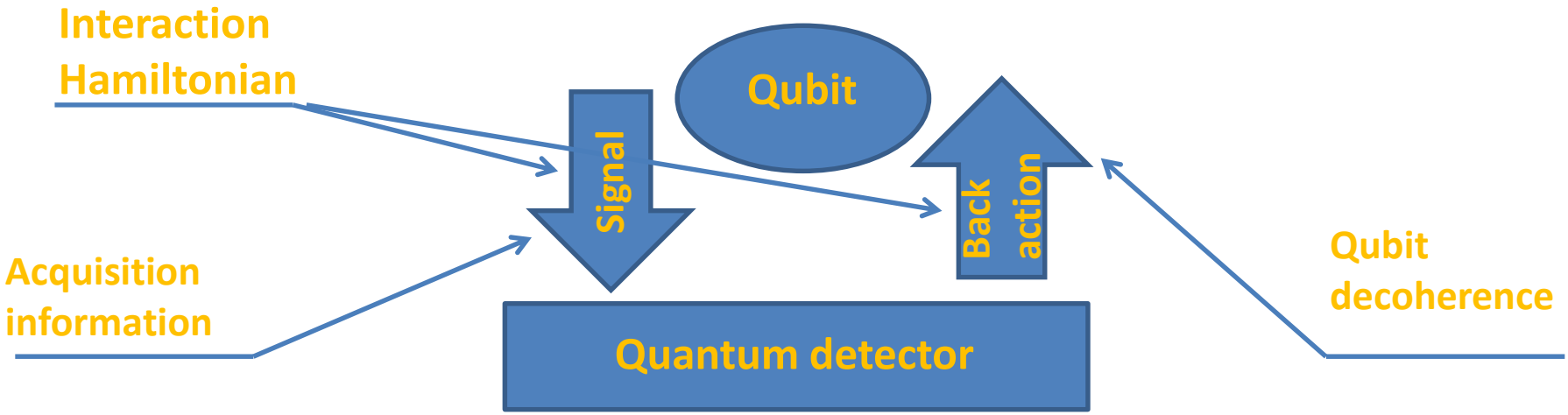
$$\tilde{\Gamma}_N(\varepsilon) = \sum_{l=-\infty}^{+\infty} \frac{\Gamma_0 F_l(\beta)\varepsilon}{(\hbar\omega_0 l)^2 - \varepsilon^2}$$

$$\tilde{\Gamma}_\phi(\varepsilon) = \sum_{l=-\infty}^{+\infty} \frac{(-1)^l \Gamma_0 F_l(\beta)\varepsilon}{(\hbar\omega_0 l)^2 - \varepsilon^2}$$

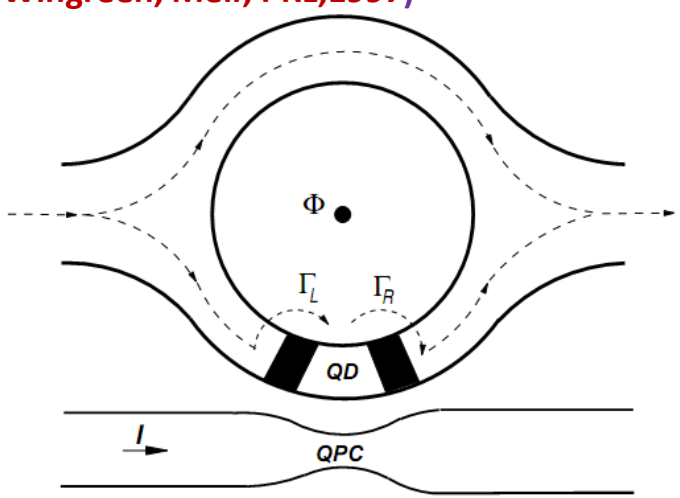
$$F_l(\beta) = e^{-\phi^2(1+2n_b)} I_l(\phi^2\sqrt{n_b(1+n_b)}) e^{-\beta\hbar\omega_0 l/2}$$

$$R^{(0)}_{\phi 0}(\varepsilon) = \frac{(4\Gamma_0^2 e^{-4\phi^2})\varepsilon^2}{\varepsilon^4 + 2\Gamma_0^2(1+e^{-4\phi^2})\varepsilon^2 + \Gamma_0^4(1-e^{-4\phi^2})^2}$$

6-7. Measurement-caused decoherence and detection of a qubit state: different realizations



Concept of charge qubit: decoherence of the elecron state in Josephson junction due to interaction with FL QPC (Aleiner, Wingreen, Meir, PRL,1997)

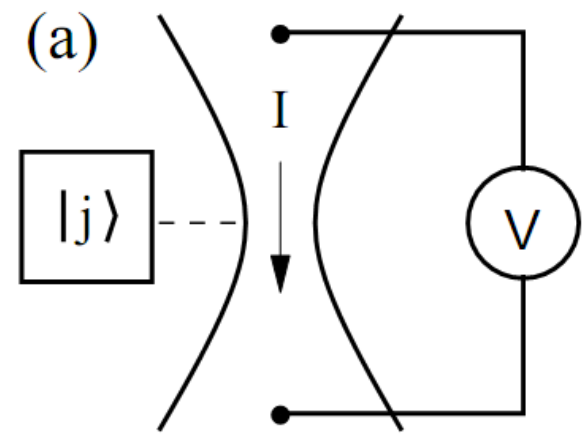


Well-known examples

-Known for the case of "free" fermions only (!) -QPCs with Fermi liquid leads(!)

However "in reality" electron-electron interaction in QPC matters (!)

General concept of a QPC as a quantum limited detector (Averin, Sukhorukov PRL,2005)



6-7. MODEL HAMILTONIAN

in papers: *G.Skorobagatko, A.Bruch, S.V.Kusminskiy, A.Romito, Phys.Rev. B, 95, 205402, (2017)* and *G.Skorobagatko, Phys.Rev.B, 98,045409 (2018)*

$$H_\Sigma = H_{LL} + H_{QD} + H_{int}$$

$$H_{LL} = \frac{1}{2\pi}\sum_{j=L,R} v_g \int_{-\infty}^{0} \left\{ g\left(\partial_x \varphi_j\right)^2 + \frac{1}{g}\left(\partial_x \theta_j\right)^2 \right\} \mathrm{dx}$$

Hamiltonian of two semi-infinite Luttinger liquids

$$H_{QD} = \sum_{n=1,2} \varepsilon_n c_n^\dagger c_n + \cancelto{0}{\gamma}\left(c_1^\dagger c_2 + c_2^\dagger c_1\right)$$

Charge-qubit part

$$H_{int} = \sum_{n=1,2} \left[\lambda_n \partial_x \theta_+ + \tilde{\lambda}_n \cos\left(\varphi_- + \mathrm{eVt}\right)\right]|_{x=0} c_n^\dagger c_n$$

Tunnel Hamiltonian in the "weak link" approximation (Kane, Fisher, PRB, 1992)

$$\theta_\pm = [\theta_L \pm \theta_R]$$
$$\varphi_\pm = [\varphi_L \pm \varphi_R]$$

$$[\theta_\alpha(x), \varphi_{\alpha'}(x')] = 2i\pi \mathrm{sgn}(x - x')\delta_{\alpha,\alpha'}$$
$$[\theta_\alpha(x), \partial_x \varphi_{\alpha'}(x')] = 2i\pi\delta(x - x')\delta_{\alpha,\alpha'}$$

$$\alpha = \pm$$

Non-local bosonic phase fields (important ingredient)

6. Results from the paper: *G.Skorobagatko, A.Bruch, S.V.Kusminskiy, A.Romito, Phys.Rev. B, 95, 205402, (2017).*

EFFICIENCY RATE FOR THE LUTTINGER LIQUID QPC AS QUANTUM DETECTOR :

$$Q \equiv W/\Gamma_{\rm tot} = W/(\Gamma + \tilde{\Gamma}) \leqslant 1$$

general formula for finite temperatures:

$$Q = \frac{\frac{1+\eta^2}{2\eta^2}\left[1 - \sqrt{1 - \left(\frac{2\eta}{1+\eta^2}\tanh(eV/2T)\right)^2}\right]}{\left(1 + \Gamma/\tilde{\Gamma}\right)}$$

$\eta = (\tilde{\lambda}_2 - \tilde{\lambda}_1)/(\tilde{\lambda}_1 + \tilde{\lambda}_2)$

Asymmetry in tunnel coupling to qubit charge-states

Ratio between "orthogonality catastrophe"- and "tunnel" decoherence rates

-For example, if: $T \gg eV$

and: $t \gg 1/\pi T$

Then:

$$\frac{\Gamma}{\tilde{\Gamma}} \simeq \left(\frac{\lambda_1 - \lambda_2}{\tilde{\lambda}_1 - \tilde{\lambda}_2}\right)^2 \frac{2}{\sqrt{\pi}} \left(\pi \frac{T}{\Lambda_g}\right)^{2-\frac{2}{g}} \sqrt{g}$$

6. Results from the paper: *G.Skorobagatko, A.Bruch, S.V.Kusminskiy, A.Romito, Phys.Rev. B, 95, 205402, (2017).*

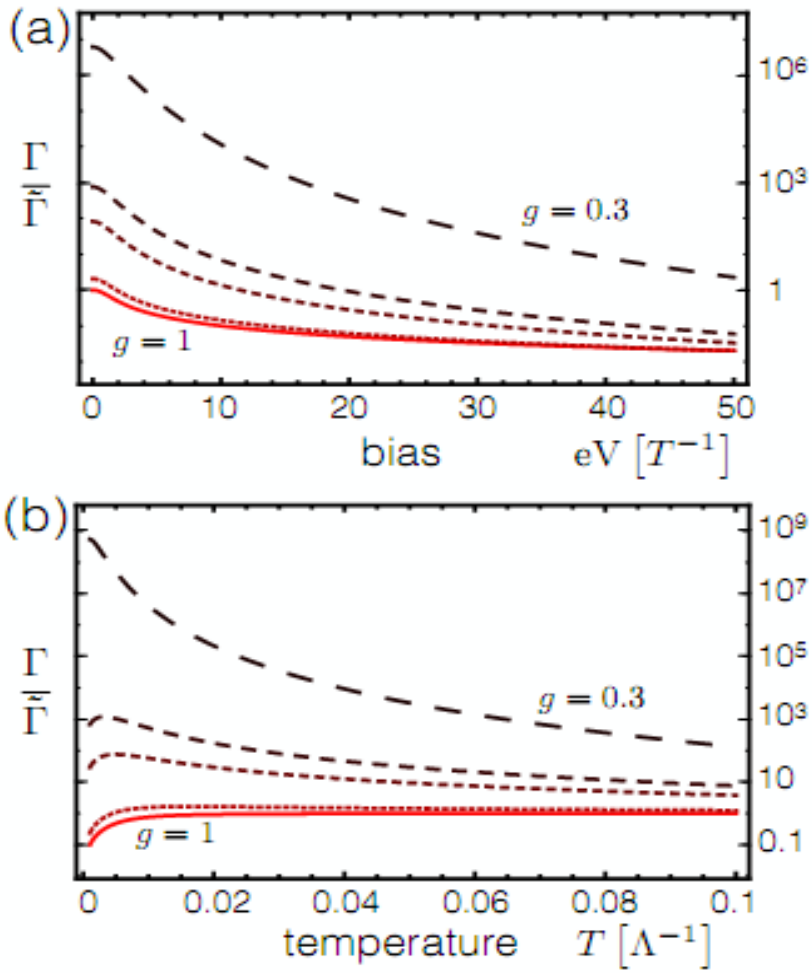


FIG. 3. (Color Online) Log-plot of the ratio between local density- and tunneling-induced decoherence as a function of (a) bias voltage and (b) temperature, *cf.* Eqs. (11), (14). For increasing interaction strength $g = 1; 0.9; 0.6; 0.5; 0.3$ from light to dark red and from continuous to coarsely dashed. $\frac{T}{\Lambda_g} = 0.01$ in (a) and $\frac{eV}{\Lambda_g} = 0.01$ in (b), $\bar{\lambda}_2 - \bar{\lambda}_1 = \lambda_2 - \lambda_1 = \Delta\lambda$.

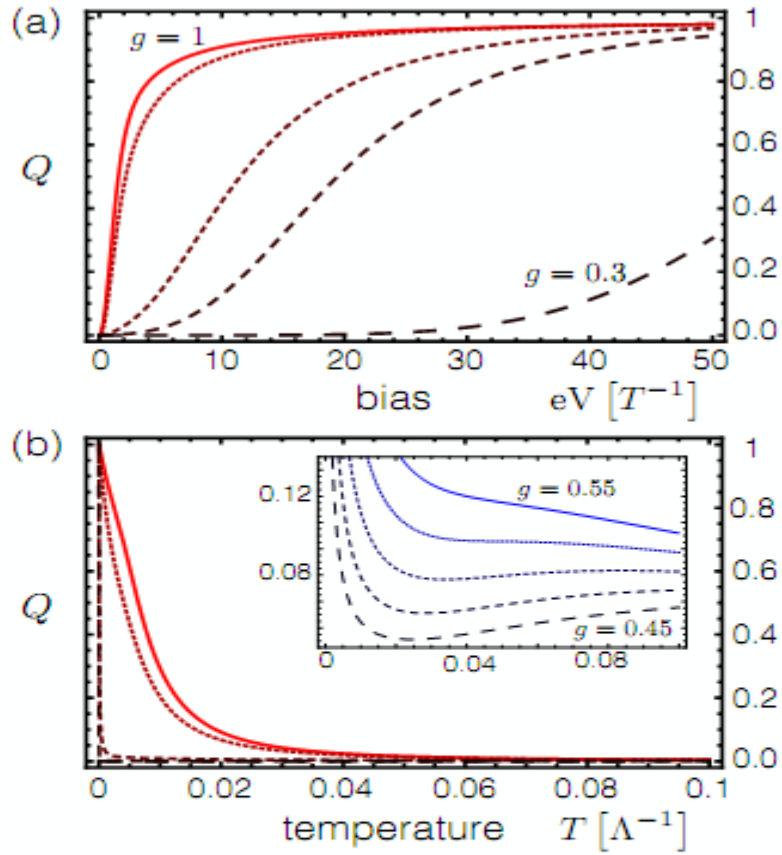


FIG. 5. (Color Online) Total detector efficiency Q for the interacting case, as function of the applied bias (a) and temperature (b). Different curves from light to dark red and from continuous to coarsely dashed are for increasing interaction strengths, $g = 1; 0.9; 0.6; 0.5; 0.3$. The figures show strong dependence of Q on g once orthogonality effects are considered. The inset in (b) shows a zoom in of the regime of cross over between monotonous and non-monotonous temperature dependence for $g \sim 0.5$ ($g = 0.55; 0.525; 0.5; 0.475; 0.45$ from light to dark blue and from continuous to coarsely dashed). We used $\eta = 0.5$, and $\frac{T}{\Lambda_g} = 0.01$ in (a), $\frac{eV}{\Lambda_g} = 0.01$ in (b).

7. Problem formulation in the paper:

G.Skorobagatko, Phys.Rev.B, 98,045409 (2018):

WHAT ABOUT THE LIMIT:

$$t \le \frac{\hbar}{T}\Big|_{T\to 0}$$

for quantum detector efficiency rate for interacting electrons in QPC?

$$\lim_{eV,T\to 0} Q = Q_K = \frac{W(\Delta\tilde{\lambda},T)}{\Gamma(\Delta\tilde{\lambda},T)+\tilde{\Gamma}_K(\Delta\lambda)}$$

$$\eta \approx 1$$

$$eV = eV(T) = \mu T$$

$$\Gamma(\Delta\tilde{\lambda},T\to 0) = \left(\frac{\Delta\tilde{\lambda}}{\Lambda_g}\right)^2 f_1(T) + \left(\frac{\Delta\tilde{\lambda}}{\Lambda_g}\right)^4 f_2(T) + \left(\frac{\Delta\tilde{\lambda}}{\Lambda_g}\right)^6 f_3(T) + \ldots$$

0

This is from our preceding paper:

G.Skorobagatko, A.Bruch,S.V.Kusminskiy, A.Romito, Phys.Rev. B, 95, 205402, (2017).

S_d=?

i.e. What about all the rest terms at "T" near zero?

S_a=?

$$W(\Delta\tilde{\lambda},T\to 0) = \left(\frac{\Delta\tilde{\lambda}}{\Lambda_g}\right)^2 w_1(T) + \left(\frac{\Delta\tilde{\lambda}}{\Lambda_g}\right)^4 w_2(T) + \left(\frac{\Delta\tilde{\lambda}}{\Lambda_g}\right)^6 w_3(T) + \ldots$$

0

7. Results from the paper: *G.Skorobagatko, Phys.Rev.B, 98,045409 (2018)*

New "Kondo-like" regime of quantum detection for Luttinger liquid quantum detector at temperatures near absolute zero

S-Theorem gives precise answer: S_a = S_d = 0 (!)

Hence, results :

$$f_1(T) \cong w_1(T)$$

$$\Gamma(\Delta\tilde{\lambda}, T) = \left(\frac{\Delta\tilde{\lambda}}{\Lambda_g}\right)^2 f_1(T)$$

$$W(\Delta\tilde{\lambda}, T) = \left(\frac{\Delta\tilde{\lambda}}{\Lambda_g}\right)^2 w_1(T)$$

$$Q_K = \frac{1}{1 + \left(\frac{\Lambda_g}{\Delta\tilde{\lambda}}\right)^2 \frac{\tilde{\Gamma}_K(\Delta\lambda)}{f_1(T)}}$$

and, as well, all the "Kondo-like" description near T=0:

$$\tilde{\Gamma}_K(\Delta\lambda) \approx \frac{\Lambda_g}{\pi} \exp\left[-\frac{1}{g}\left(\frac{\Lambda_g}{\Delta\lambda}\right)^2\right]$$

- ARE EXACT (!)

Remarkably, this limit implies (see the plot):

$$\frac{1}{\sqrt{2}} \le \alpha \le 1$$

$$g_{cr} = g_{cr}(T) = \frac{\sqrt{3}\alpha}{2\left|\frac{\Delta\lambda}{\Lambda}\right|\sqrt{\ln\left(\frac{\Lambda}{2\pi \cdot T}\right)}}$$

7. It turns out, that theory of low-temperature instability of quantum detection from *G.Skorobagatko, Phys.Rev.B, 98,045409 (2018)* can explain unusually long timescale for Rabi oscillations damping in modern experiments with charge-qubits

Charge-qubit operation of an isolated double quantum dot

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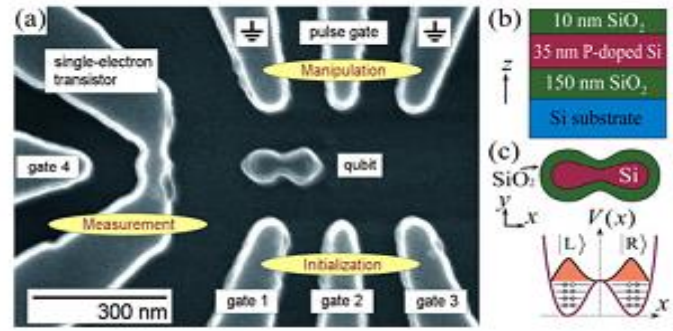
[2]Hitachi Cambridge Laboratory, Hitachi Europe Ltd., Cambridge CB3 0HE, United Kingdom



Experimental effect explanation in *G.Skorobagatko, Phys.Rev.B, 98,045409 (2018)*