Residual conductance of correlated one-dimensional nanosystems

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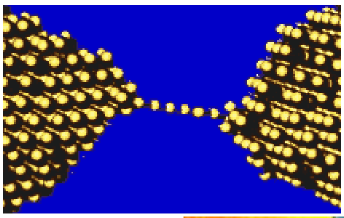
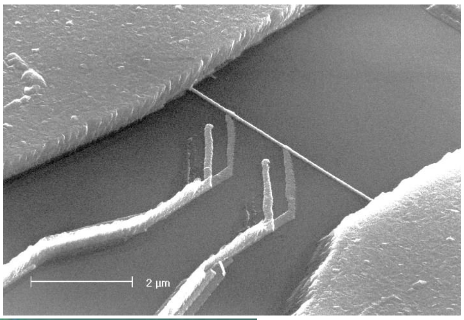
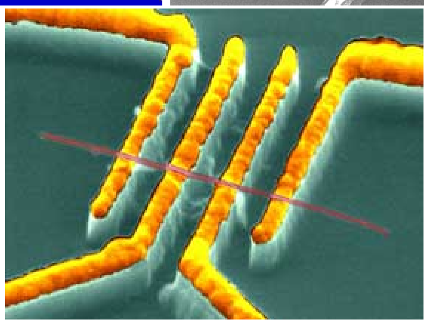
Low-dimensional mesoscopic systems

v. Ruitenbeek





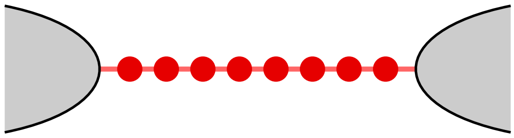
Groupe Quantronique Saclay



Schönenberger

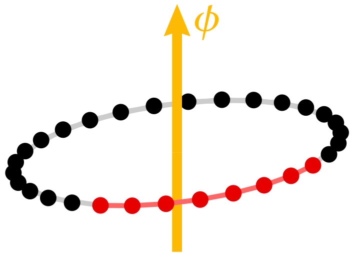
- ➢ electronic transport is coherent
- ➢ electronic correlations may become important

Transport through interacting region



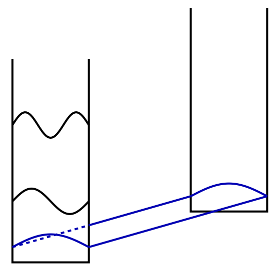
difficulties:

- excitations in the interacting region possible
  not for zero-bias conductance at $T = 0$
- coupling to leads → open system
  embedding method [Favand, Mila 1998]



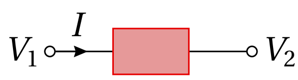
Overview

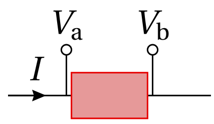
Conductance of a coherent channel



Conductance per open channel:

$$\frac{e^2}{h}$$





two-terminal conductance

$$G = \frac{I}{V_1 - V_2} = \frac{e^2}{h} T$$

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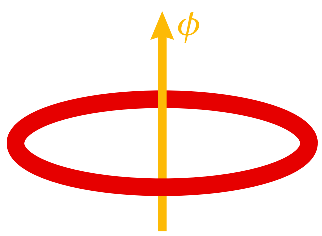
accounts for contact resistance

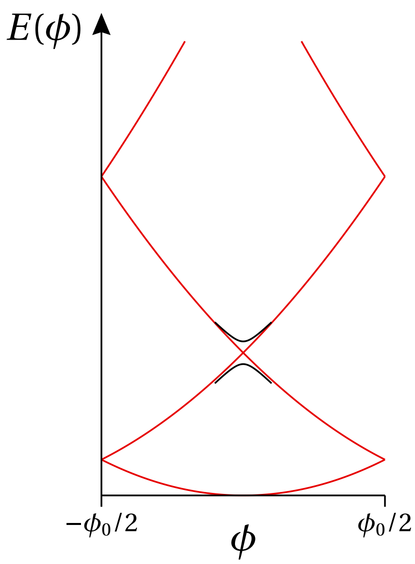
four-terminal conductance

$$G = \frac{I}{V_a - V_b} = \frac{e^2}{h} \frac{T}{1-T}$$

Flux-threaded ring



$$\Phi = \frac{\phi}{\phi_0}, \quad \phi_0 = \frac{h}{e}$$



persistent current: $J = -\frac{\partial E}{\partial \phi}$

curvature: $c = -\frac{\partial^2 E}{\partial \phi^2}$

charge stiffness: $D = (-1)^N \frac{L}{2}\big(E(0) - E(\pi)\big)$

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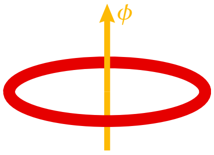
Kohn conductivity

Kohn 1964



time-dependent flux: $\phi \sim \frac{E\mathrm{e}^{\mathrm{i}\omega t}}{\mathrm{i}\omega}$

➔ current response: $J = \sigma E \mathrm{e}^{\mathrm{i}\omega t}$

with $\lim\limits_{\omega\to 0} \omega\sigma''(\omega) \sim -\frac{\partial^2 E}{\partial\phi^2}$ Drude weight

- curvature is a measure of the number of extended states
- paramagnetic or diamagnetic response possible

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How and why does the embedding method work?

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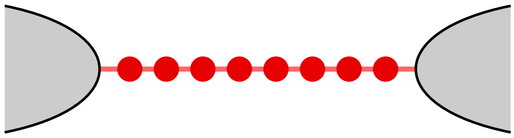
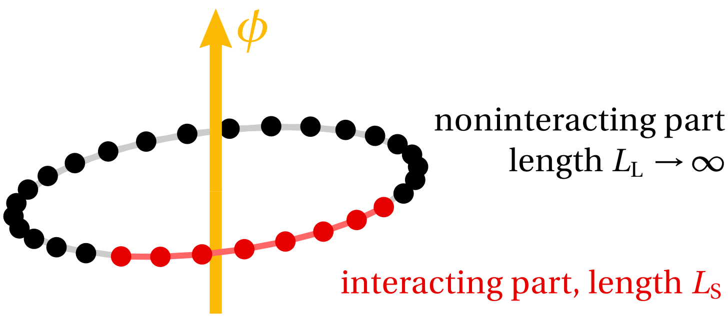
Transport through interacting region



- are there extended states in the interacting region?
  → persistent current for interacting region,
  Kohn conductivity
- can we get electrons into the interacting region?
  → compressibility [Berkovits, Avishai 1996]
  → embedding method

Transmission through an interacting region



persistent current takes into account

- number of extended states
- contacts between interacting region and lead

embedding setup = tool to determine transmission

- no decoherence in the lead
- no Luttinger correlations in the noninteracting part

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Persistent current and transmission

point scatterer with transmission t in a noninteracting ring [Gogolin, Prokof'ev 1994]

$$J(\Phi, N\text{ odd}) = -\frac{ev_\mathrm{F}}{\pi L}\frac{\mathrm{Arccos}\big(|t(E_\mathrm{F})|\cos(\Phi)\big)}{\sqrt{1-|t(E_\mathrm{F})|^2\cos^2(\Phi)}}|t(E_\mathrm{F})|\sin(\Phi)$$

$$J(\Phi, N\text{ even}) = J(\Phi-\pi; N\text{ odd})$$

conductance:

$$g = \lim_{L_\mathrm{L}\to\infty}\left(\frac{J(\pi/2)}{J^0(\pi/2)}\right)^2$$ (J^0 : persistent current of clean ring)

requires complex DMRG algorithm

Charge stiffness and transmission

relation to transmission:

$$D = \frac{\hbar v_\mathrm{F}}{2}\left[\frac{\pi}{2} - \mathrm{Arccos}(|t(E_F)|)\right]$$

conductance:

$$g = \lim_{L_\mathrm{L}\to\infty}\sin^2\left(\frac{\pi}{2}\frac{D}{D^0}\right)$$

real DMRG algorithm sufficient

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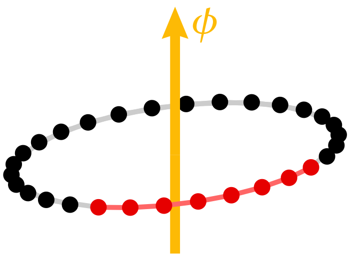
A few references on the embedding method

- J. Favand, F. Mila, Eur. Phys. J. B **2**, 293 (1998)
- O. P. Sushkov, Phys. Rev. B **64**, 155319 (2001)
- R. A. Molina et al., Phys. Rev. B **67**, 235306 (2003)
  R. A. Molina et al., Eur. Phys. J. B **39**, 107 (2004)
  R. A. Molina et al., Europhys. Lett. **67**, 96 (2004)
- V. Meden, U. Schollwöck, Phys. Rev. B **67**, 193303 (2003)
  V. Meden et al., Europhys. Lett. **64**, 769 (2003)
- T. Rejec, A. Ramšak, Phys. Rev. B **68**, 033306 (2003)
  T. Rejec, A. Ramšak, Phys. Rev. B **68**, 035342 (2003)

Spinless fermions



$$H = -t\sum_{i=1}^{L}\left(c_i^\dagger c_{i-1} + c_{i-1}^\dagger c_i\right) + \sum_{i=2}^{L_S} U\,(n_i - V_+)\,(n_{i-1} - V_+)$$

boundary condition: $c_0 = \mathrm{e}^{\mathrm{i}\Phi} c_L$

$\nu = 1/2$ $\quad V_+ = 1/2$ (particle-hole symmetry)

$\nu \neq 1/2$ $\quad V_+$ must be determined by iteration

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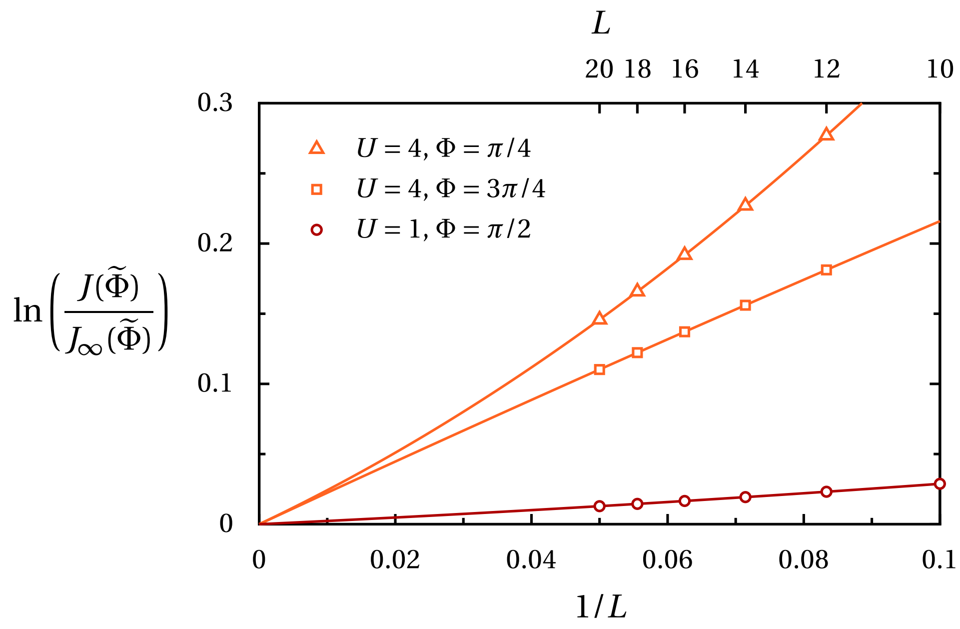
Scaling to infinite ring length (I)

half filling ($\nu = 1/2$), $L_S = 6$



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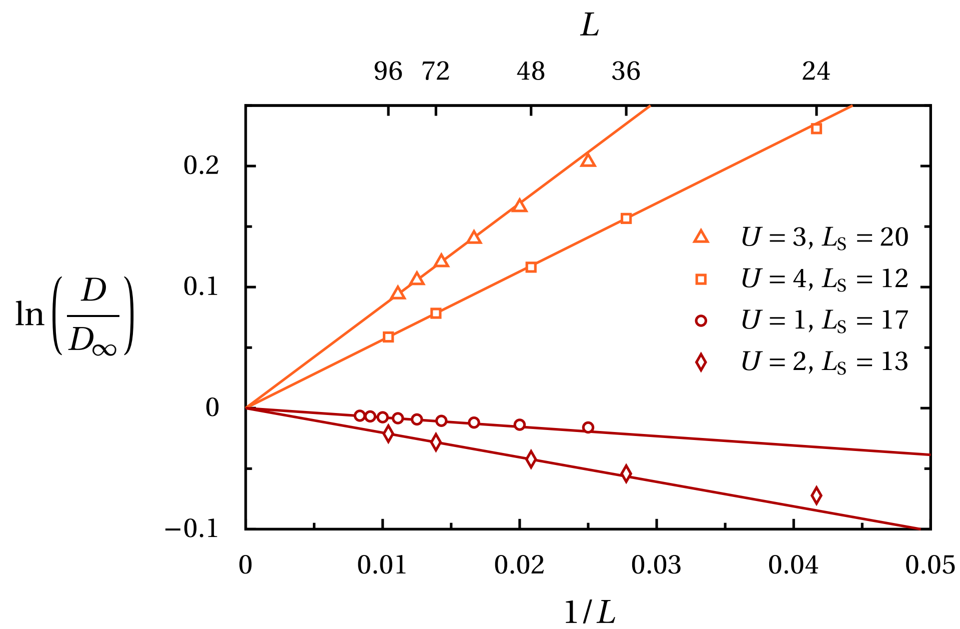
Scaling to infinite ring length (II)

linear scaling for charge stiffness

$$D(U, L_S, L_L) = D_\infty(U, L_S) \exp\left(\frac{C(U, L_S)}{L}\right)$$



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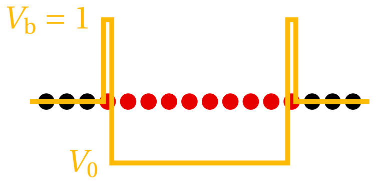
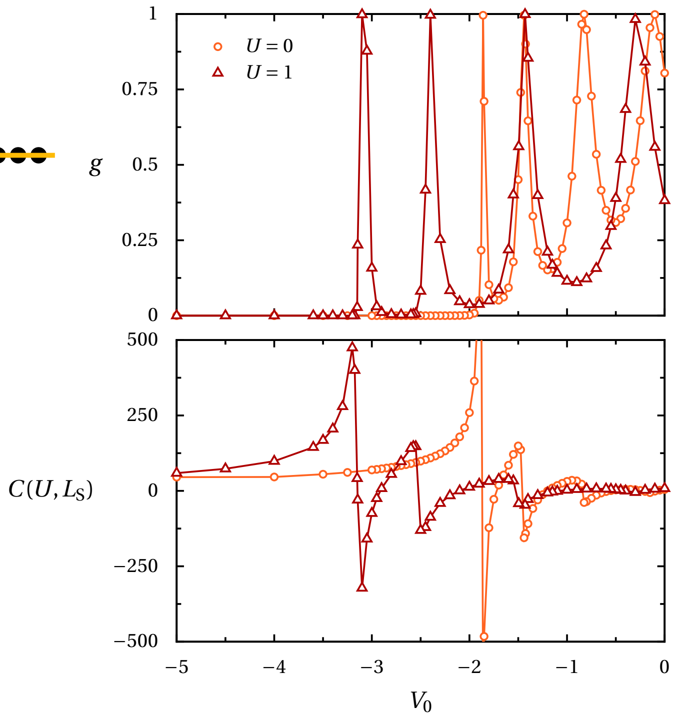
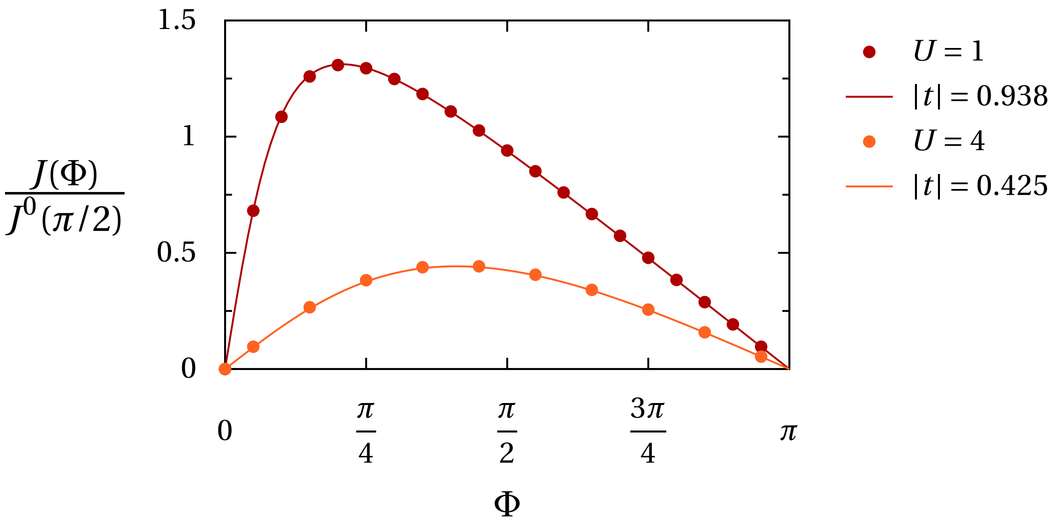
Resonances





Flux dependence of persistent current



➔ interacting region can be described by an effective point scatterer with transmission t

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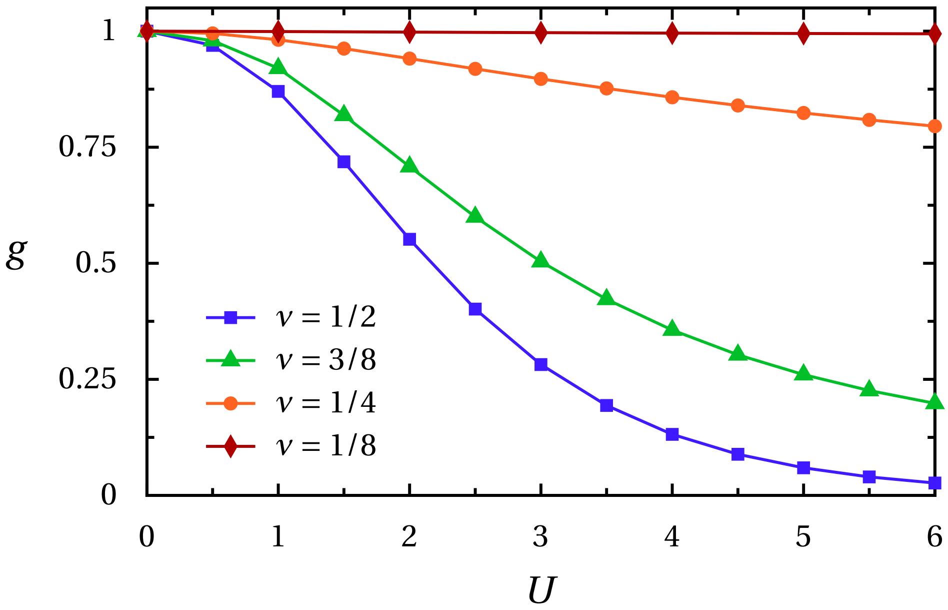
Some basic aspects of transport through a correlated region

Outside half filling



- signature of Mott transition
- suppression of the conductance is most effective at half filling

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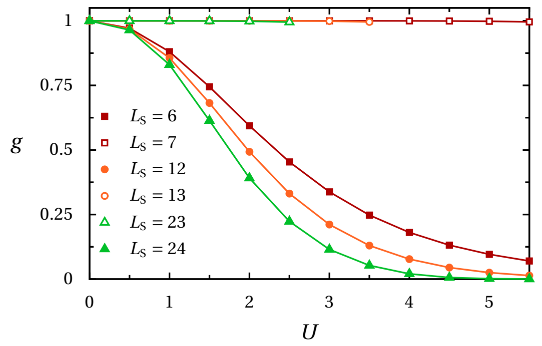
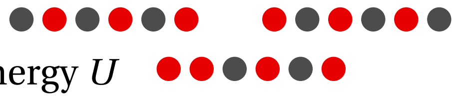


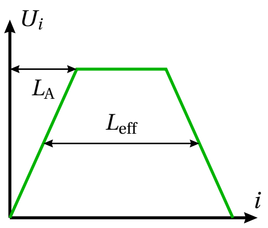
even number of lattice sites: 

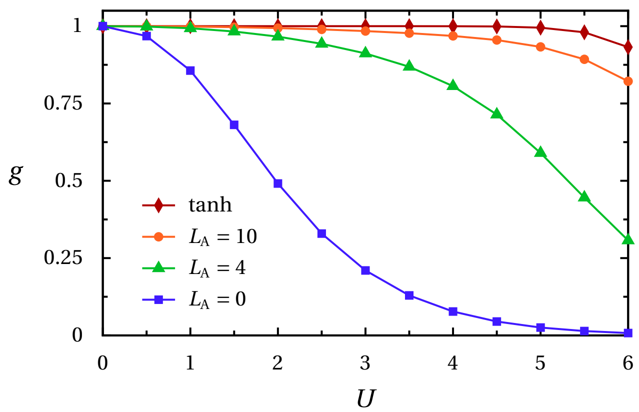
➔ additional electron costs energy U

odd number of lattice sites: 

➔ transfer of electrons does not cost energy

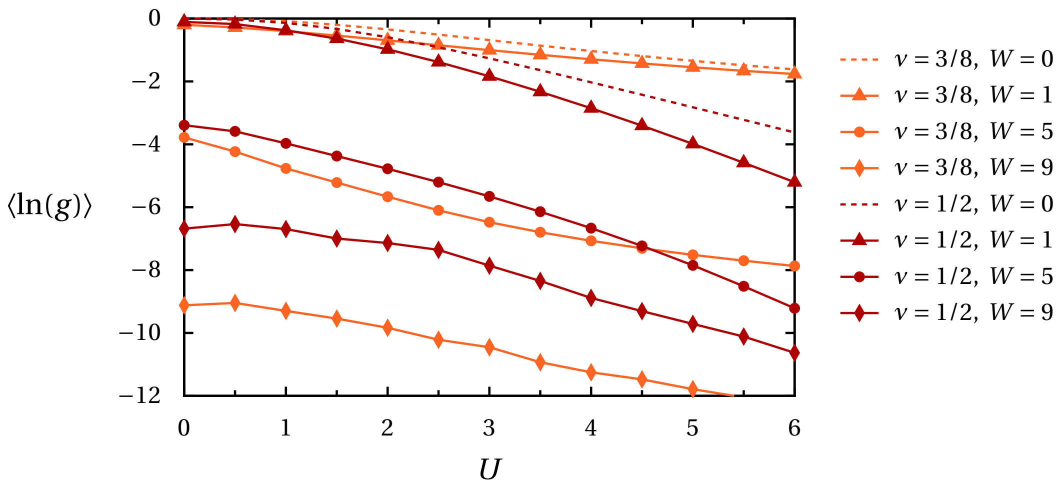
Influence of contacts





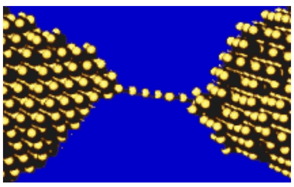
➔ smoothing of the contacts increases the conductance

Disorder and interaction



➔ repulsive interaction can increase the conductance for sufficiently strong disorder

Application to the conductance of atomic chains



possible explanantion of conductance oscillations as a function of length in break junction contacts
[R. A. Molina, D. Weinmann, J.-L. Pichard, Europhys. Lett. **67**, 96 (2004)]

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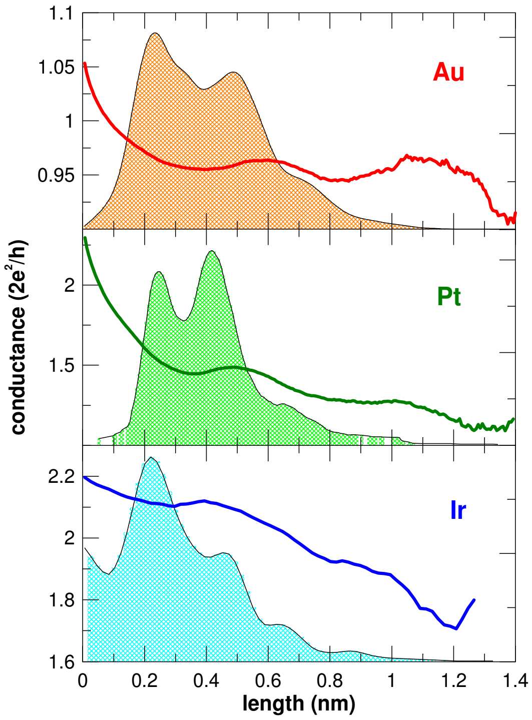
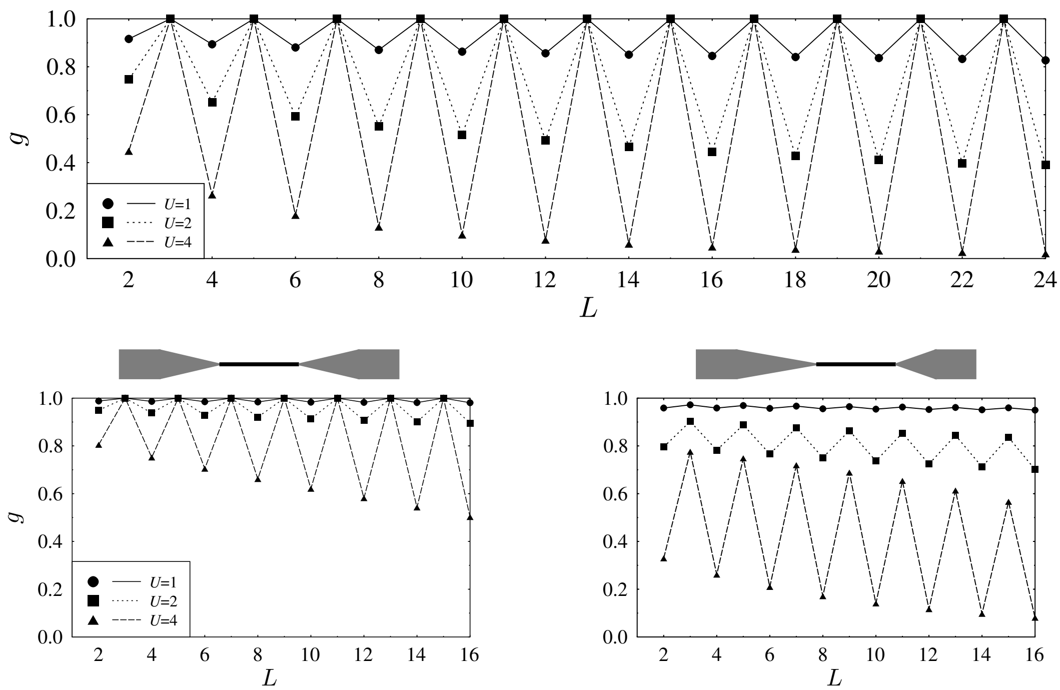
Even-odd effects in atomic chains



R. H. M. Smit et al.,
Phys. Rev. Lett. **91**, 076805 (2003)

Length-dependent oscillations

R. A. Molina et al., Europhys. Lett. **67**, 96 (2004)



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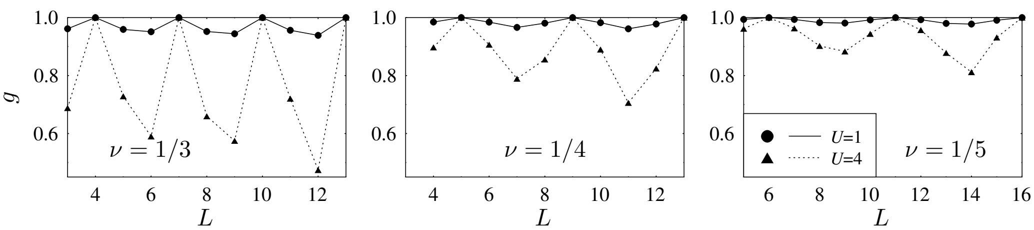
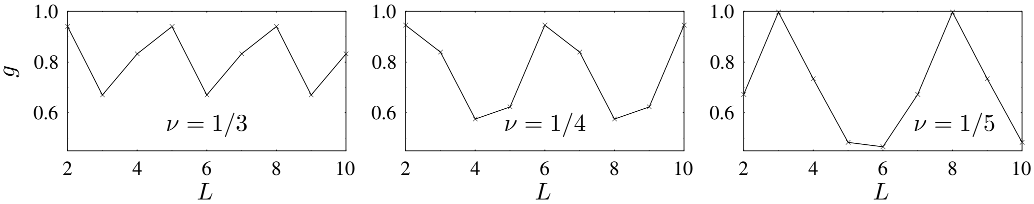
Period of oscillation

finite interaction:



non-interacting:



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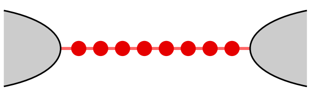

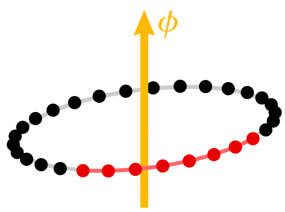

embedding method

- ✗ close an interacting system to a ring by means of a noninteracting lead
- ✗ interacting region can be described by an effective point scatterer
- ✗ residual conductance can be obtained from the persistent current or charge stiffness

- Phys. Rev. B **67**, 235306 (2003)
- Eur. Phys. J. B **39**, 107 (2004)

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