Introduction to quantum transport, thermoelectrics, and mesoscopic heat engines

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Outline

- Mesoscopic transport
- (Multi-terminal) thermoelectrics
- Quantum-dot energy harvesting
- Chiral thermoelectrics
- Phase-coherent heat transport

Mesoscopic physics

Physical length scales

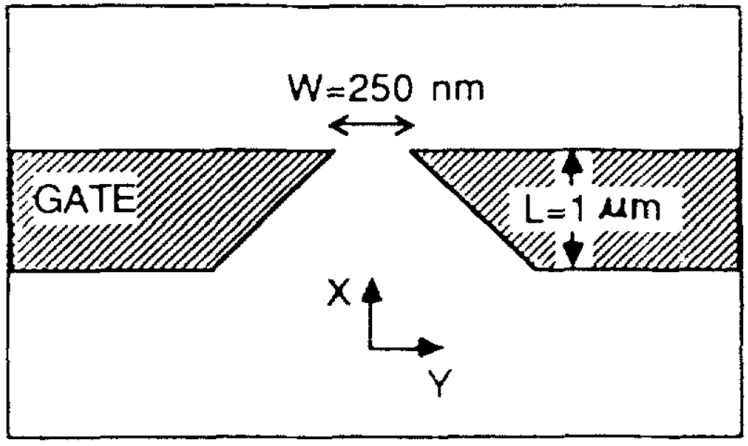
- Geometrical dimension L
- Fermi wave length λ_F
- Elastic scattering length l_e
- Inelastic scattering length l_{in}
- Phase coherence length l_ϕ

Mesoscopic conductor

- Phase-coherent $L \ll l_\phi$
- Ballistic $L \leq l_e$ vs. diffusive $L \gg l_e$
- Size quantization if $L \leq \lambda_F$

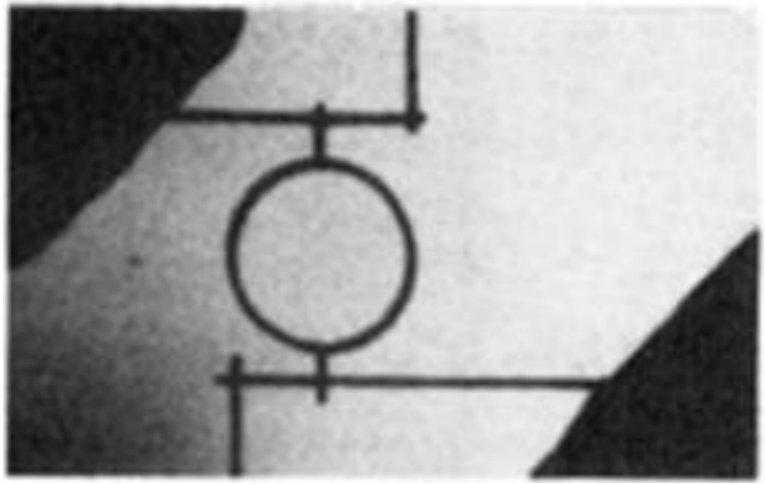
Mesoscopic conductors

Quantum point contact



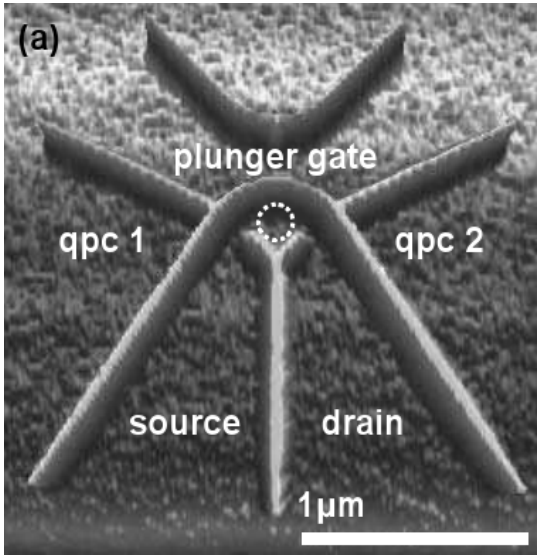
van Wees et al. PRL 1988

Aharonov-Bohm ring



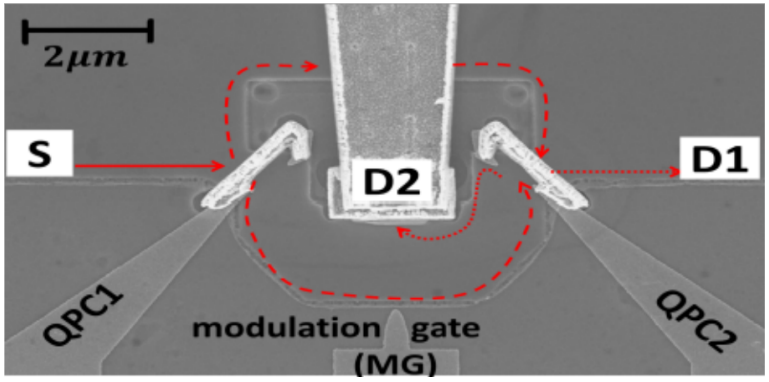
Webb et al. PRL 1985

Quantum dots



Komijami et al. EPL 2008

Mach-Zehnder interferometer

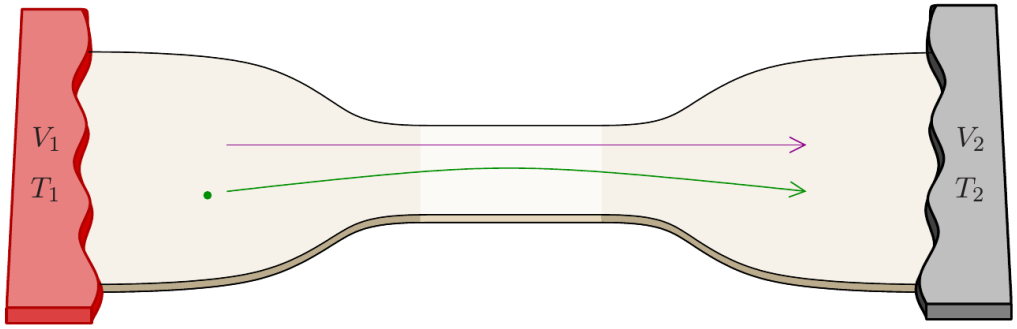


Gurman et al. PRB 2016

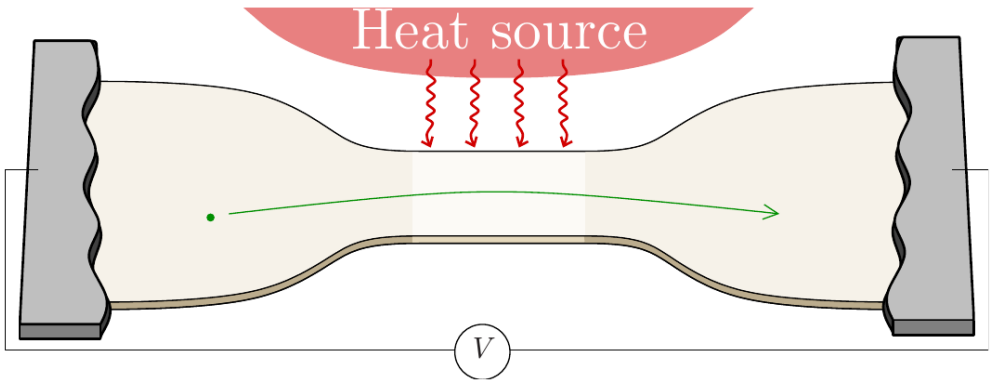
Mesoscopic thermoelectrics

BS, Sánchez, Jordan, Nanotechnology 2015

Two-terminal thermoelectrics



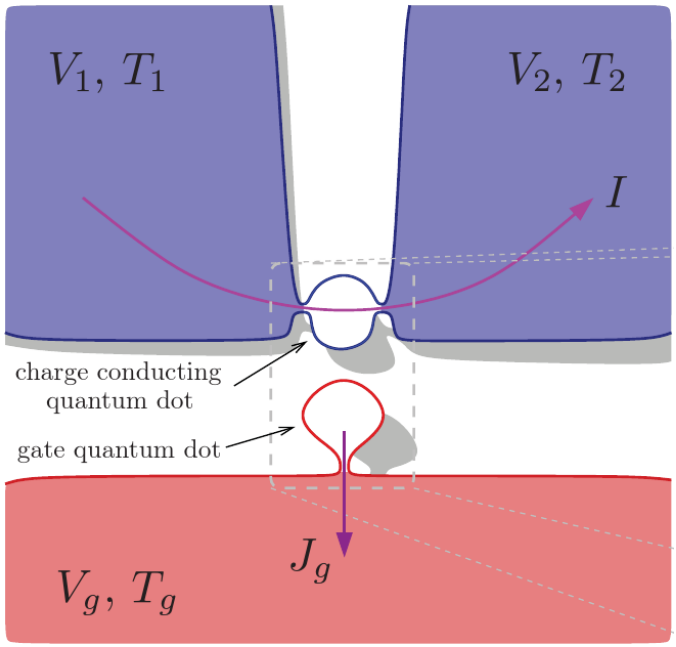
Three-terminal thermoelectrics

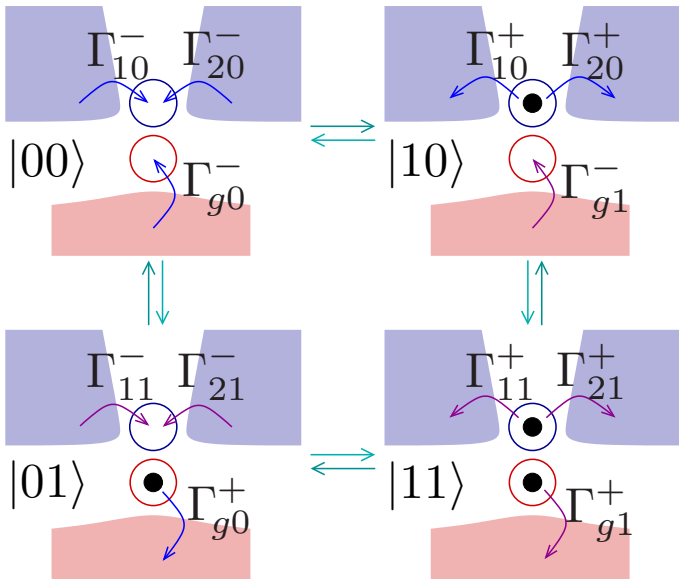


- Separation of hot and cold reservoirs
- Crossed flow of heat and charge

Thermoelectric energy harvesting with quantum dots

Sánchez, Büttiker, PRB 2011

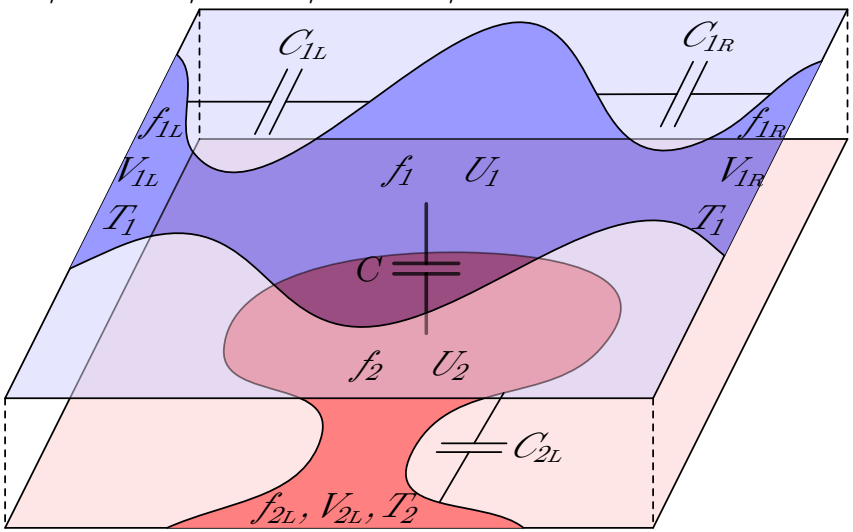




- Quantum dots in Coulomb-blockade regime
- Capacitive coupling between dots
- High efficiency $\eta_{\mathsf{max}} = \eta_C$, $\eta_{\mathsf{maxP}} = \eta_C/2$
- Small current and power

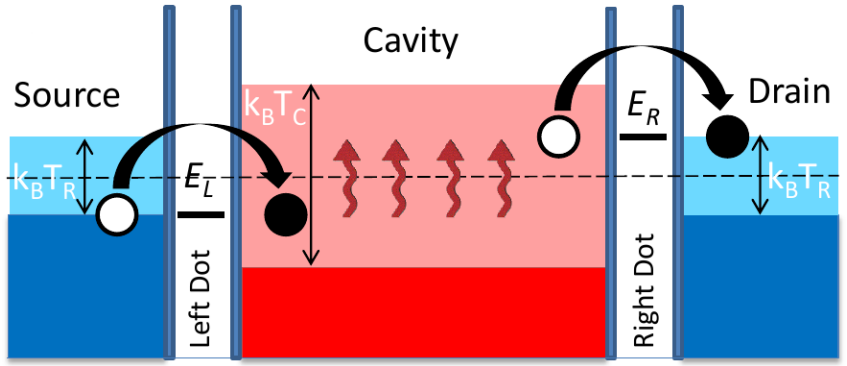
Thermoelectric energy harvesting with quantum dots

BS, Sánchez, Jordan, Büttiker, PRB 2012



- Chaotic cavities
- Large current
- Small power and efficiency

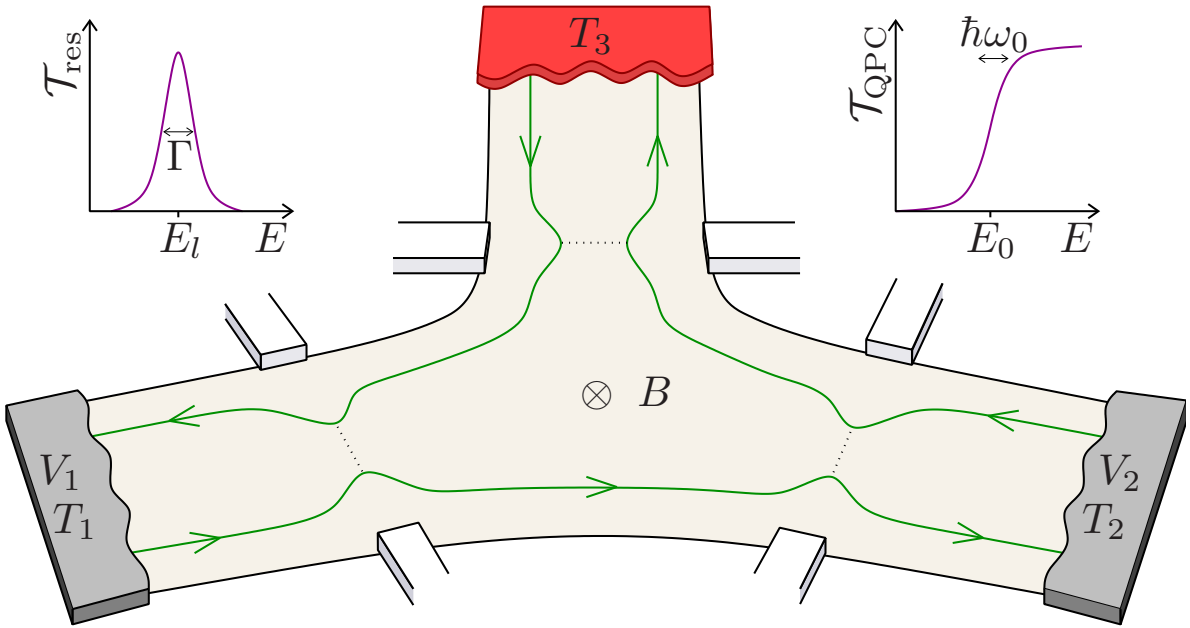
Jordan, BS, Sánchez, Büttiker, PRB 2013



- Resonant tunneling
- Large power and current
- Good efficiency
  $\eta_{\text{maxP}} \approx 0.2\eta_C$

Chiral thermoelectrics

Sánchez, BS, Jordan, EPL 2014, PRL 2015, NJP 2015



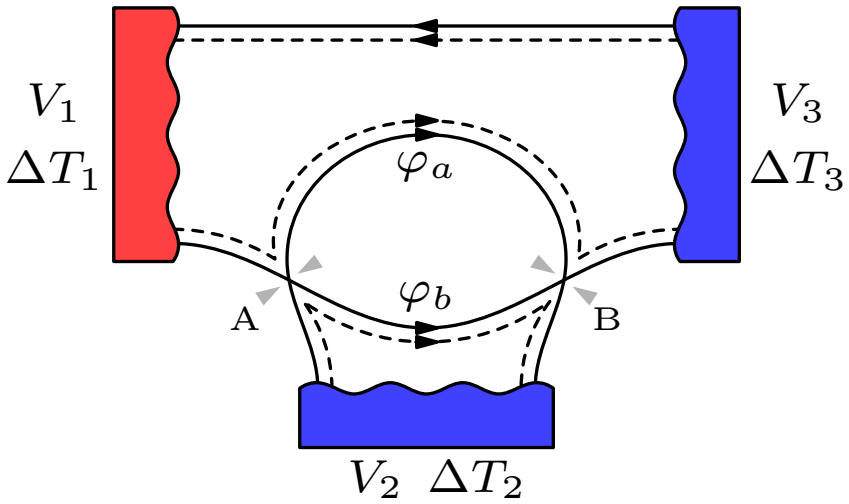
- Quantum Hall effect: Chiral edge states

$$\begin{pmatrix} I_e \\ I_h \end{pmatrix} = \begin{pmatrix} L_{eV} & L_{eT} \\ L_{hV} & L_{hT} \end{pmatrix} \begin{pmatrix} F_V \\ F_T \end{pmatrix}$$

$$L_{eT} \neq L_{hV}$$

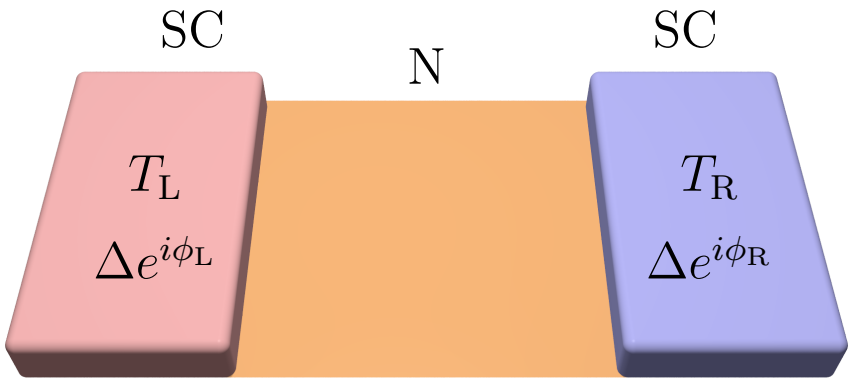
Interferometer-based heat engines

Hofer, BS, PRB 2015; Samuelsson, Kheradsoud, BS, PRL 2017



- Phase difference $\varphi_a - \varphi_b = \phi + E\tau/\hbar$
- Thermoelectric effect of purely quantum-mechanical origin
- Asymmetric Onsager coefficients

Phase-coherent heat transport



- Charge current Josephson, Phys. Lett. 1962

$$I_c = I_{\mathrm{c,qp}} + I_{\mathrm{c,jos}} \sin\phi + I_{\mathrm{c,int}} \cos\phi$$

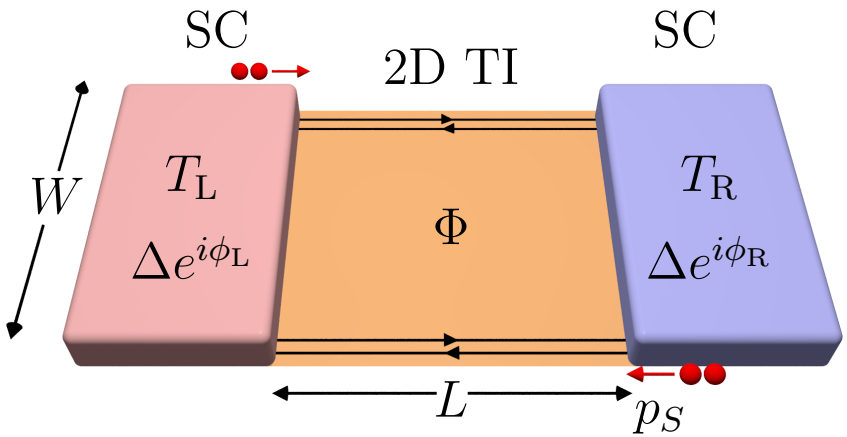
- Heat current Maki, Griffin, PRL 1965

$$I_h = I_{\mathrm{h,qp}} + I_{\mathrm{h,jos}} \sin\phi + I_{\mathrm{h,int}} \cos\phi$$

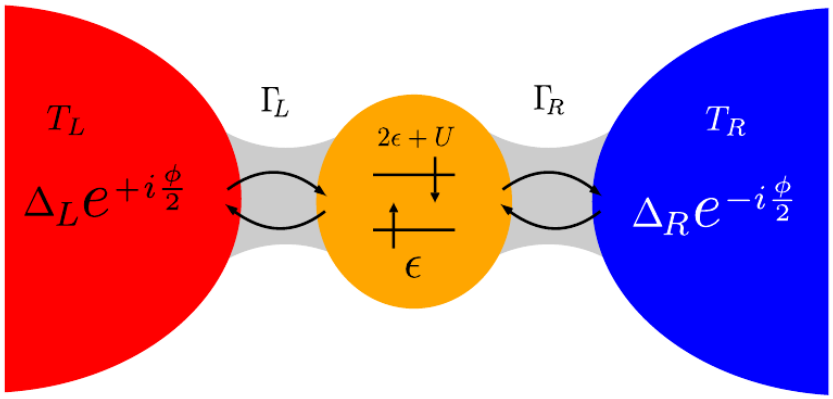
Phase-dependent heat currents

BS, Hankiewicz, PRB 2016

BS, Giazotto, Hankiewicz NJP 2017



- Detection of topological Andreev bound states
- Thermal switch



- Interplay of nonequilibrium, superconductivity and Coulomb interactions