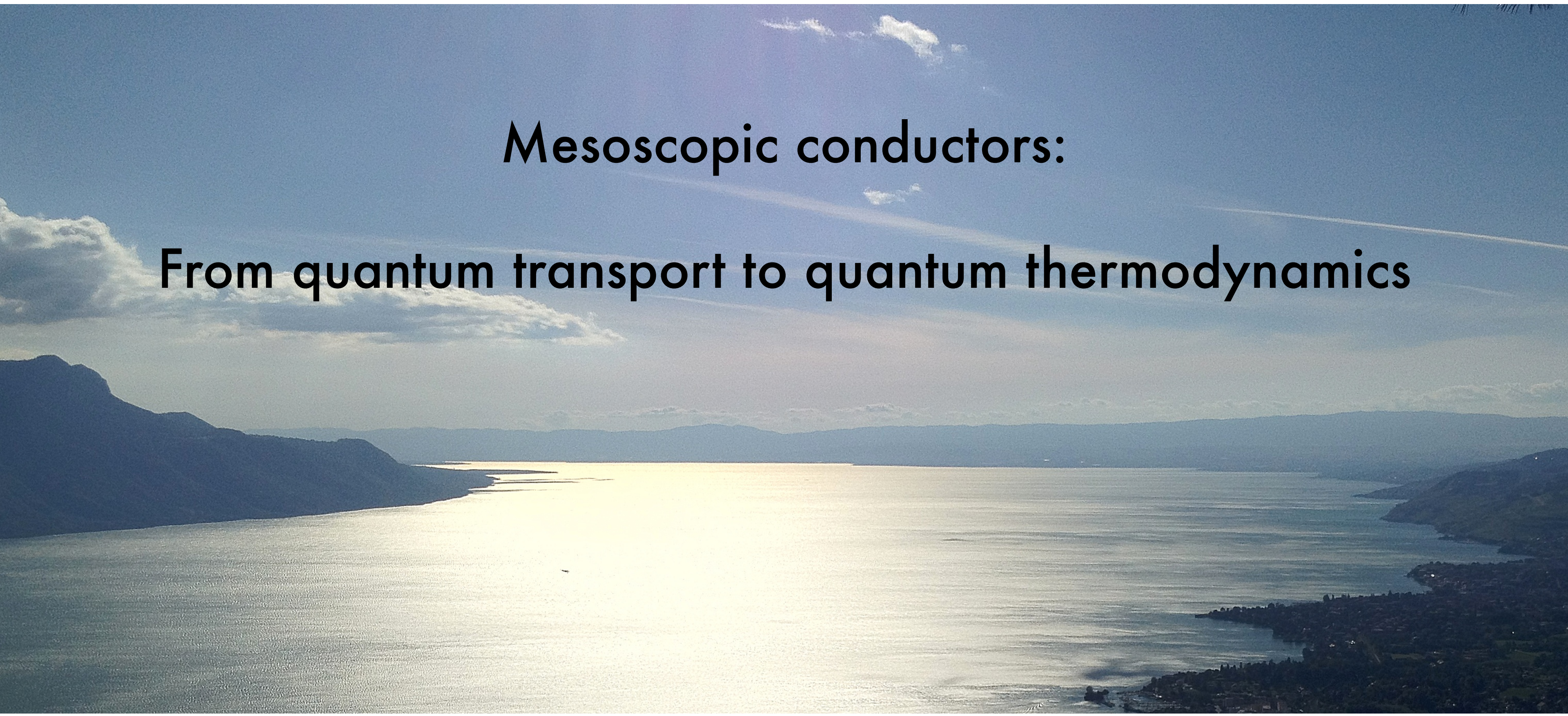
Mesoscopic conductors:

From quantum transport to quantum thermodynamics



Géraldine Haack

Department of Applied Physics GAP, University of Geneva

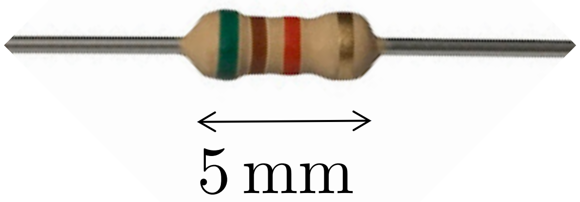
LQSS, 16th of October 2019

EPFL

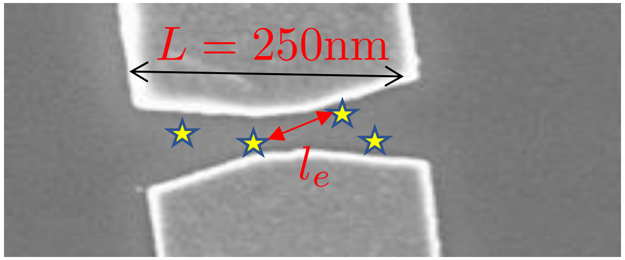
SWISS PHOTONICS

UNIVERSITÉ DE GENÈVE

Mesoscopic physics is defined by physical length scales



Classical transport



Quantum transport

See A. Fontcuberta's talk

L : Geometrical length of the system

l_e : Elastic scattering length
(typical length between two scattering events, without energy exchange)

l_{in} : Inelastic scattering length
(typical length over which an energy kT has been exchanged)

l_ϕ : Quantum phase-coherence length

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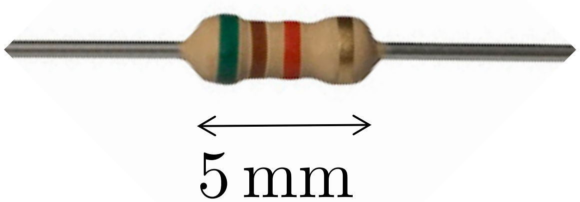
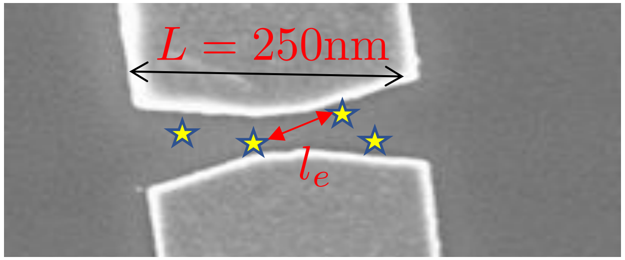


Classical transport

$l_\phi \leq l_{in} \ll L$



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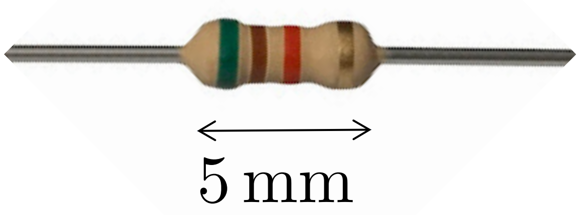

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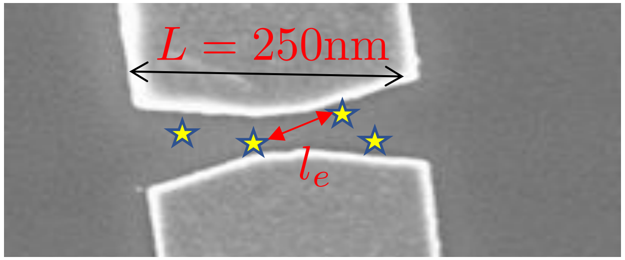

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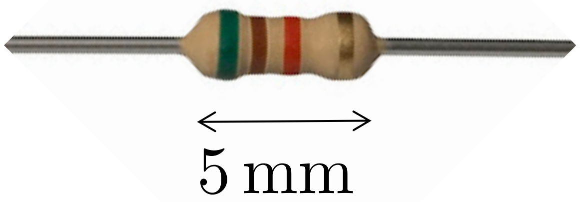

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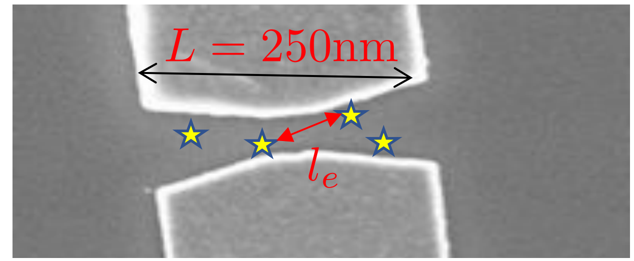

Quantum transport

$$l_\phi \sim L \leq l_{in}$$

Ballistic transport: $l_\phi \sim L \leq l_e \ll l_{in}$

Diffusive transport: $l_e \leq l_\phi \sim L \ll l_{in}$

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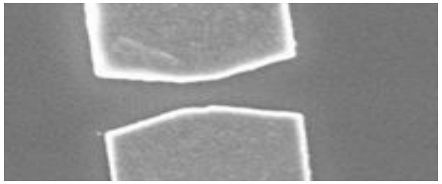
Theoretical tools for quantum transport

Source



Drain

- Semi-classical approach
- Hamiltonian approaches
(Green functions, master equations)
- Scattering-matrix approach

Theoretical tools for quantum transport

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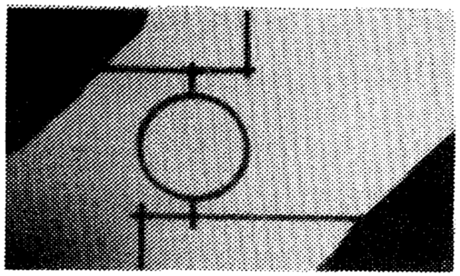

Webb et al., PRL 54 (1985)

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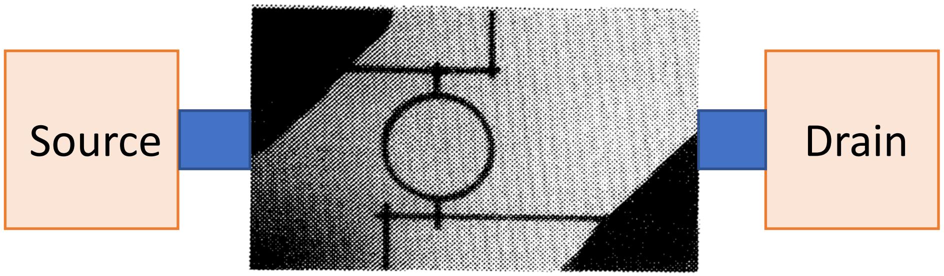

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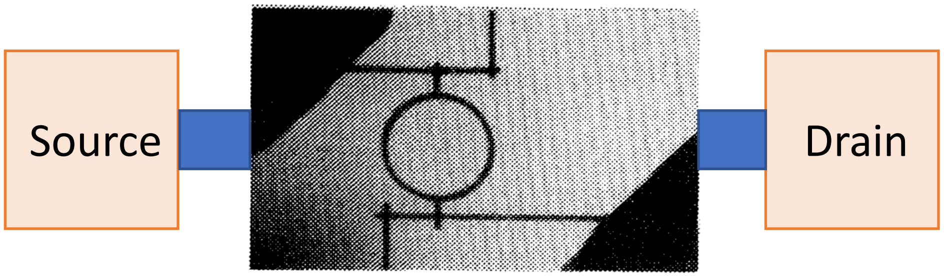

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Reservoirs

Leads

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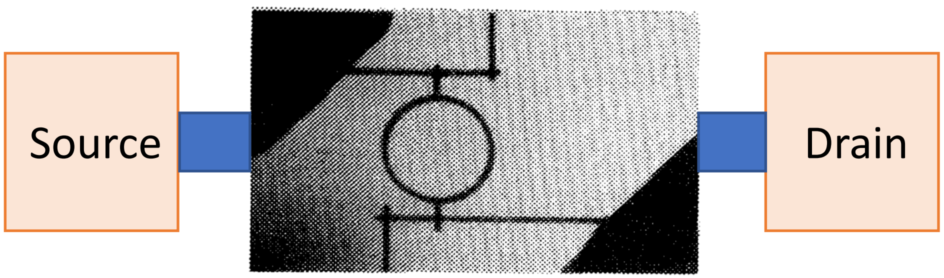

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Reservoirs

At equilibrium

Fermionic black-body sources

Fermi-Dirac distribution : μ, T

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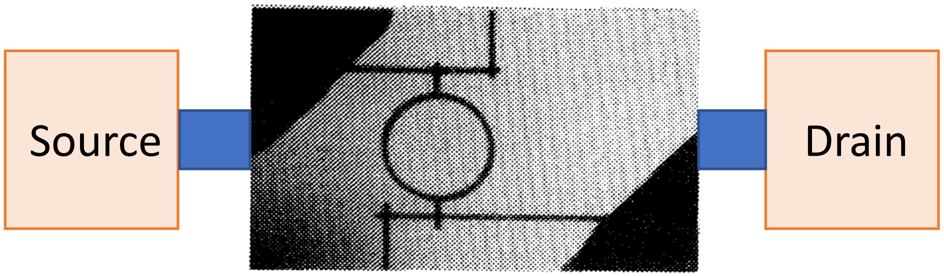

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Incoming states @ equilibrium

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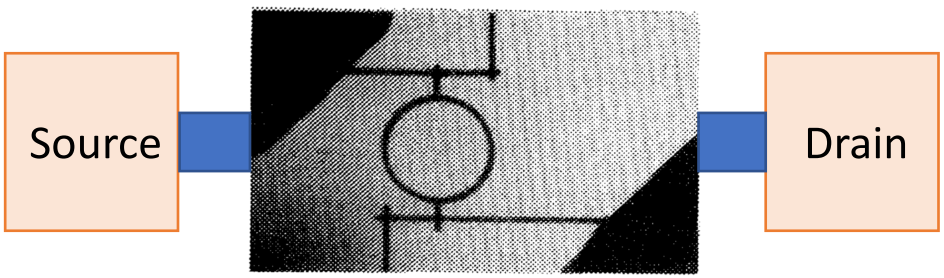

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Characterized by reflection & transmission amplitudes

Charge conservation

$$R + T = 1$$

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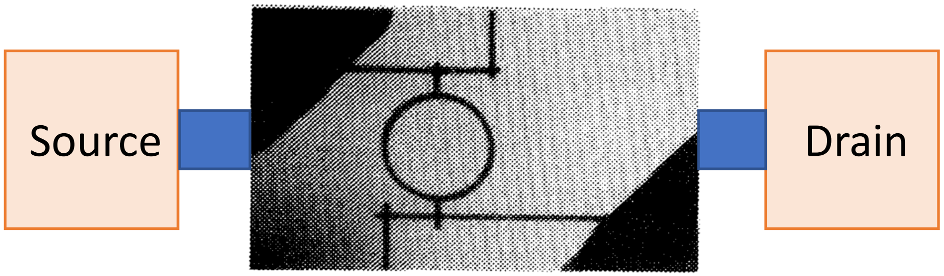

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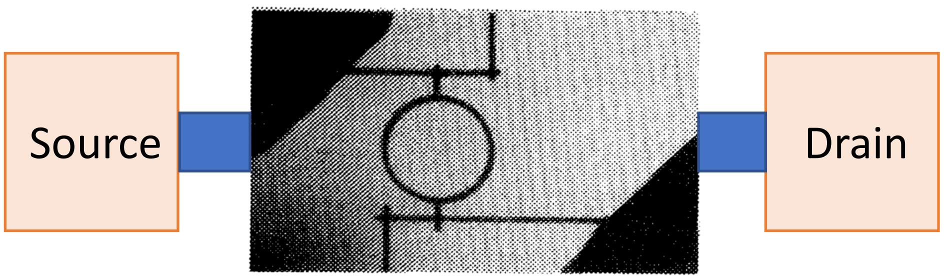
No interaction, single-particle picture

Lots of analogies with quantum optics -> towards quantum information

Theoretical tools for quantum transport



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Outline

1. Introduction to mesoscopic conductors

2. Scattering-matrix approach to quantum conduction

3. Example of a Aharonov-Bohm ring (quantum transport in presence of a magnetic field)

4. Towards quantum thermodynamics (through thermoelectricity)

Books

- Y. Imry "Introduction to mesoscopic physics" (Oxford University Press, 1997)
- S. Datta "Electronic transport in mesoscopic systems" (Cambridge University Press, 1995)
- Yu. V. Nazarov & Ya. M. Blanter "Quantum transport" (Cambridge University Press, 2009)
- K. Behnia "Fundamentals of Thermoelectricity" (Oxford University Press, 2015)

Review articles

- Beenakker , van Houten, Solid State Physics 44, 1 (1991), *Quantum Transport in Semiconductor Nanostructures*.
- Blanter, Büttiker, Phys. Rep. 336, 1 (2000), *Shot Noise in Mesoscopic Conductors.*
- Benenti, Casati, Saito, Whitney, Physics Reports, 694, 1 (2017), *Fundamental aspects of steady-state conversion of heat to work at the nanoscale.*

Lecture notes by M. Büttiker, D. C. Glattli, J. Splettstoesser, A. Jordan