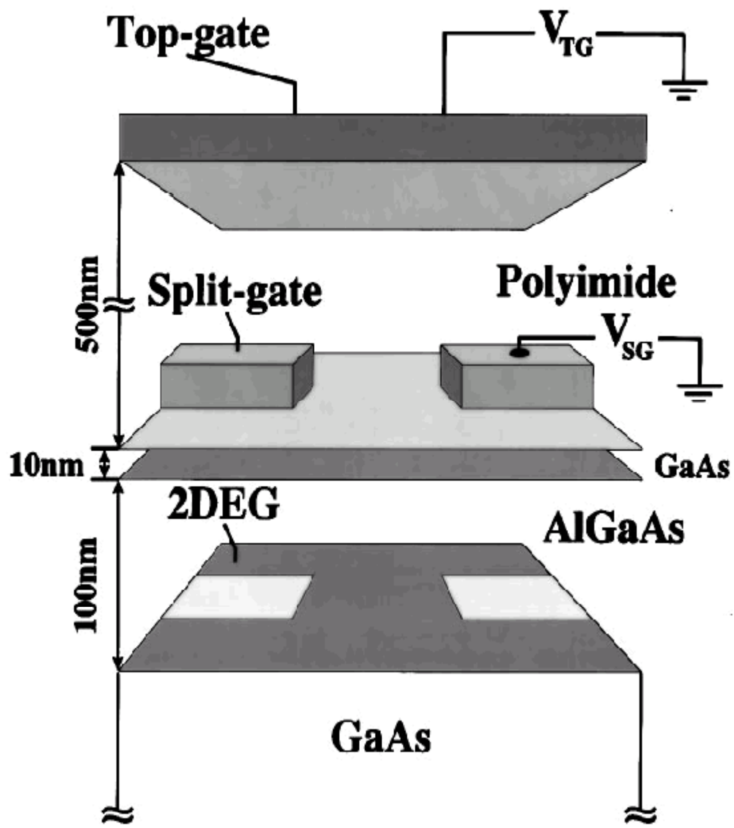
Nano- and micro-electronic systems / devices

Ballistic quantum wires and quantization of conductance, in units of e^2/h.

Landauer-Buttiker formula for the conductance of a quantum wire with and without scattering.

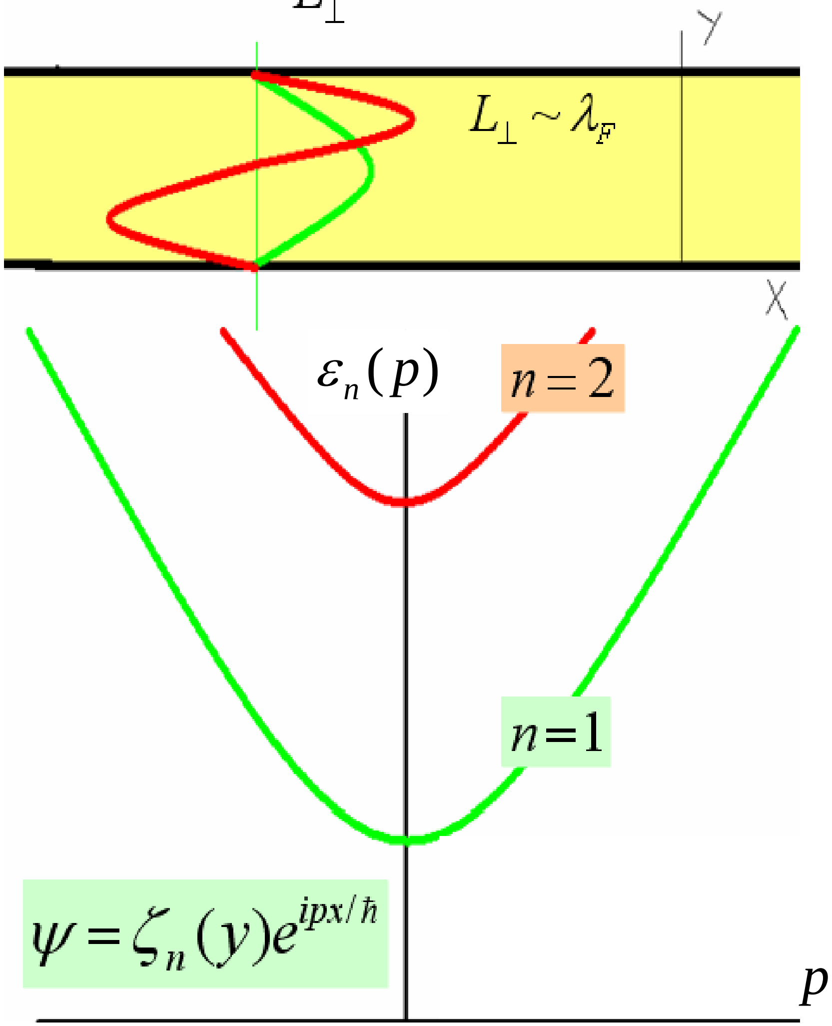
Metallic point contacts.

Quantum transport in ballistic quasi-one-dimensional wires



Electronic wave-guides

$$\zeta_n(y) \sim \sin\frac{n\pi x}{L_\perp}$$

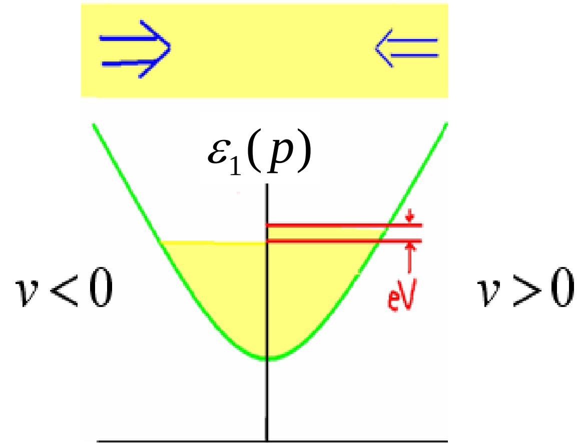


$$\psi = \zeta_n(y) e^{ipx/\hbar}$$

$$\varepsilon_n(p) = E_n + \frac{p^2}{2m} \qquad E_n = \frac{(\pi n\hbar / L_\perp)^2}{2m_e}$$

One-dimensional wire

$$\frac{(\pi\hbar / L_\perp)^2}{2m_e} = E_1 < E_F < E_2 = \frac{4(\pi\hbar / L_\perp)^2}{2m_e}$$



$$I = e\int_{p(E_F - eV/2)}^{p(E_F + eV/2)} v(p)\frac{dp}{2\pi\hbar} = \frac{e}{h}\int_{E_F - eV/2}^{E_F + eV/2} d\varepsilon = \frac{e^2 V}{h}$$

$$v = \frac{d\varepsilon}{dp}$$

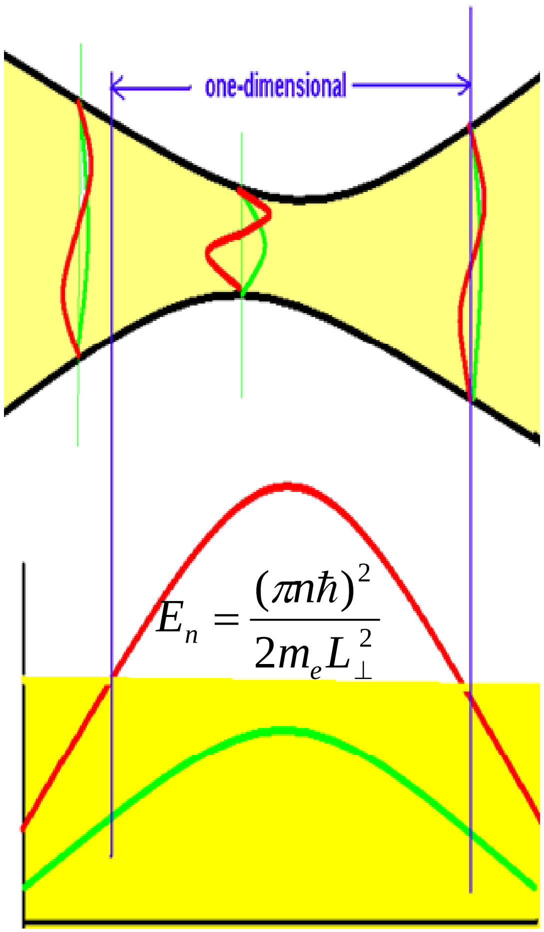
$$G_\uparrow = \frac{I_\uparrow}{V} = \frac{e^2}{h} \qquad G_{\uparrow+\downarrow} = \frac{I_\downarrow + I_\uparrow}{V} = \frac{2e^2}{h}$$

Spin-1/2 (Kramers degeneracy)

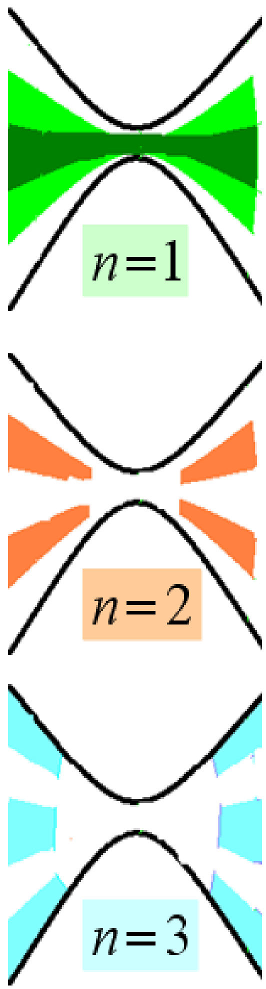
Smooth (adiabatic) constriction

$$L_\perp \sim \lambda_F << r$$

$$L_\perp\left(\frac{x}{r}\right)$$



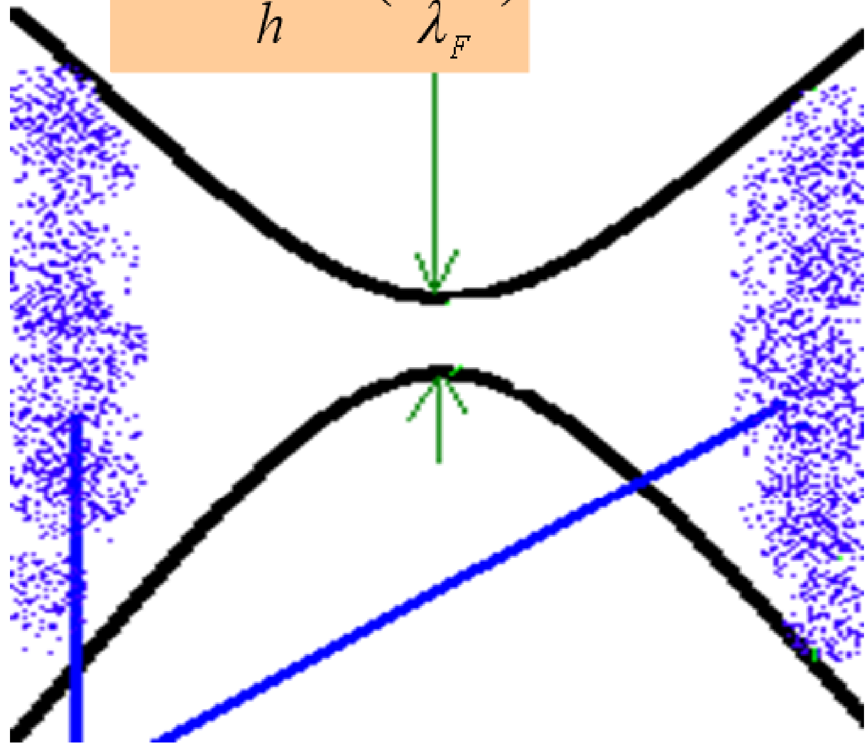
$$E_n = \frac{(\pi n\hbar)^2}{2m_e L_\perp^2}$$



Motion across the wire is quantum, whereas along the wire it is one-dimensional classical: it either passes through without any scattering, or it is fully reflected.

Landauer-Buttiker formula for ballistic adiabatic wire

$$G = \frac{2e^2}{h} N\left(\frac{L_\perp^{\min}}{\lambda_F}\right)$$



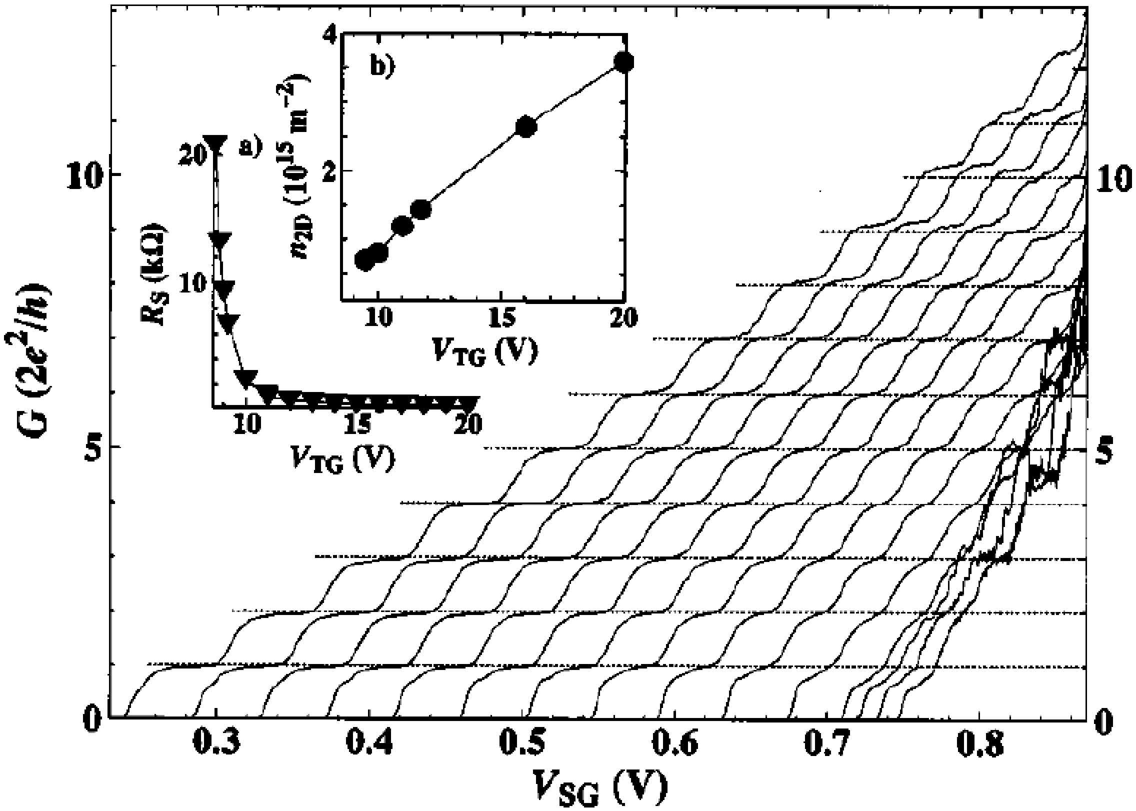
Energy relaxation and scattering between very few ballistically transmitted modes and an infinite number of fully scattered modes (momentum relaxation) take place in reservoirs, far away from the contact.

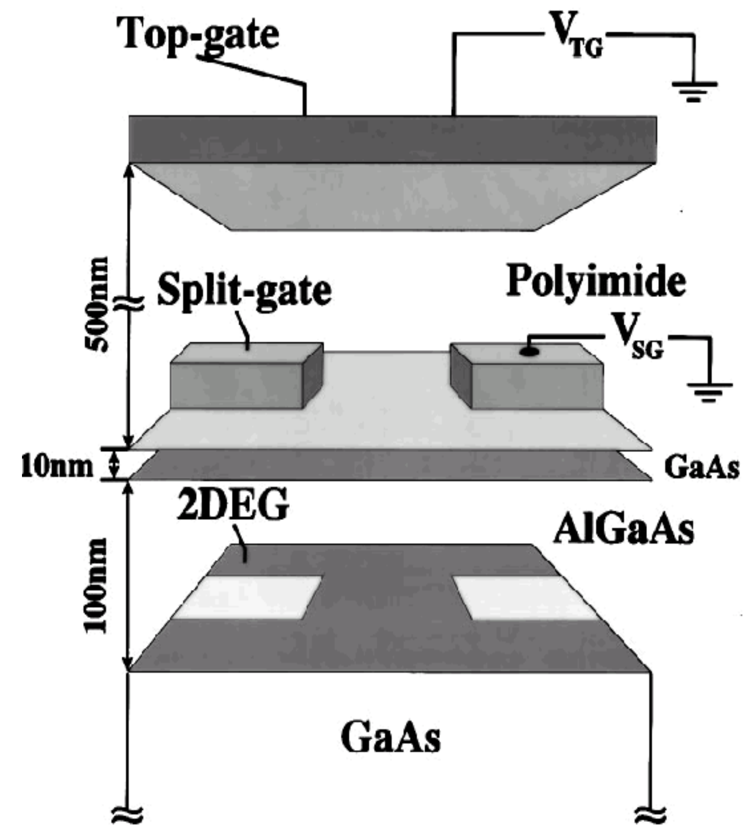
A finite resistance of a ballistic adiabatic point contact,

$$R = \frac{h}{2e^2 N_{\min}}$$

is formed in the regions where the most of modes arriving from an infinitely large reservoir are reflected back.

Quantum conductance (resistance)

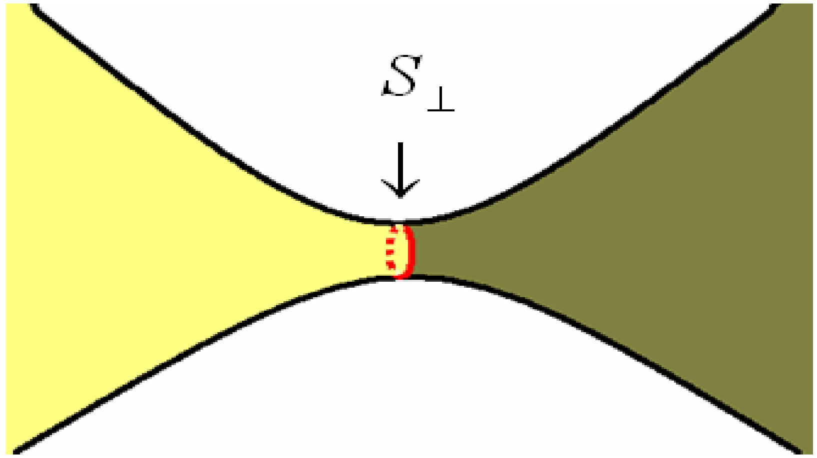




$$G_q = \frac{e^2}{h}$$

$$R_q = \frac{1}{G_q} = \frac{h}{e^2} = 25.812807\ k\Omega$$

‘Point contact’ between two bulk 3D metals



$$G = \frac{2e^2}{h} N_{ballistic}$$

$$\uparrow$$

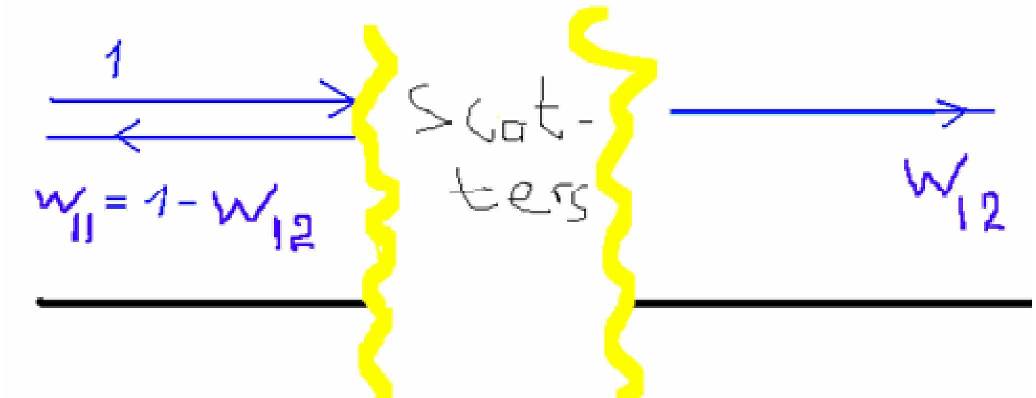
$$N\left(\frac{S_\perp^{\min}}{\lambda_F^2}\right) \sim \frac{S_\perp^{\min}}{\lambda_F^2}$$

$$G = a_{geom} \frac{2e^2}{h} \frac{S_\perp^{\min}}{\lambda_F^2}$$

Sharvin 1982

Landauer-Buttiker formula for a quantum wire with a scatterer

$$I = 2e\int_{E_F - eV/2}^{E_F + eV/2} w_{12}(\varepsilon)\cdot V_F v_F \, d\varepsilon = \frac{2e^2 V}{h} w_{12}(\varepsilon_F)$$

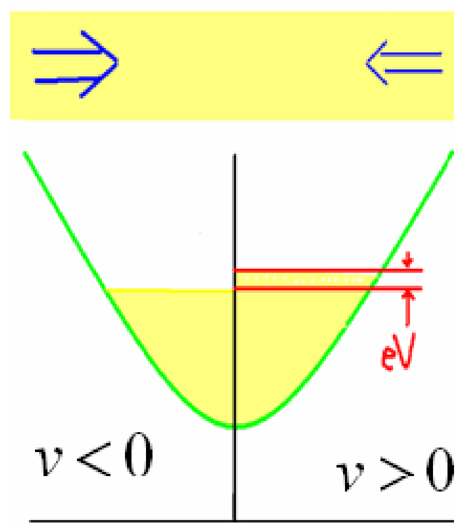


ballistic 1D wire

ballistic 1D wire

$$G = \frac{2e^2}{h} w_{12}(\varepsilon_F)$$

Landauer, Buttiker 1984



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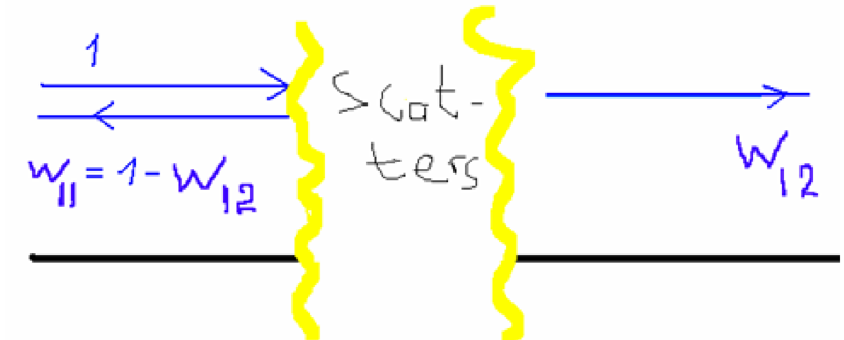
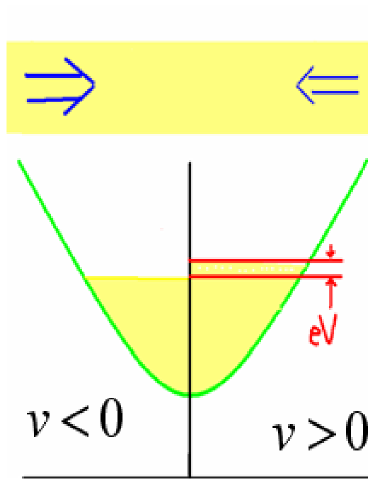


ballistic 1D wire   ballistic 1D wire



$$G = \frac{2e^2}{h} w_{12}(\varepsilon_F)$$

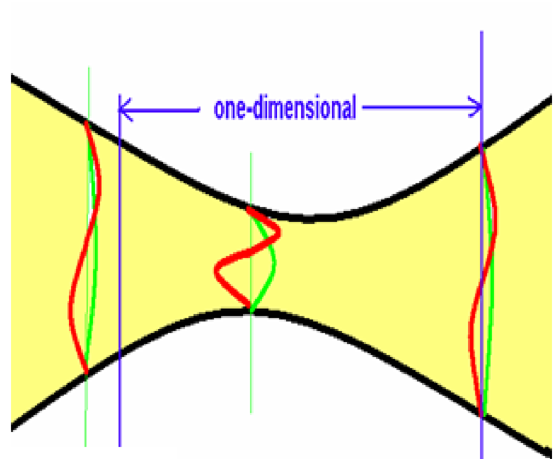
Landauer, Buttiker 1984

$w_{12}=1$	$w_{12}=0$
full transmission for lower 1D subbands	*completely blocked for higher 1D subbands*

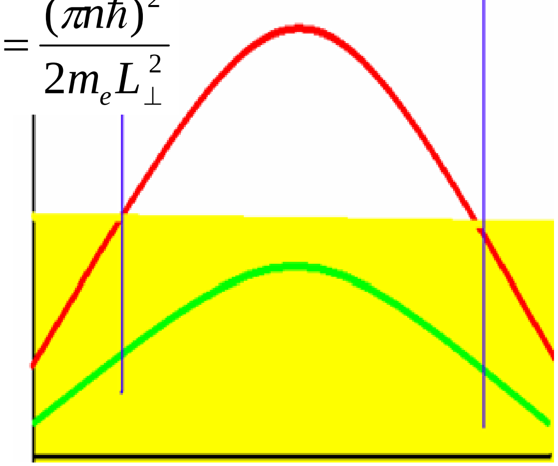
Smooth (adiabatic) constriction

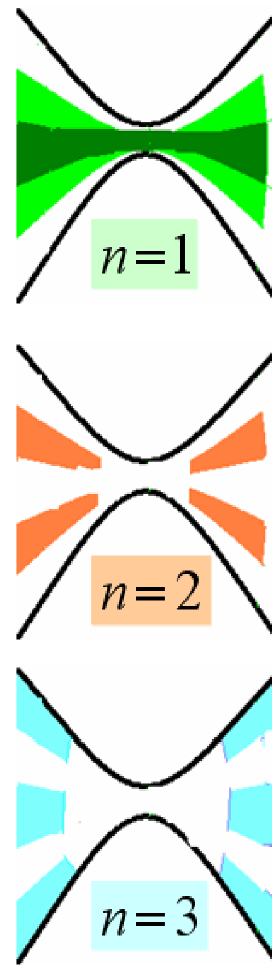
$$L_\perp \sim \lambda_F << r$$

$$L_\perp\left(\frac{x}{r}\right)$$



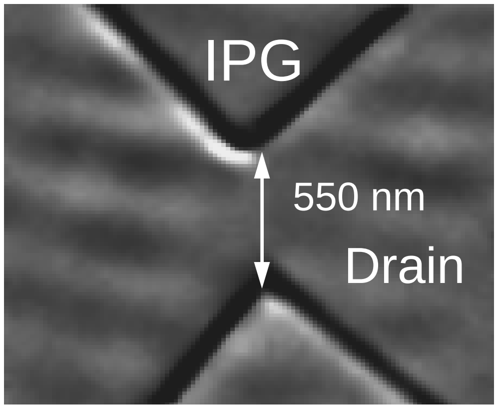
$$E_n = \frac{(\pi n \hbar)^2}{2 m_e L_\perp^2}$$

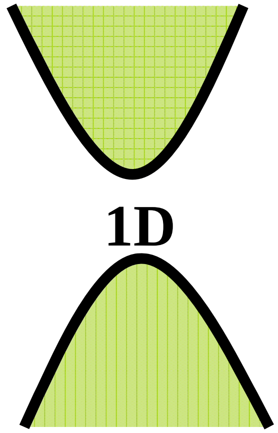


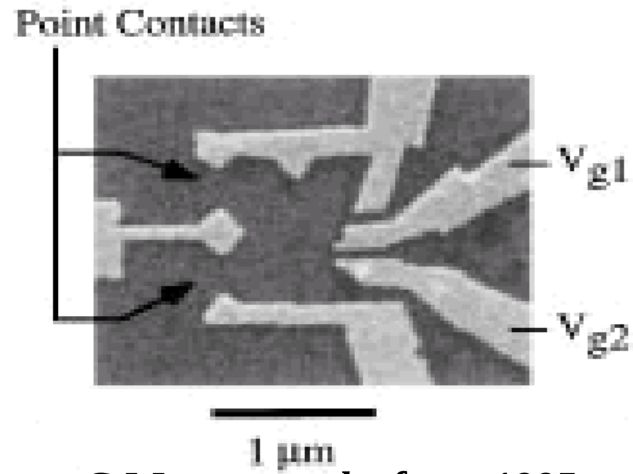


Motion across the wire is quantum, whereas along the wire it is one-dimensional classical: it either passes through without any scattering, or it is fully reflected.

Quantum transport effects

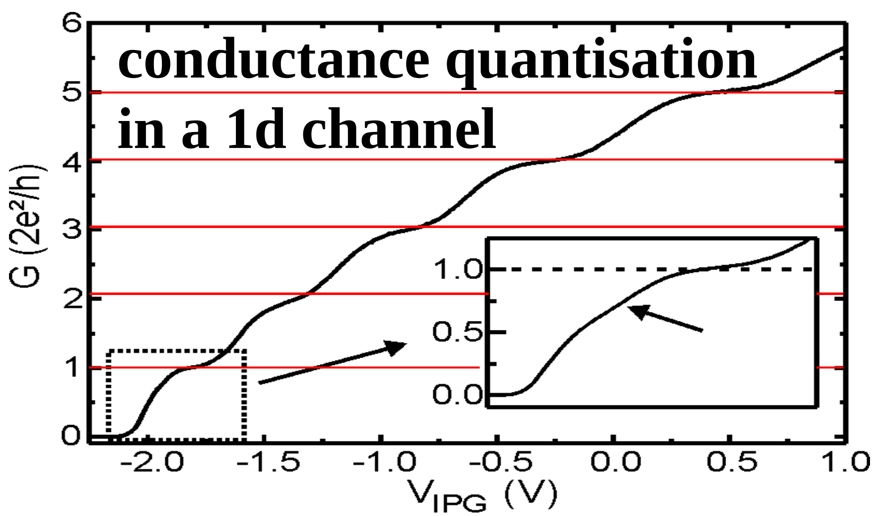


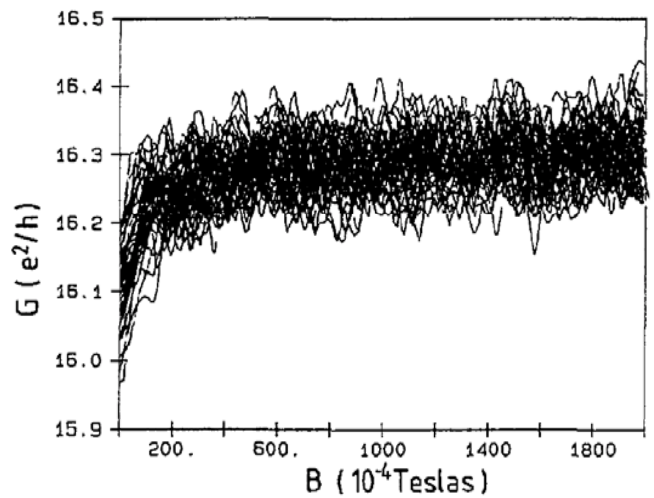




C.Marcus *et al* – from 1995

Haug *et al*, Appl. Phys. Lett.81, 2023 (2002)





D.Mailly, M.Sanquer - 1992