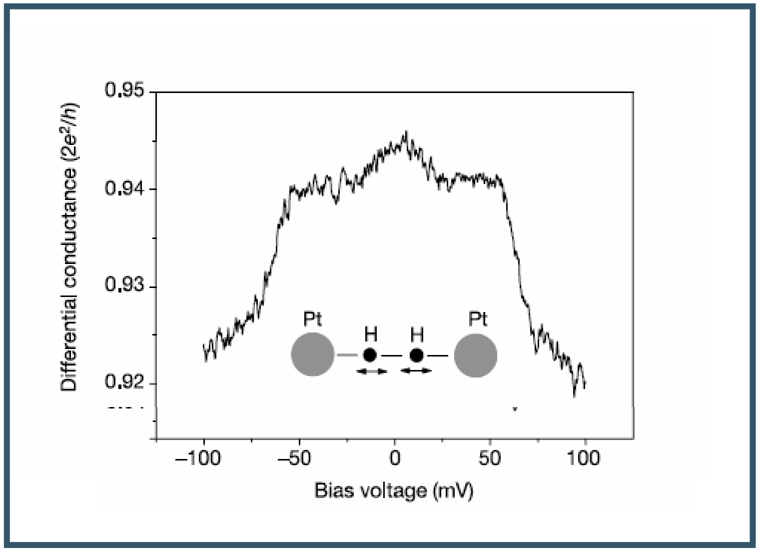
Bottom-up view of conductance

"Measurement of the conductance of a hydrogen molecule," R.H. M. Smit, et al., *Nature*, **419**, 31 Oct. 2002



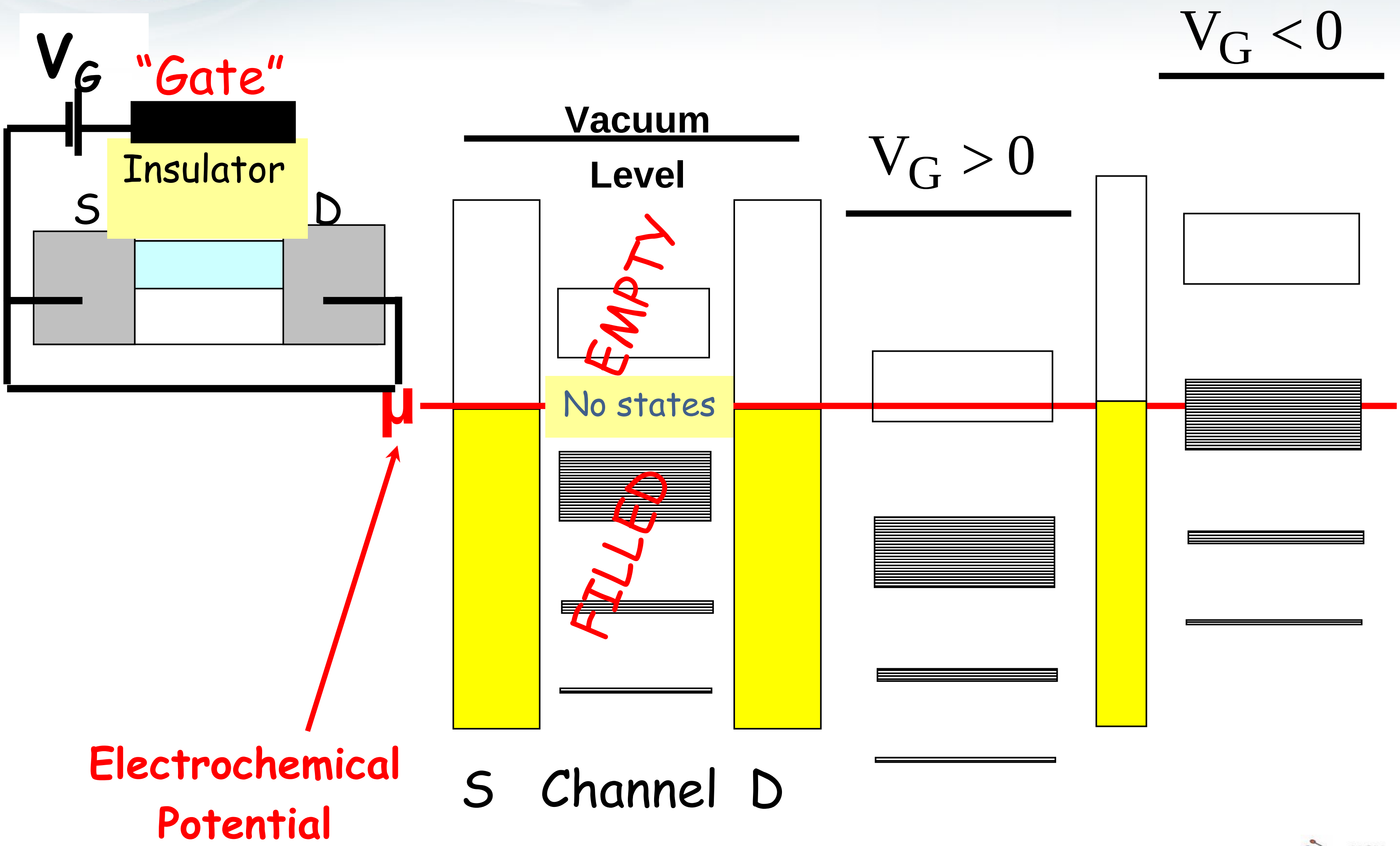
Supriyo Datta on:

1) Why maximum conductance of a small conductor is

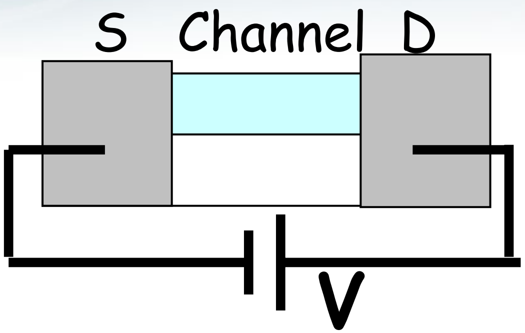
$$2q^2/h \approx 1/12.8\,K\Omega$$

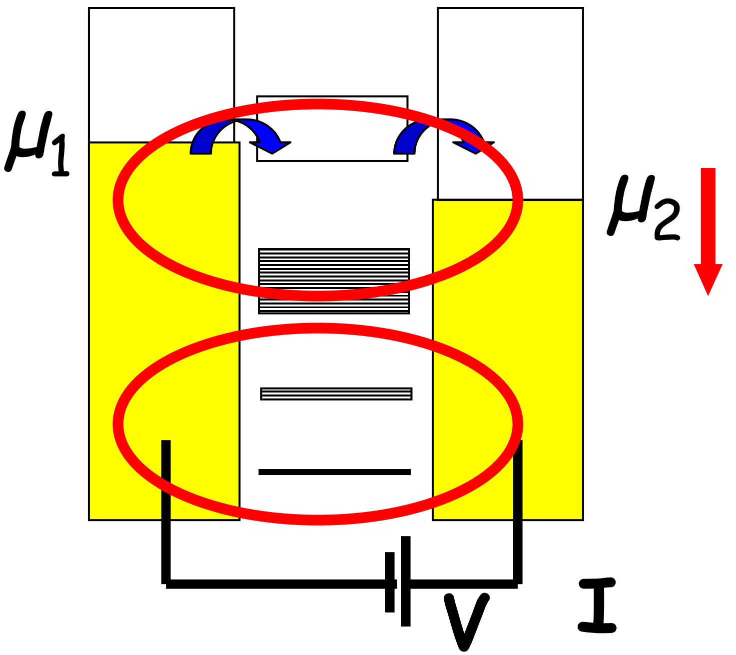
2) Why the conductance of large conductors ~ A/L

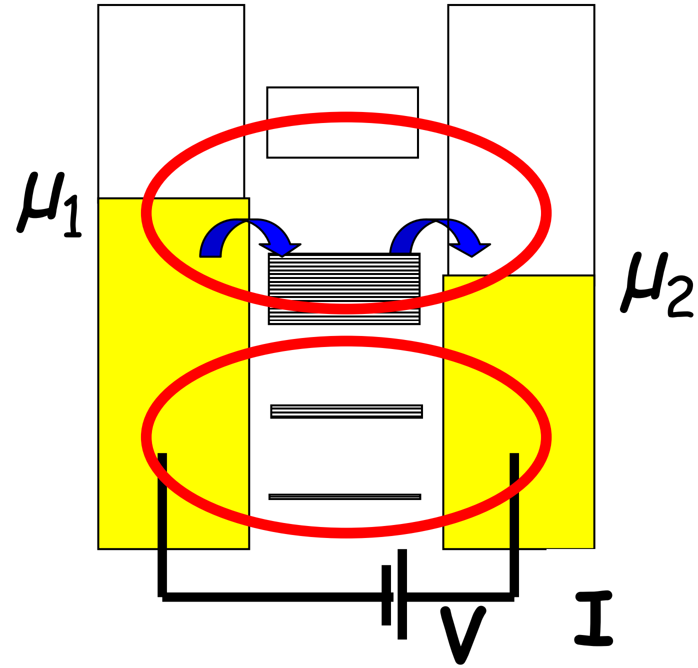
Equilibrium Energy Level Diagram



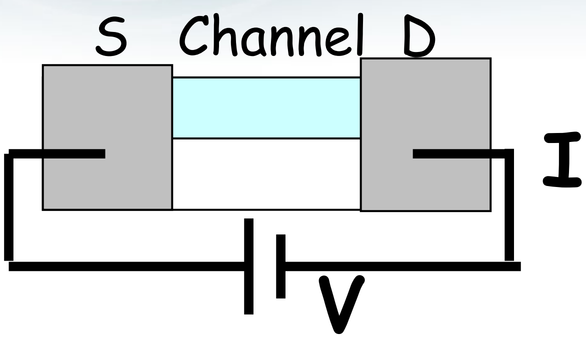
What makes electrons flow?

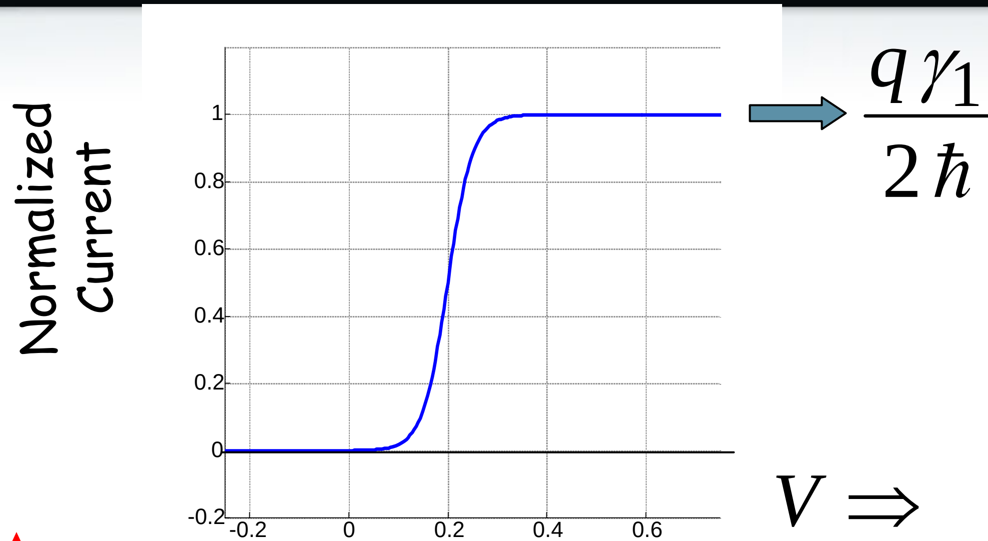


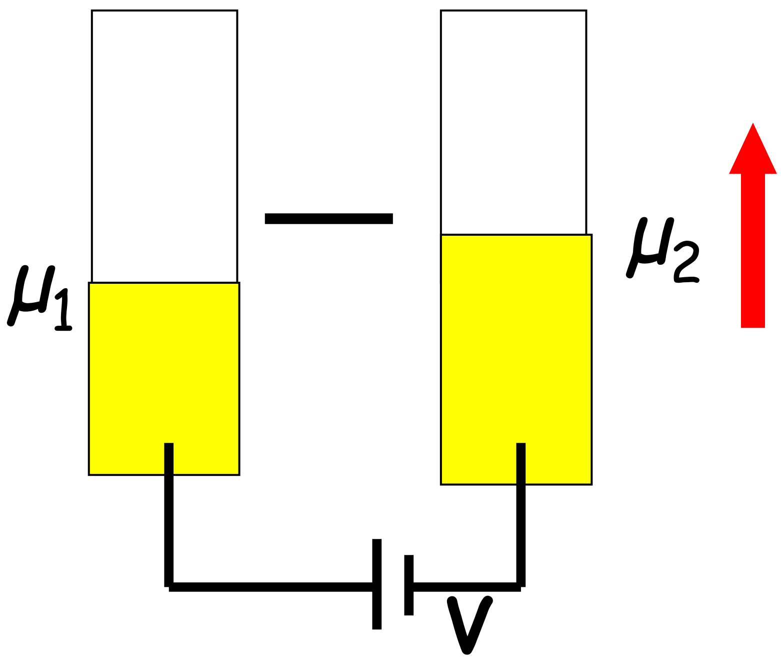


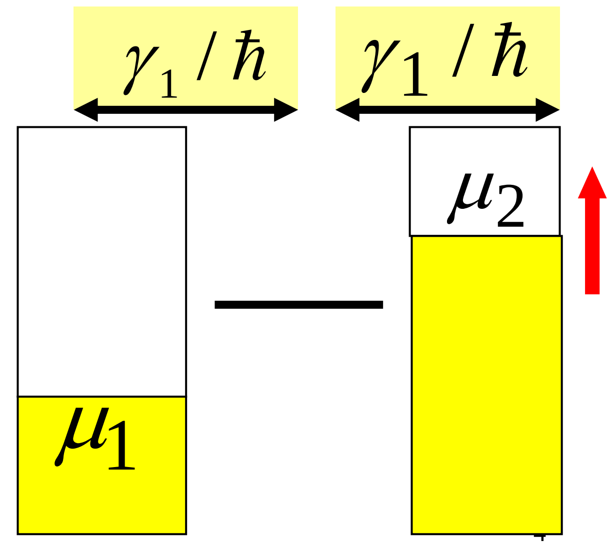


Current through a 1-level conductor

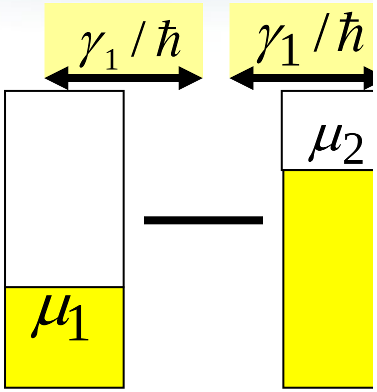


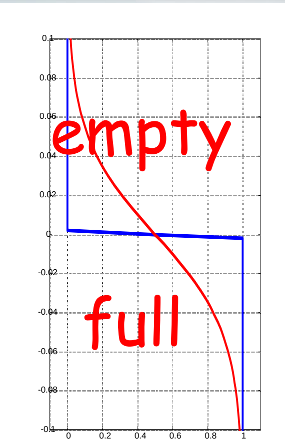


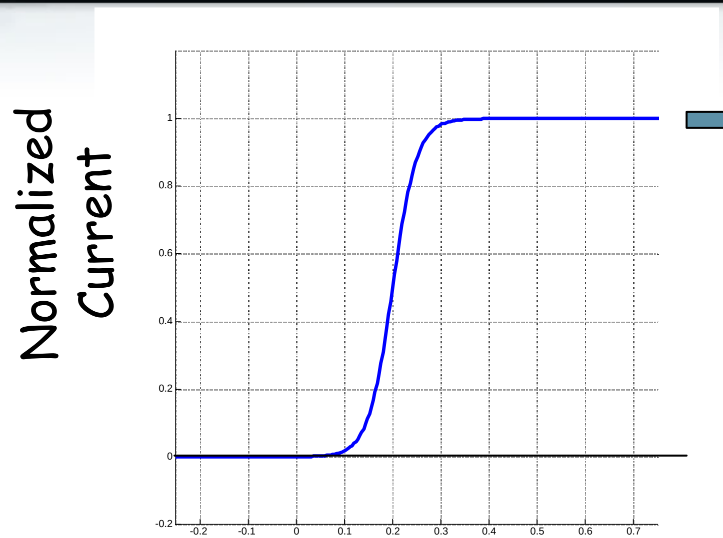




Conductance ?



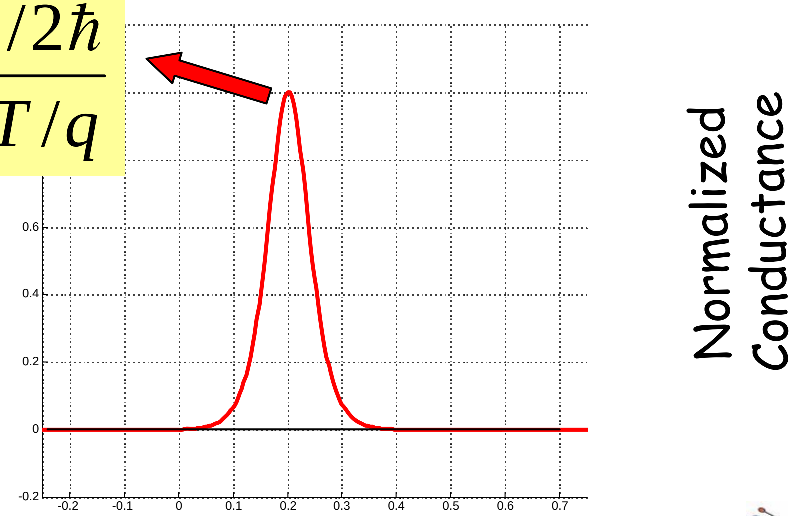




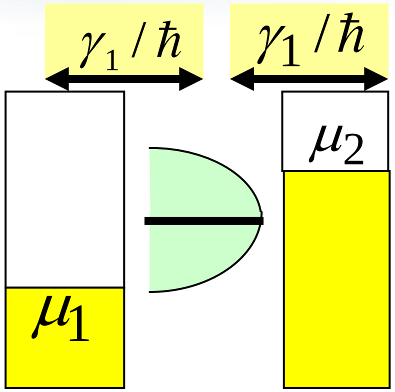
$$\Rightarrow \frac{q\gamma_1}{2\hbar}$$

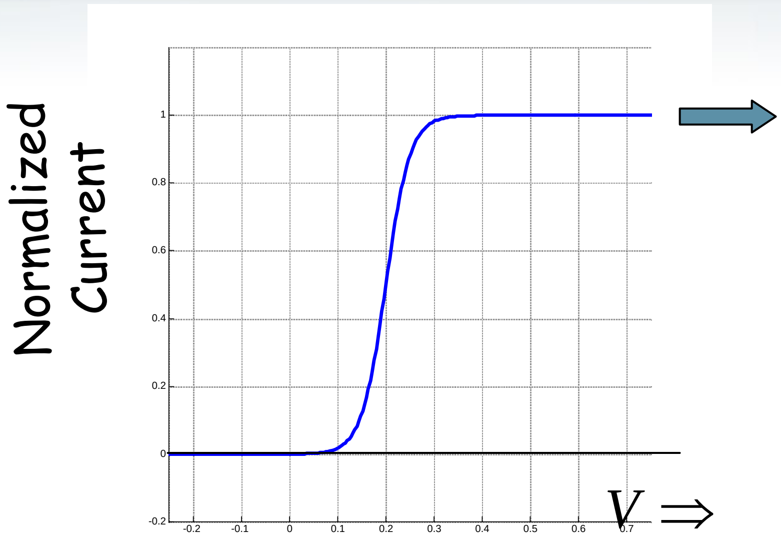
$V \Rightarrow$

$$\frac{dI}{dV} \sim \frac{q\gamma_1/2\hbar}{4kT/q}$$



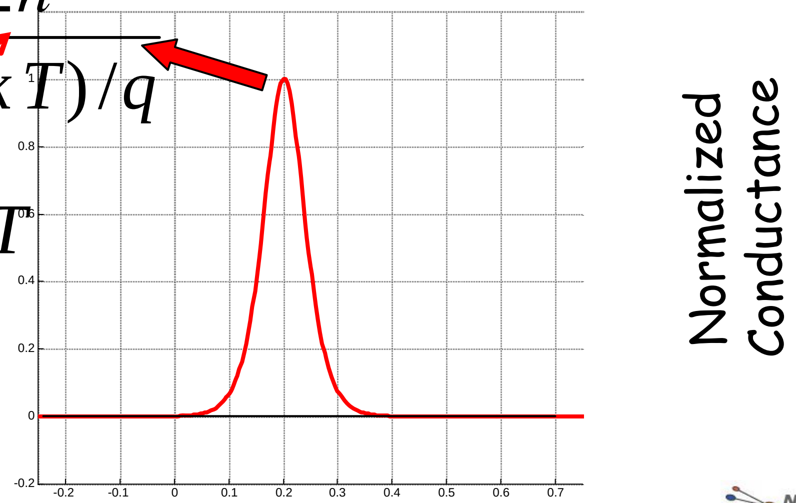
Conductance quantum





$$\frac{dI}{dV} \sim \frac{q\gamma_1/2\hbar}{(2\gamma_1 + 4kT)/q}$$

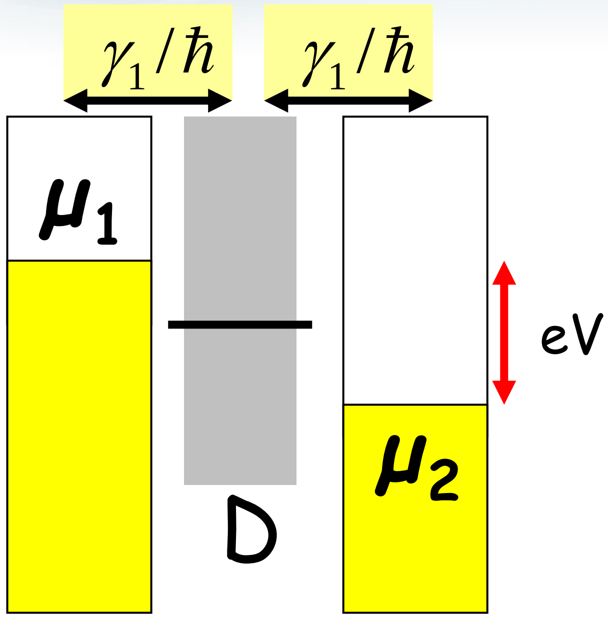
$$\sim \quad q^2/4\hbar \quad \text{if} \quad \gamma_1 >> kT$$



Conductance quantum

$$\sim \quad q^2/2\pi\hbar \quad \sim \quad 1/25.8\ K\Omega$$

Conductance: for any DOS, D



$$I \sim \underbrace{\frac{q\,\gamma_1}{2\,\hbar}}_{\text{Current per state}} \underbrace{D\,qV}_{\text{Number of states}}$$

D: Density of states

$$I/V = \underbrace{\frac{q^2}{2\pi\hbar}}_{\text{Conductance Quantum}} \underbrace{\pi D \gamma_1}_{\text{Transmission}}$$

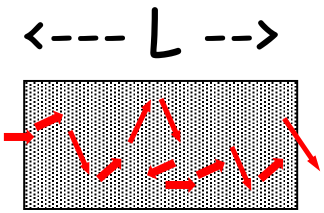
Bottom-up view

0.1 mm

Macroscopic dimensions

$$G = \sigma A / L$$

10 μm

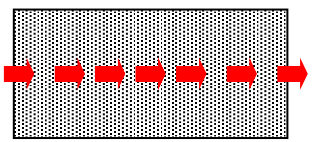


1 μm

$$\gamma \sim \frac{2\hbar D}{L^2} \rightarrow D\gamma \sim A/L$$

$$G = (q^2/h)\ (\pi D \gamma), \qquad D \sim AL$$

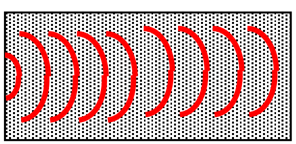
0.1 μm



10 nm

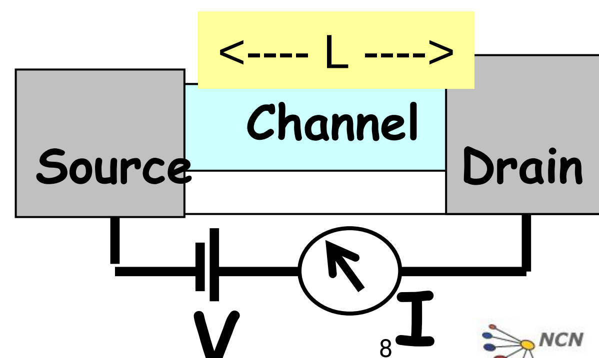
$$\gamma \sim \frac{\hbar v}{L} \rightarrow D\gamma \sim A$$

1 nm



0.1 nm

$$G = \underbrace{(q^2/h)}_{1/25.8\ K\Omega}$$

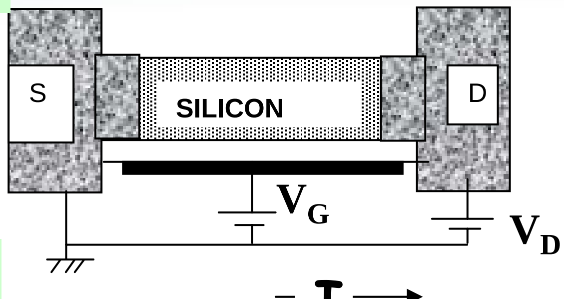


Atomic dimensions

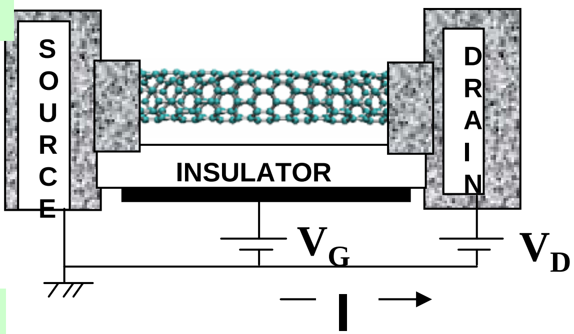
NCN

unified viewpoint

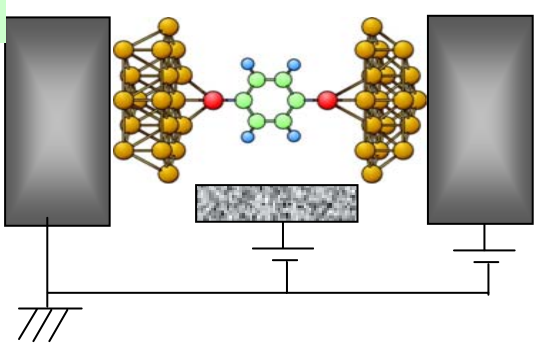
Nanowires

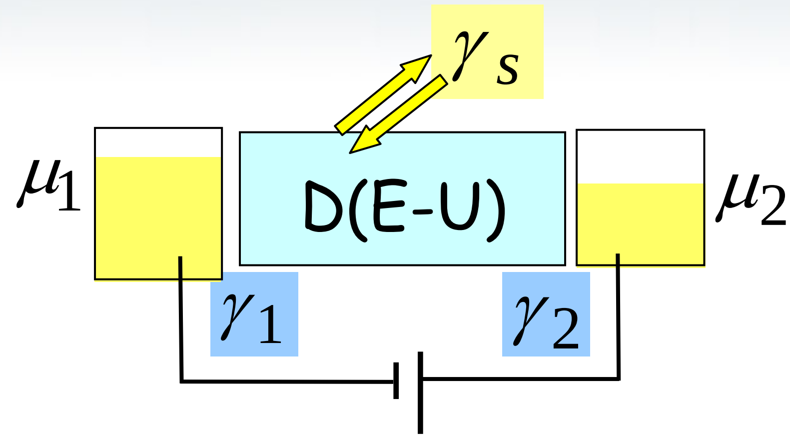


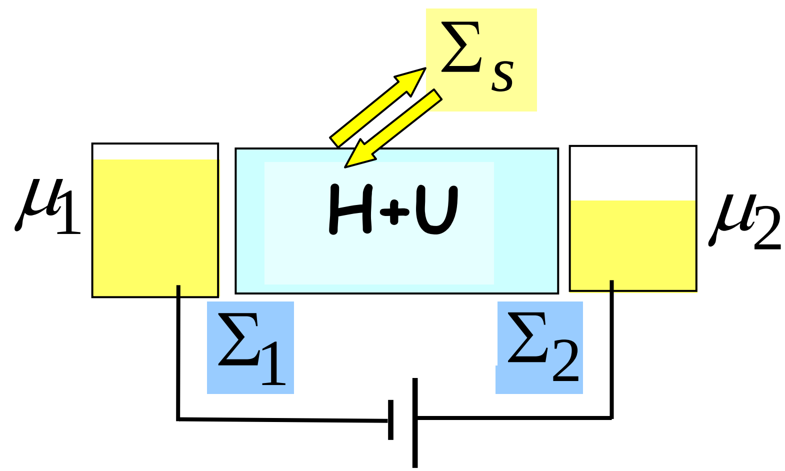
Nanotubes /Graphene



Molecules







See: S. Datta,

http://www.nanohub.org/courses/cqt