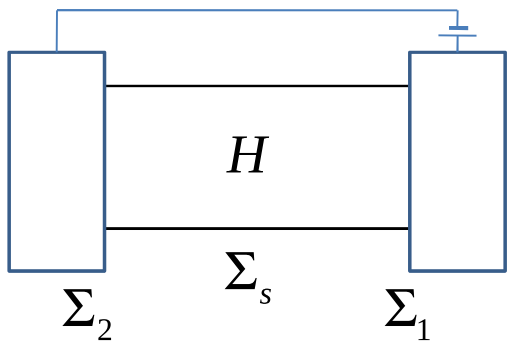
# ECE 659 Quantum Transport: Atom to Transistor

Lecture 42: Summing Up

Supriyo Datta

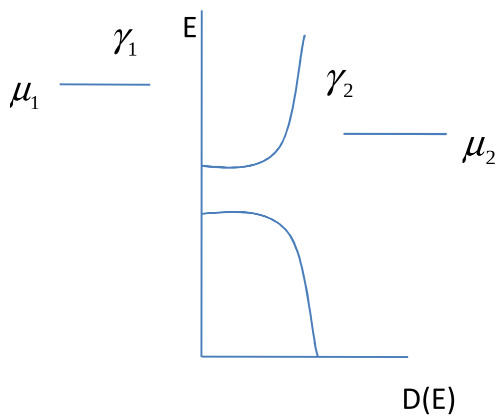
Spring 2009

Notes prepared by Samiran Ganguly




$$G = \left[EI - H - \Sigma\right]^{-1}$$

$$G^n = G\Sigma^{in}G^+$$




Newton's Law:

$$\vec{r}, \vec{p}, t$$

$$\frac{d\vec{r}}{dt} = \nabla_p E$$

$$\frac{d\vec{p}}{dt} = -\nabla E$$

Statistical Mechanics

Equilibrium Problems

$$T, \mu$$

$$\frac{dS}{dE} = \frac{1}{E}$$

Non-equilibrium Problems

Boltzman Equation

$f\left(\vec{r}, \vec{k}, t\right) \longrightarrow$ Newton's Law +
scattering (Entropic forces)

## Quantum Mechanics

$\psi(r)$ ⟶ Schrodinger Equation

NEGF ⟶ Quantum Boltzman Equation
(Schrodinger Equation + scattering)

## Landauer Model

Channel ⟶ dynamics

Contact ⟶ thermodynamics

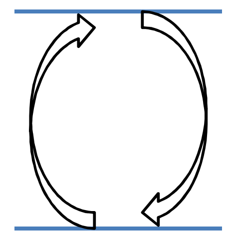
Applications: small devices, large device in low bias

## Multi-particle Schrodinger Equation

$$\Psi(r_1, r_2, \ldots)$$

$$i\hbar \frac{d\Psi}{dt} = H\Psi$$

$$\rho = \frac{1}{Z}\exp\left(-\frac{H-\mu N}{k_B T}\right)$$



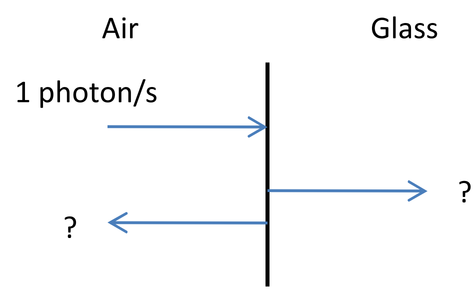
Works well when
coupling of levels is low

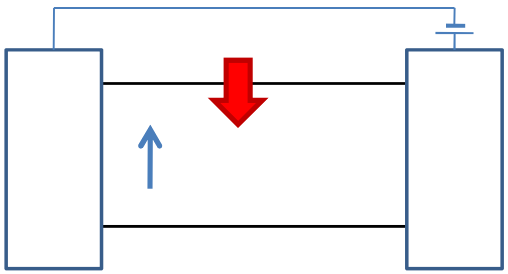
## Photons

$$E^2 = m^2c^4 + p^2c^2$$

Maxwell's Equation ⟶ Schrodinger Equation for photons

$$\vec{E}(\vec{r}) \Rightarrow \Psi(r)$$





$\uparrow\Downarrow$ a + $\downarrow\Uparrow$ b

$$i\hbar\frac{\partial}{\partial t}\begin{pmatrix}\uparrow\Downarrow \\ \downarrow\Uparrow\end{pmatrix} = \begin{bmatrix} & * \\ * & \end{bmatrix}\begin{pmatrix}\uparrow\Downarrow \\ \downarrow\Uparrow\end{pmatrix}$$

$$\psi = a(r_1)b(r_2) - a(r_2)b(r_1)$$

if $r_1 = r_2$

$$\psi = 0$$

$\psi$ cannot be measured

$\psi^*\psi$ can be measured

In case of photons, the '-' sign is replaced by a '+' sign so many photons can be in a single state, which gives a big magnitude for electric field, that can be measured

Multi-electron Schrodinger Equation

$$\Psi(r_1, r_2, \ldots)$$

This becomes an operator in second quantization

$$G = [EI - H - \Sigma]^{-1}$$

$$G^n = G\Sigma^{in}G^+$$

$$G^n = \langle \psi\psi^+ \rangle$$