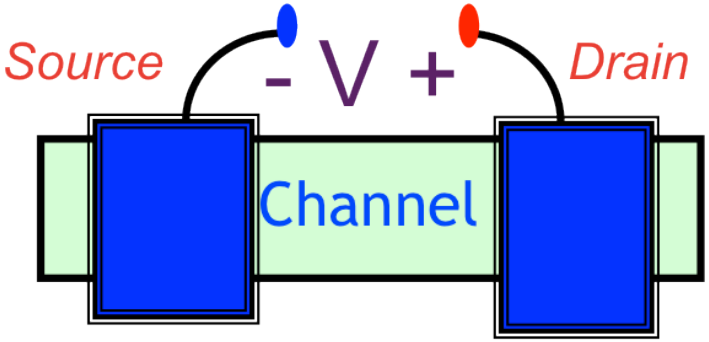
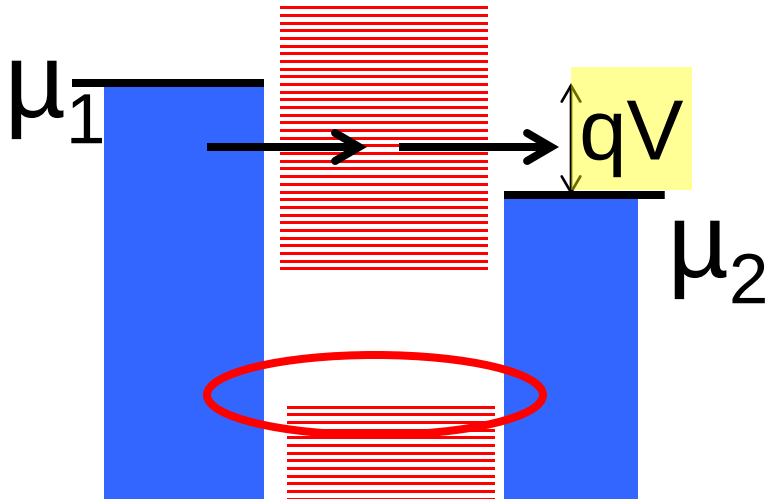
# FUNDAMENTALS OF NANOELECTRONICS




$$G = \frac{q^2 D}{2t}$$

D: Density of states

t : transfer time

A. Basic Concepts:

Semiclassical (SC) Model

1. The new perspective
2. Energy band model
3. What and where is the voltage?
4. Heat & electricity:

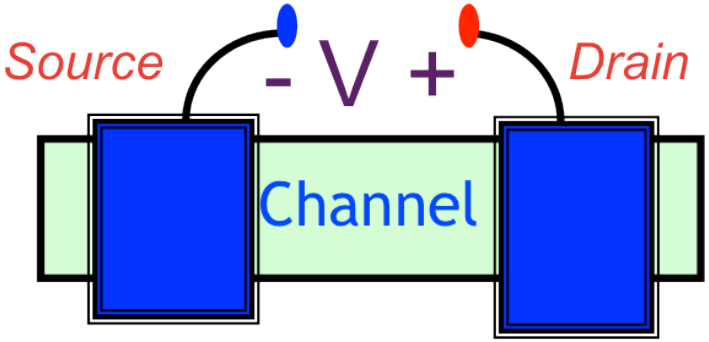
Second law & information

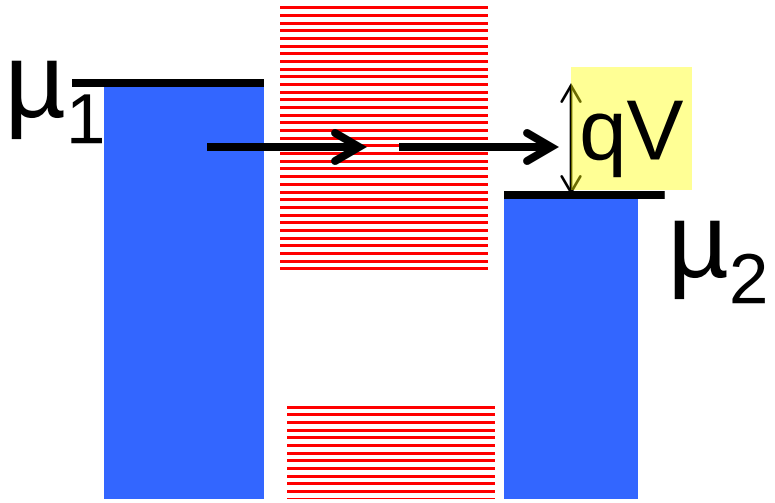
From SC to Q

B. Quantum (Q) Model

1. Schrodinger Equation
2. Contact-ing Schrodinger
3. NEGF Method
4. Spin Transport

## Drude Formula




$$\sigma = \frac{q^2\, n\, \tau}{m}$$

$$\sigma = \frac{G_B}{A}\lambda$$

$$\frac{G_B\,\lambda}{L+\lambda}$$

***M: Number of "modes"***

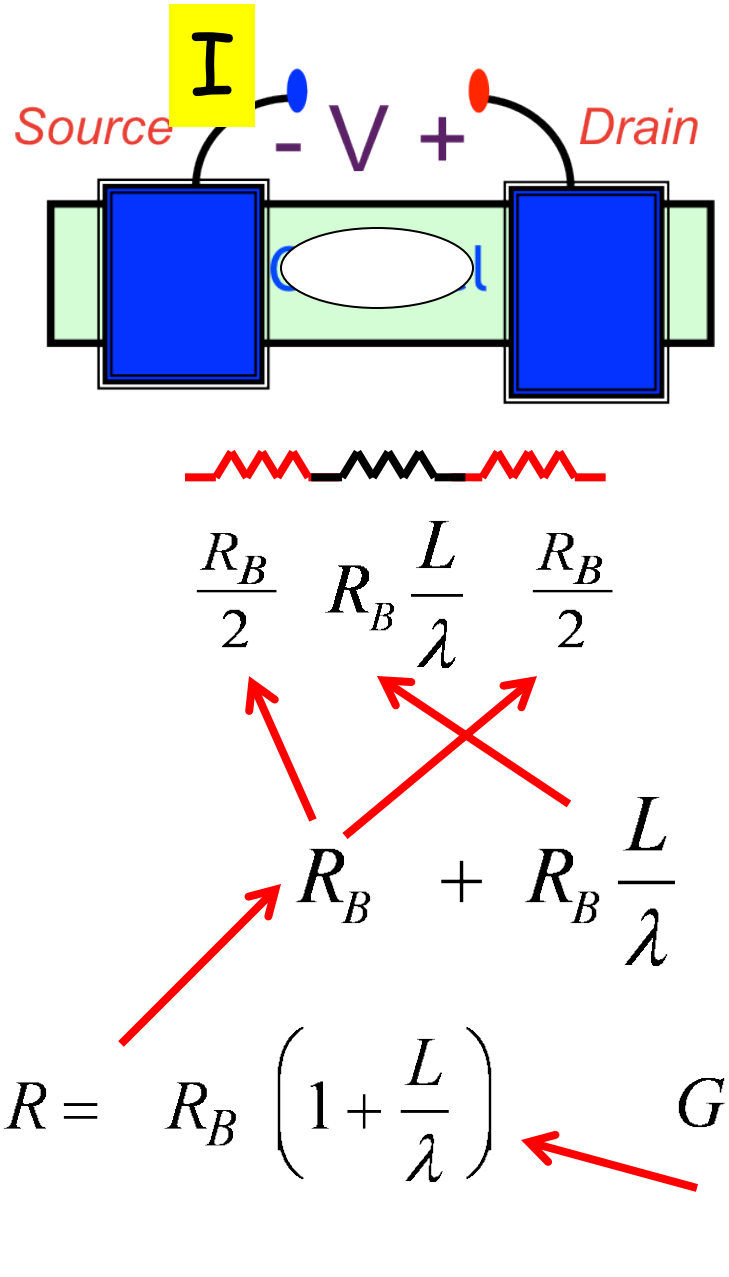
$$G_B = \frac{q^2}{h}M$$

**NEW** $$G = \frac{q^2 D}{2t} \rightarrow G_B = \frac{q^2 D\bar{u}}{2L} \rightarrow G = \frac{G_B}{1+\frac{L}{\lambda}}$$

# Where is the Resistance?

1. The new perspective
2. Energy band model
3. What and where is the voltage?
4. Heat & electricity:

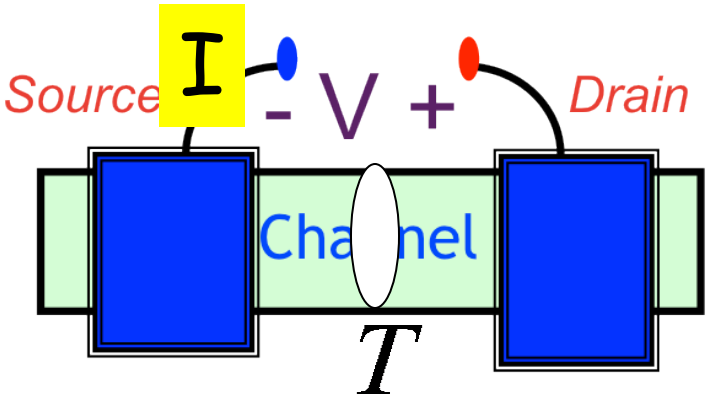
   Second law & information

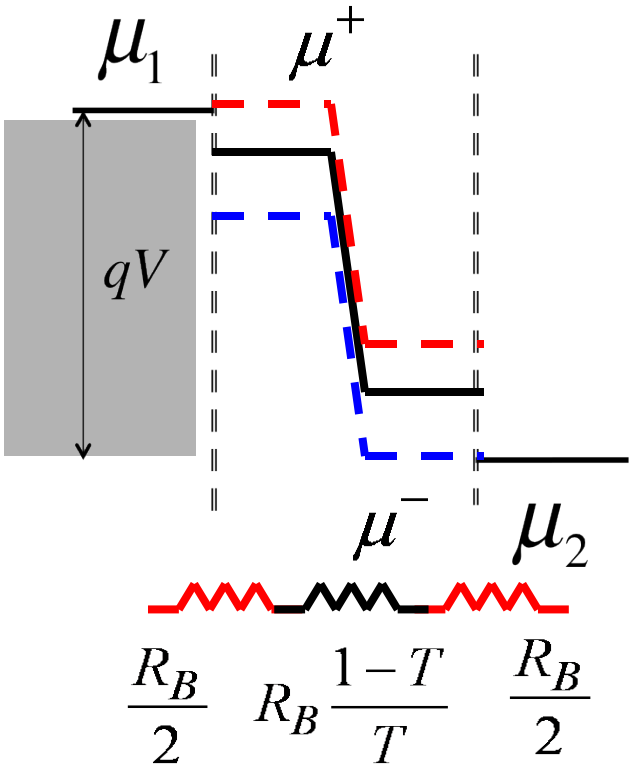



Resistance is associated with

- Joule Heating: $I^2R$
- Voltage drop: $IR$

# What & where is the voltage?



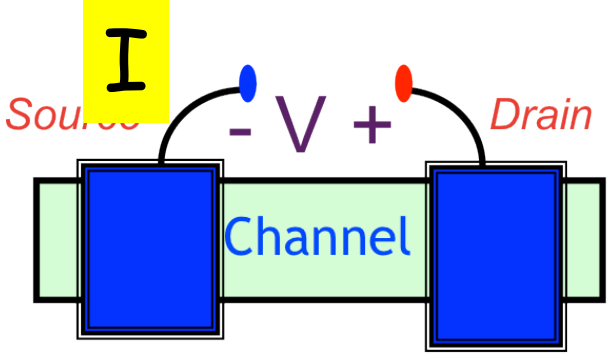

1. The new perspective
2. Energy band model
3. What and where is the voltage?
4. Heat & electricity:

   Second law & information

➢ Voltage drop: IR

➢ Quasi-Fermi Levels (QFL)

# "Elastic Resistor"




$\frac{R_B}{2}$ $\frac{R_B}{2}$

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2. Energy band model
3. What and where is the voltage?
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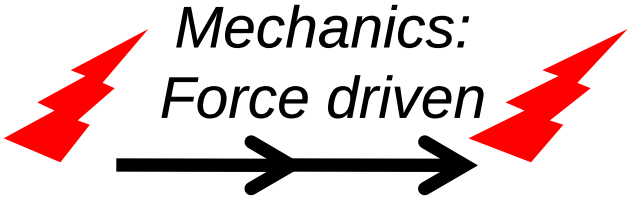
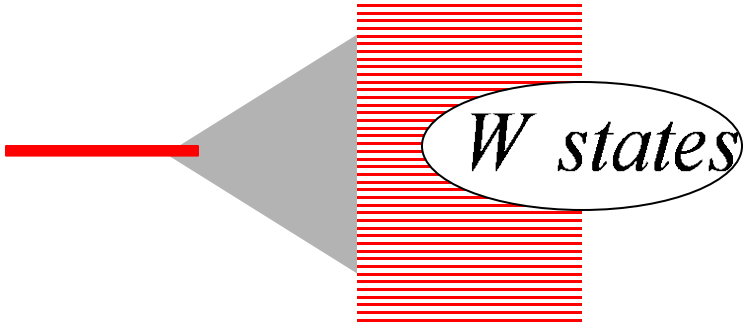
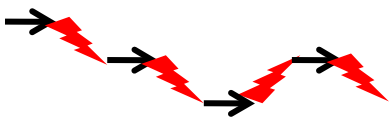



*Thermodynamics: Entropy driven*

$$I \sim G(E) \times \left(f_1(E) - f_2(E)\right)$$




$$S = k \ell n W$$



Usually all mixed up !!

Part A:
Semiclassical Transport

Newton + ⚡ =

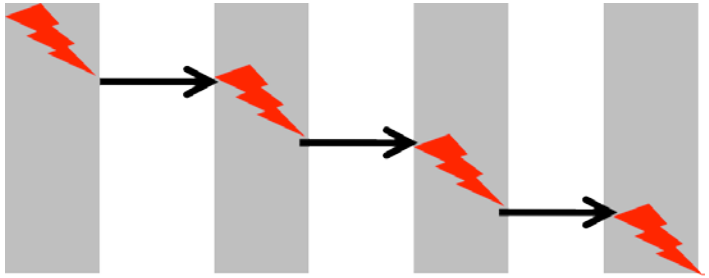
$$E\psi = H\psi$$

Schrodinger + ⚡ = NEGF

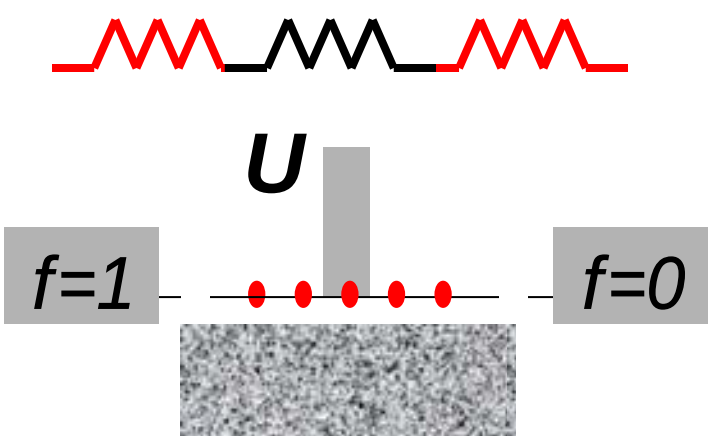
Part B:
Quantum Transport

- *Provides approximate physical picture in general*
- *Agrees with rigorous theory for low bias*

*Long Resistors*



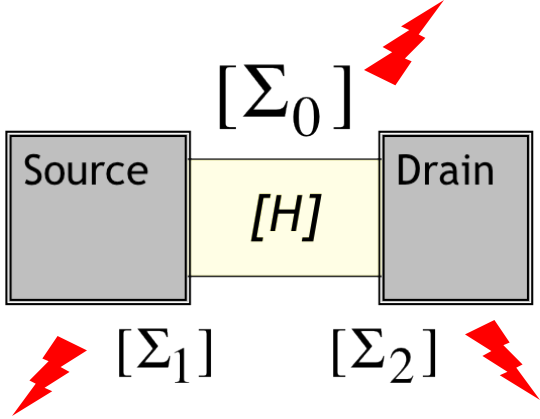
# An Example



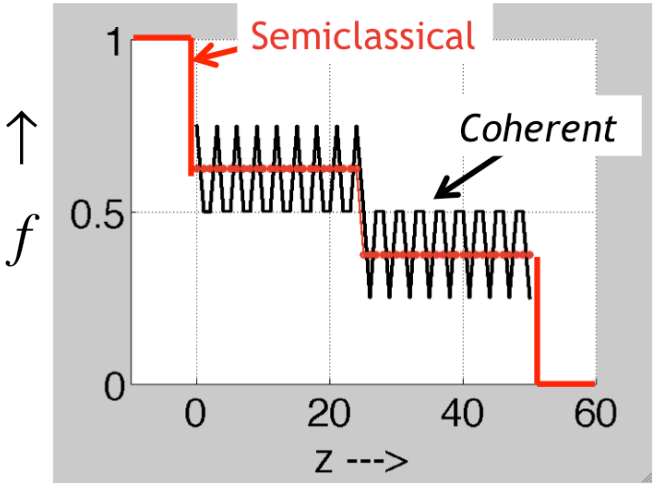

*NEGF*

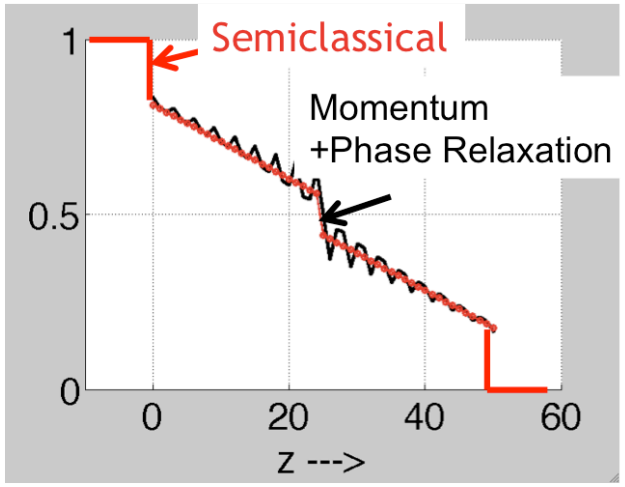
*Non – Equilibrium*

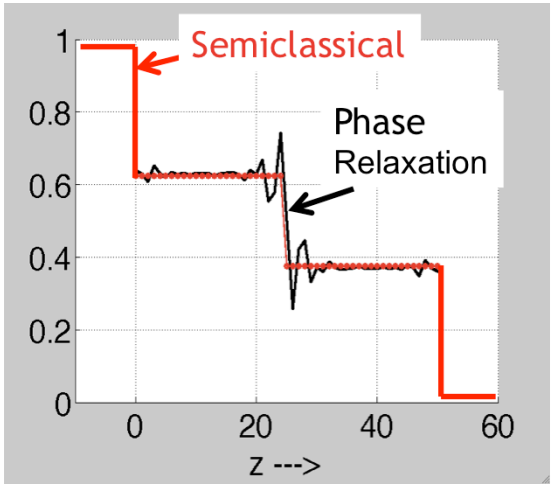
*Green's Function*



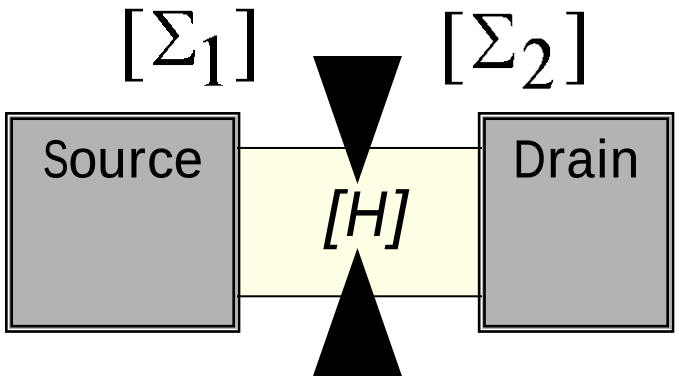

$+(\Sigma_0)_{diss}$



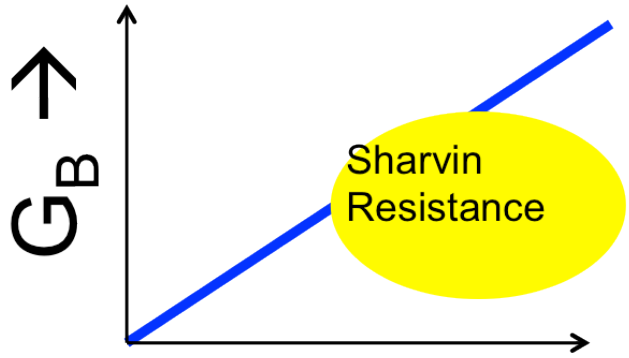



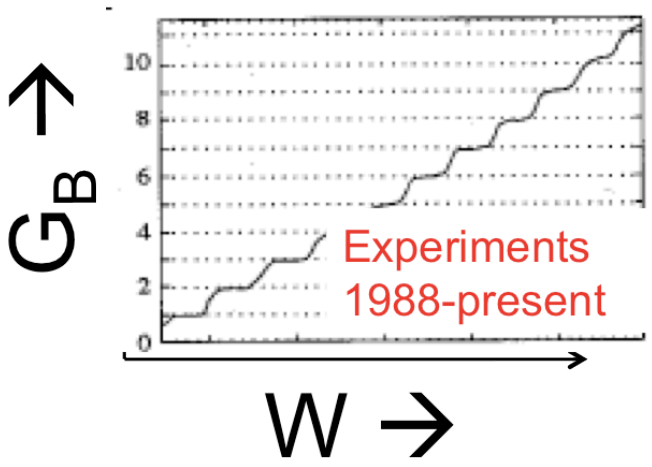



# More examples

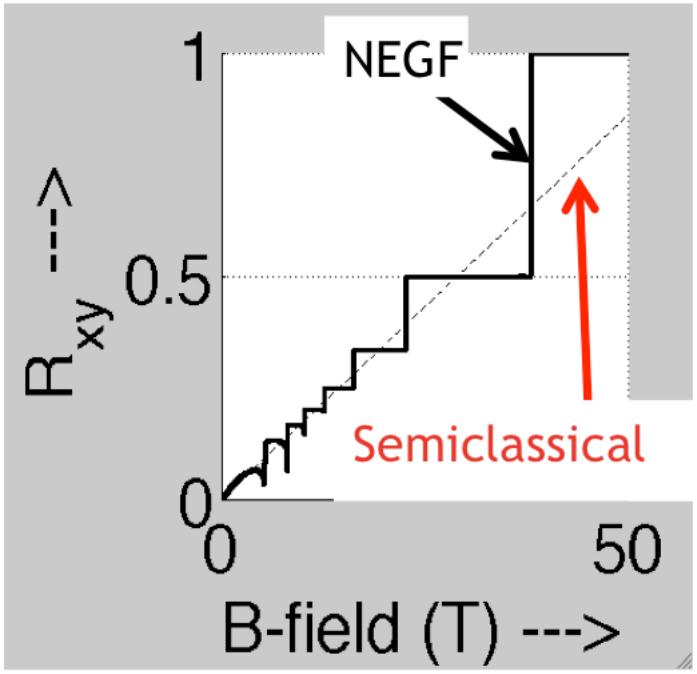


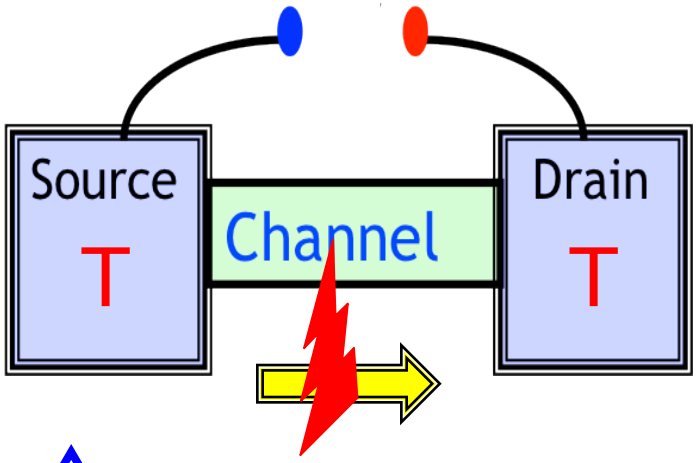

*Quantized conductance*

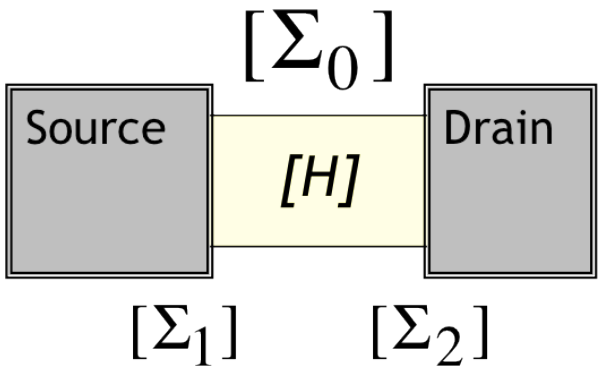


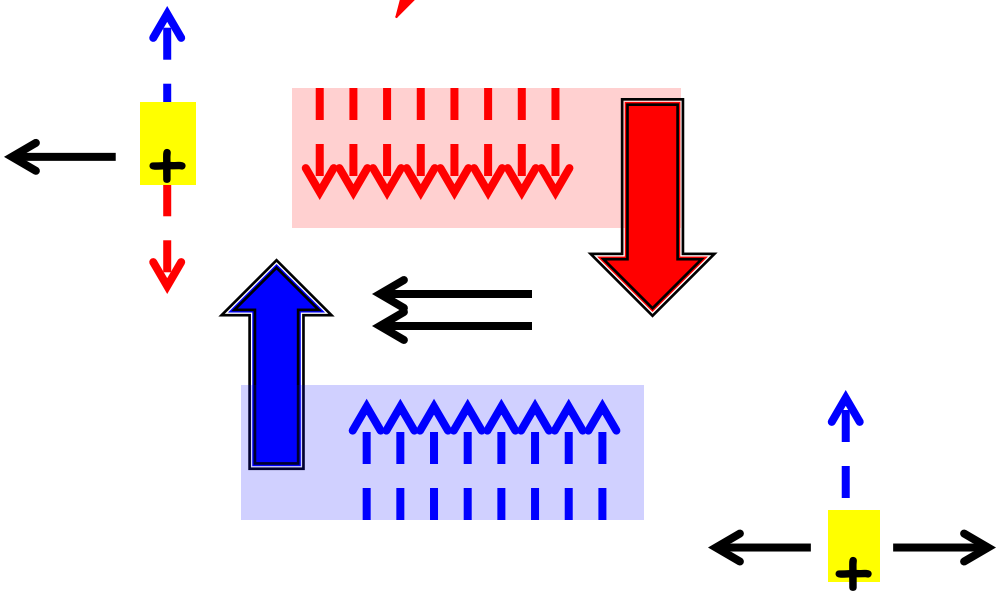




*Quantum Hall Effect* (1980)





## B. Quantum (Q) Model

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Similar to "Spin-flip Transistor"
Bauer et al. 2001

# FUNDAMENTALS OF NANOELECTRONICS

*Prerequisite: Calculus,*

*Elementary Differential Equations*

*Part B requires Matrix Algebra*

*Text:*

*Lessons From Nanoelectronics:*

*A New Perspective on Transport*

*World Scientific (2012)*

*II Edition 2015:*

*Manuscript will be available*

*to registered students*

*First offered on nanoHUB-U,*

*Spring 2012*

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