FUNDAMENTALS OF NANOELECTRONICS

Basic Concepts

The New Perspective

2. Energy Band Model

3. What and Where

   is the Voltage?

4. Heat & Electricity:

Second Law & Information

1.1. Introduction

1.2. Two Key Concepts

1.3. Why Electrons Flow

1.4. Conductance Formula

1.5. Ballistic(B) Conductance

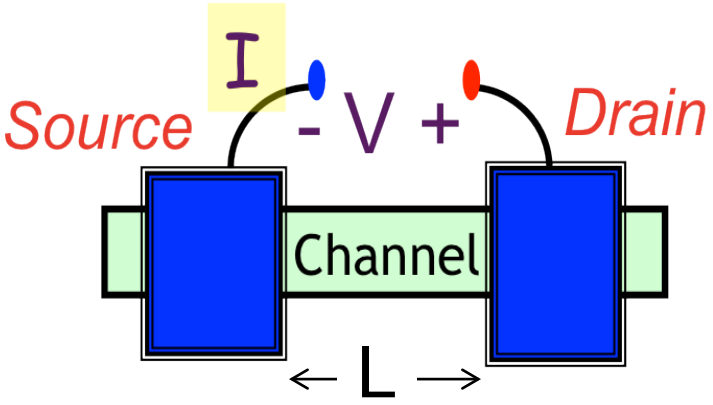
1.6. Diffusive(D) Conductance

1.7. Connecting B to D

1.8. Angular Averaging

1.9. Drude Formula

1.10. Summing up ..



τ : *mean free time*

m: effective mass

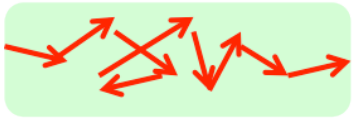
n: "free" electrons

Drude formula

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

0.1 mm

Diffusive



10 µm

1984 →

1 µ m

$$G \equiv \frac{1}{R} = \frac{\sigma A}{L} \leftarrow R \equiv \frac{V}{I}$$

$$\sigma A = G_B \lambda$$

0.1 µm

2014 →

Ballistic

10 nm

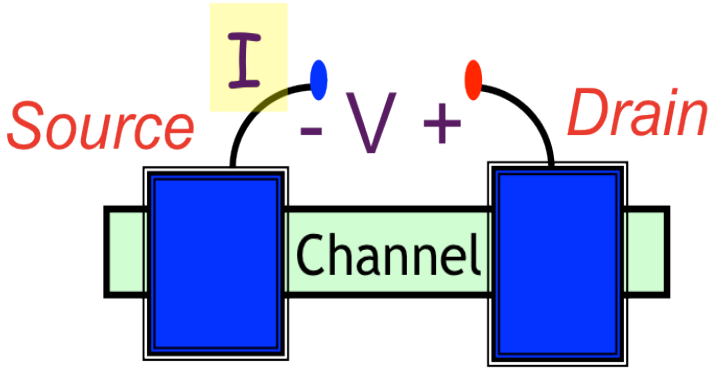
$$G = \underbrace{\frac{q^2}{h} M}_{G_B} \times \frac{\lambda}{L + \lambda}$$

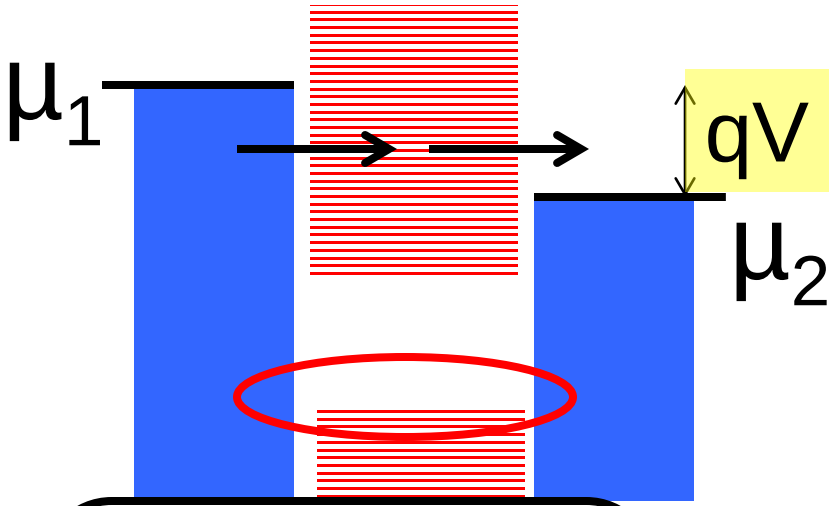
1 nm

Atoms →

0.1 nm

Mean free path





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

D: Density of states

t : transfer time

Drude formula

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

$$m\frac{dv_d}{dt} = qF - \frac{mv_d}{\tau}$$

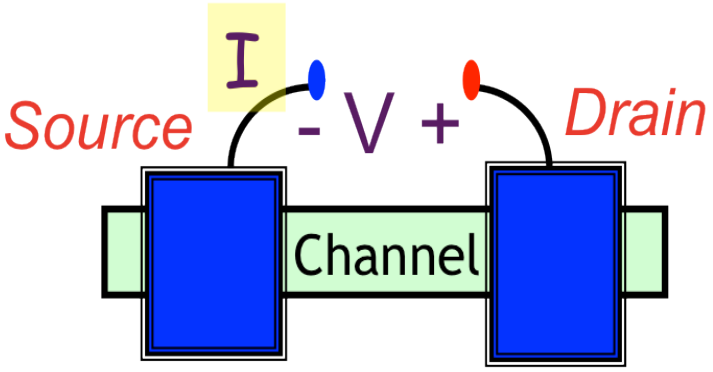
$$\rightarrow \quad v_d = \frac{q\tau}{m} F$$

mobility

$$I = Aqnv_d = A\frac{q^2 n\tau}{m} F$$

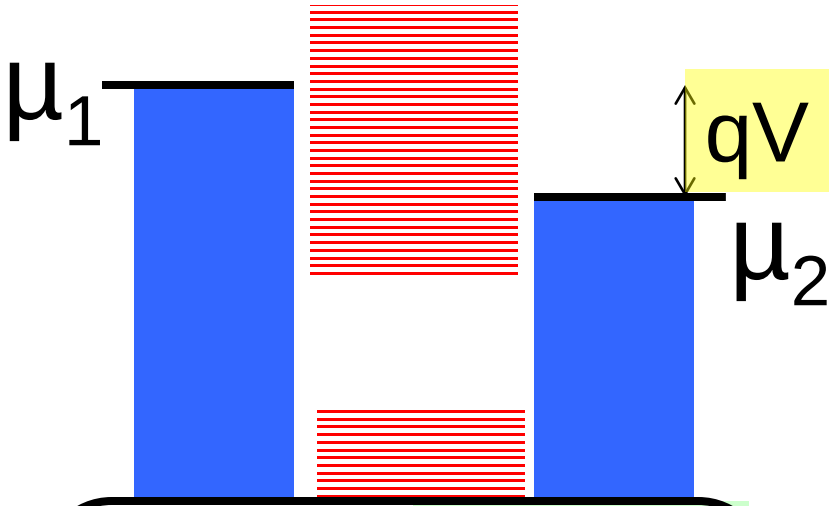
" Filled bands do not conduct "

n: "free" electrons



Drude formula

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



More general result usually obtained from advanced formalisms

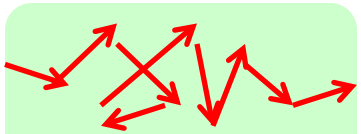
$$\sigma = q^2 \frac{D}{AL} \bar{D}$$

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

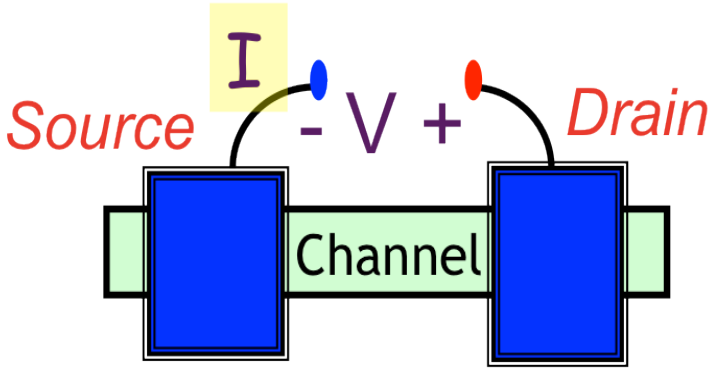
D: Density of states

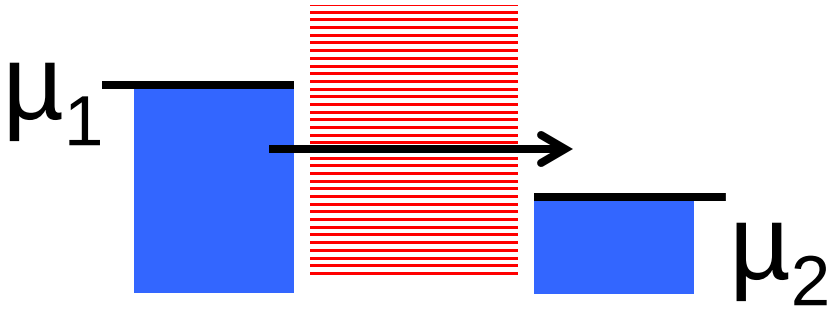
t : transfer time

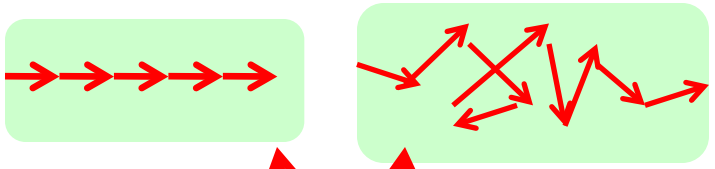
Diffusive



$$t = \frac{L^2}{2\bar{D}}$$



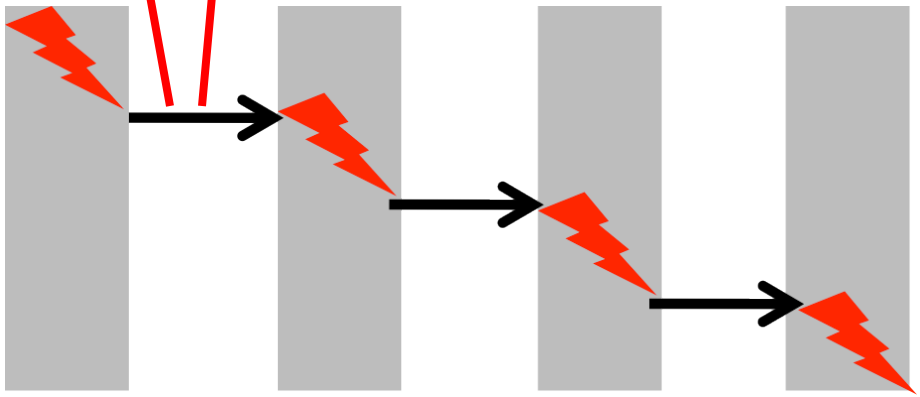




Elastic

NOT Ballistic

Long Resistors



Mechanics: Force driven

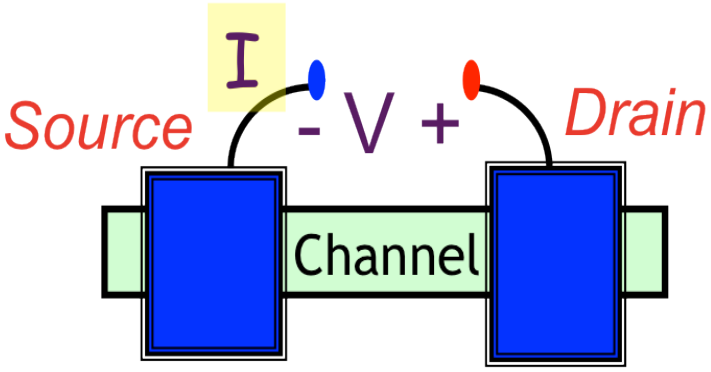
Thermodynamics: Entropy driven

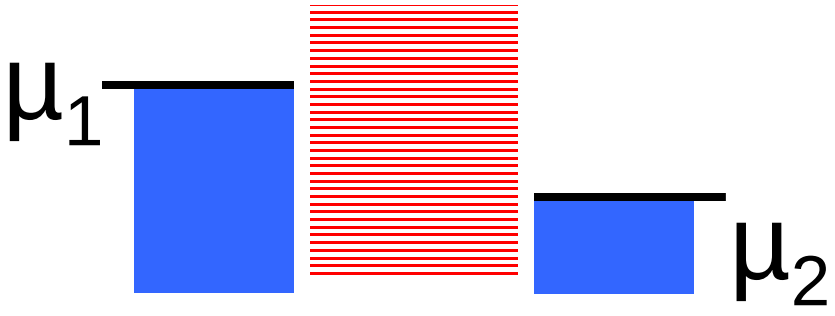
- *Results agree exactly with BTE for low bias*

BTE

Newton + ⚡ =

Elastic or Landauer Resistor





1. *Density of States*

2. *Fermi function* $f(E) = \dfrac{1}{1 + e^{(E-\mu)/kT}}$

Coming up next ..