

FUNDAMENTALS OF NANO ELECTRONICS

Basic Concepts

1. The New Perspective
2. Energy Band Model

3. What & Where is the “Voltage”?

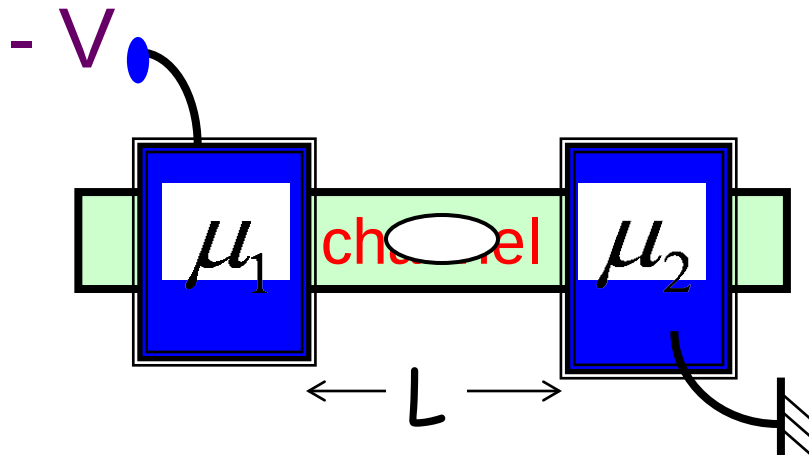


4. Heat & Electricity:
Second Law & Information

3.1. Introduction

- 3.2. A New Boundary Condition
- 3.3. Quasi-Fermi Levels (QFL's)
- 3.4. Current from QFL's
- 3.5. Landauer Formulas
- 3.6. What a Probe Measures
- 3.7. Electrostatic Potential
- 3.8. Boltzmann Equation
- 3.9. Spin voltages
- 3.10. Summing up ..

3.1a Introduction



Resistance is associated with

➤ ~~Joule Heating: I^2R~~

➤ Voltage drop: IR

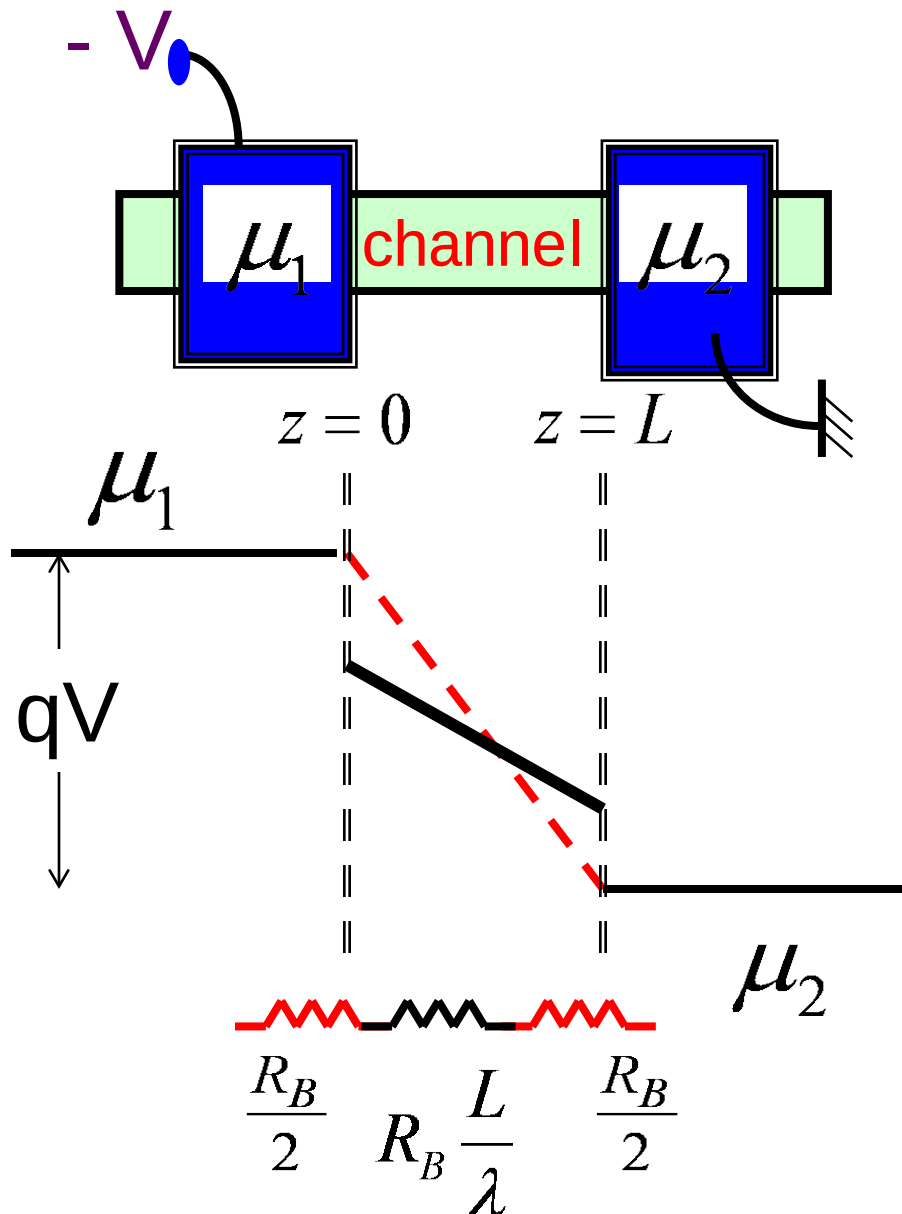
$$R_0 = \frac{1}{G_0} = R_B + R_B \frac{L}{\lambda}$$

$$I = G_0 V$$

$$G_0 = G_B \frac{\lambda}{L + \lambda}$$

$$R_B \equiv \frac{1}{G_B}$$

3.1b Introduction



Where is the voltage drop?

What is Voltage ?

Common answer

Electrostatic Potential

$\times J \sim \sigma_0 F \sim \frac{\sigma_0}{q} \frac{dU}{dz}$

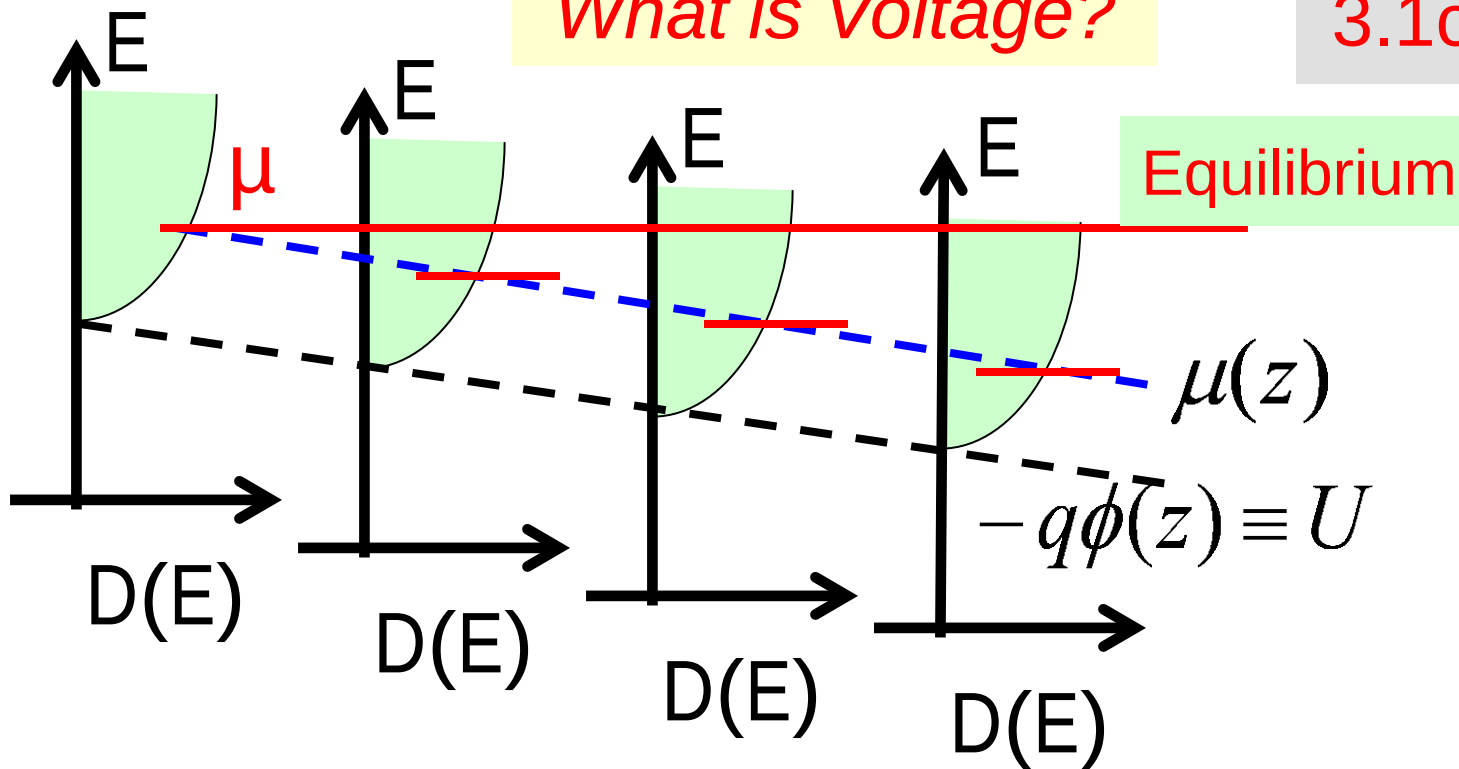
Correct answer

Electrochemical Potential

$$J \sim \frac{\sigma_0}{q} \frac{d\mu}{dz}$$

What is Voltage?

3.1c Introduction



Equilibrium

$\mu(z)$

$-q\phi(z) \equiv U$

μ is difficult to define under non-equilibrium conditions

$$-\frac{\sigma_0}{q} \frac{d}{dz} (\mu - U)$$

Electron Current

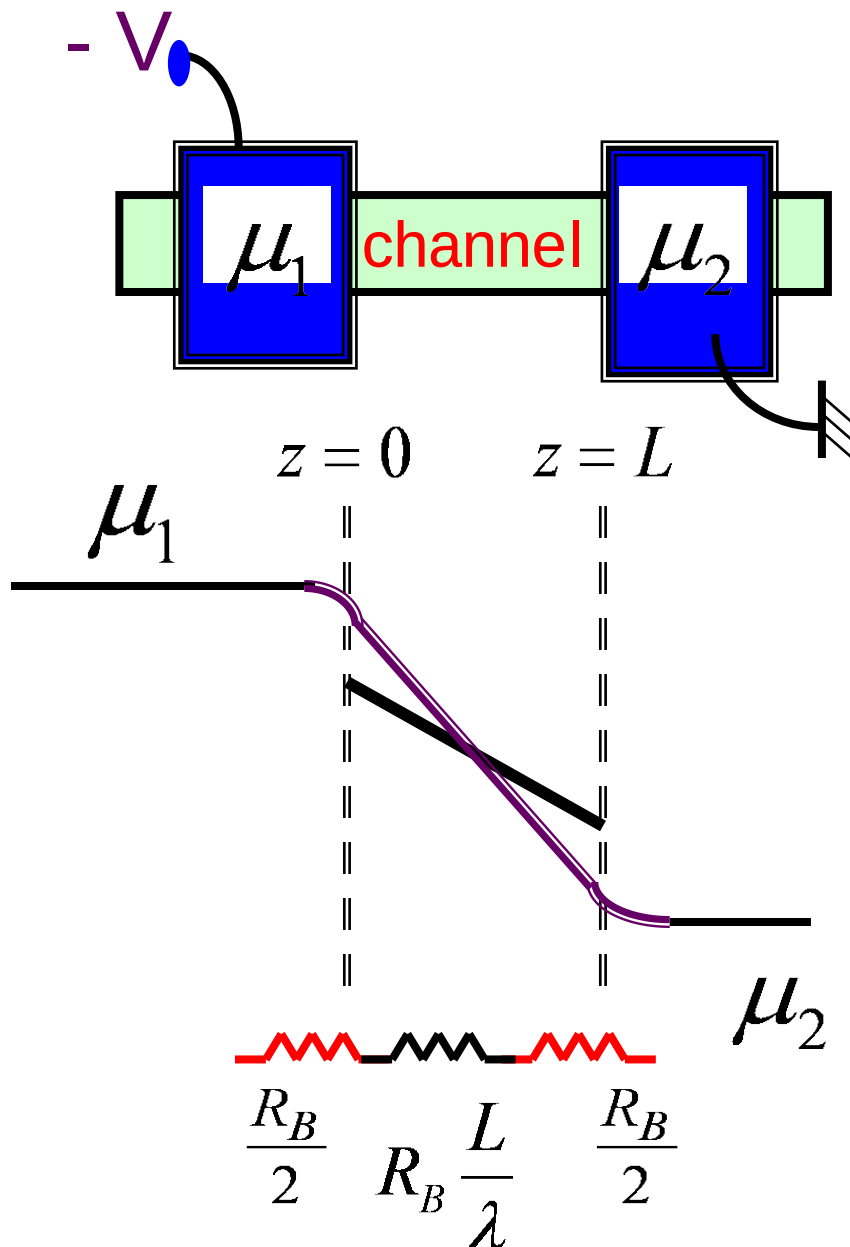
$$J = -\frac{\sigma_0}{q} \frac{dU}{dz} - q \frac{dn}{dz}$$

DRIFT

DIFFUSION

$$\rightarrow J = -\frac{\sigma_0}{q} \frac{d\mu}{dz}$$

3.1d Introduction



Electrostatic
Potential

Electrochemical
Potential

μ_1 ---

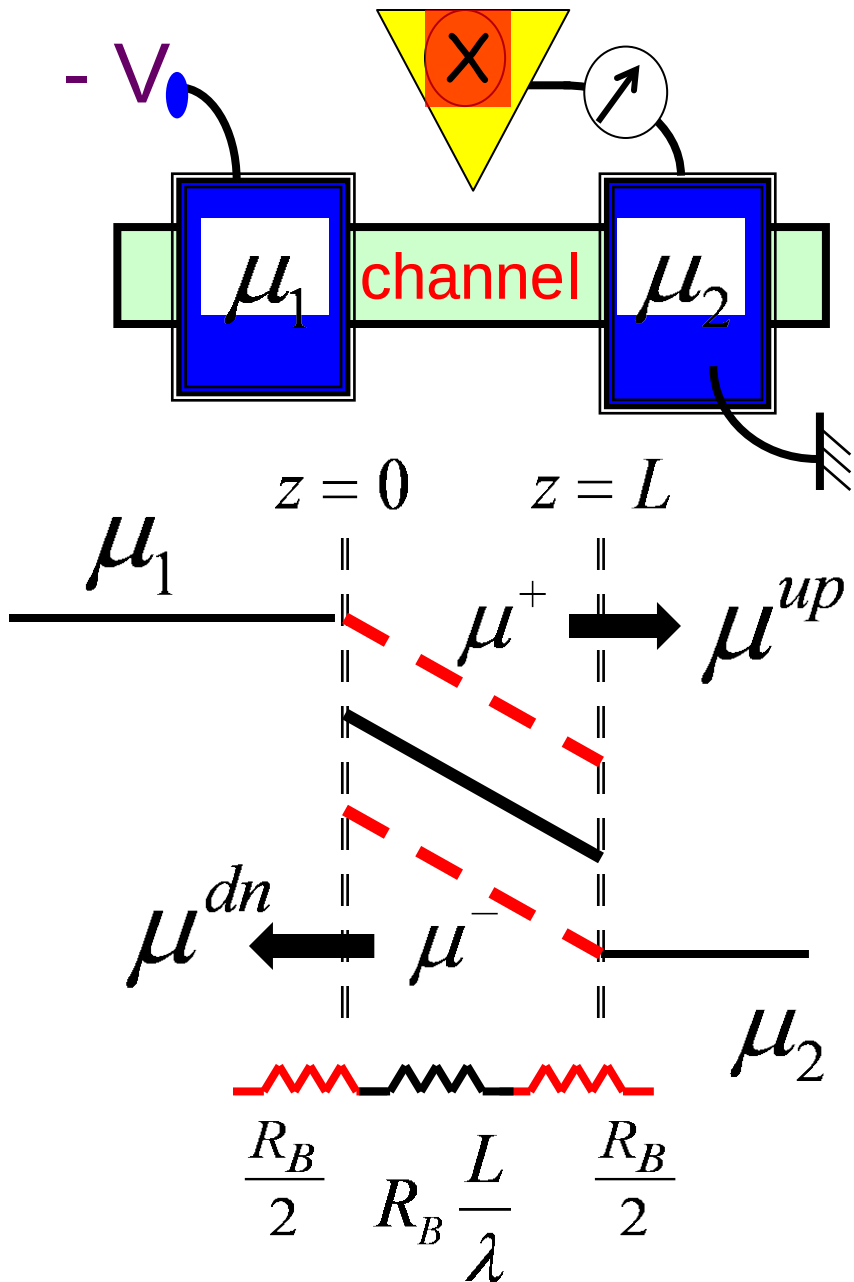
McLennan et al.
Phys. Rev. B43,
13846 (1991)
*NEGF-based
Calculation*

--- μ_2

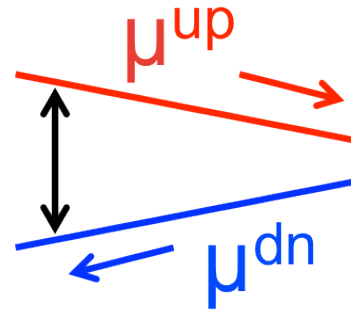
μ is difficult
to define under
non-equilibrium
conditions

*Boltzmann
Equation*

$$J = - \frac{\sigma_0}{q} \frac{d\mu}{dz}$$



Spin Potential



Topological Insulators

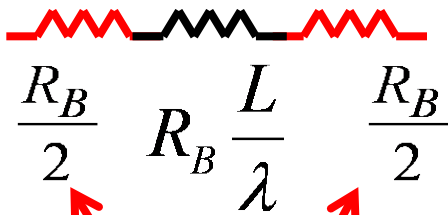
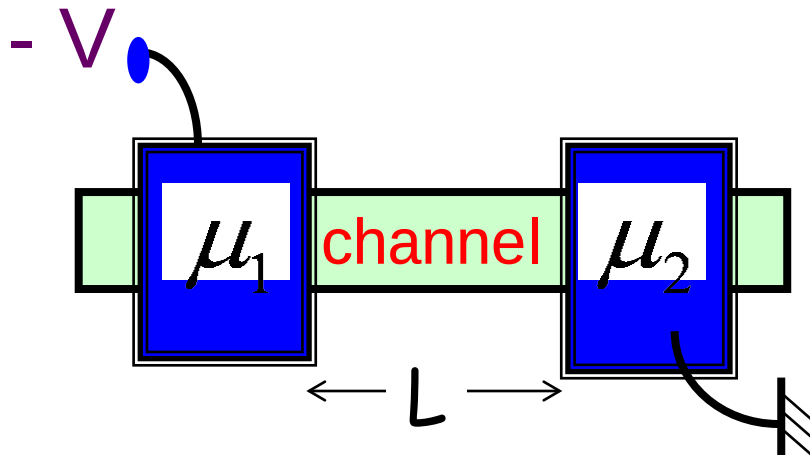
Spin-momentum locking

Quasi-Fermi Levels (QFL's)

Boltzmann Equation

$$J = - \frac{\sigma_0}{q} \frac{d\mu}{dz}$$

Coming up next ..



$$R_0 = \frac{1}{G_0} = R_B + R_B \frac{L}{\lambda}$$

Red arrows point from the R_B terms in the equation to the corresponding resistors in the circuit diagram above.

3.1. Introduction

3.2. A New Boundary Condition

3.3. Quasi-Fermi Levels (QFL's)

3.4. Current from QFL's

3.5. Landauer Formulas

3.6. What a Probe Measures

3.7. Electrostatic Potential

3.8. Boltzmann Equation

3.9. Spin voltages

3.10. Summing up ..