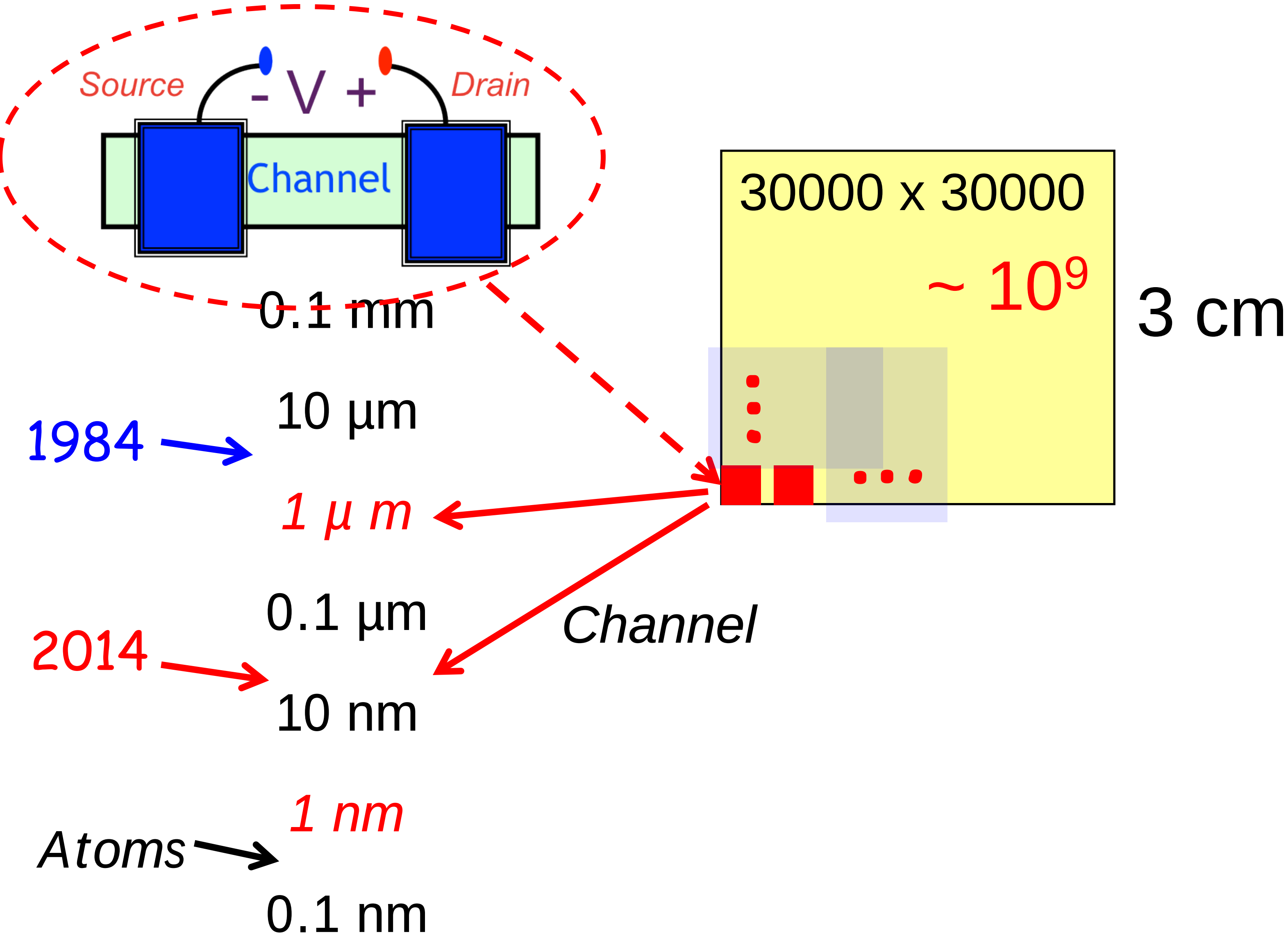
FUNDAMENTALS OF NANOELECTRONICS

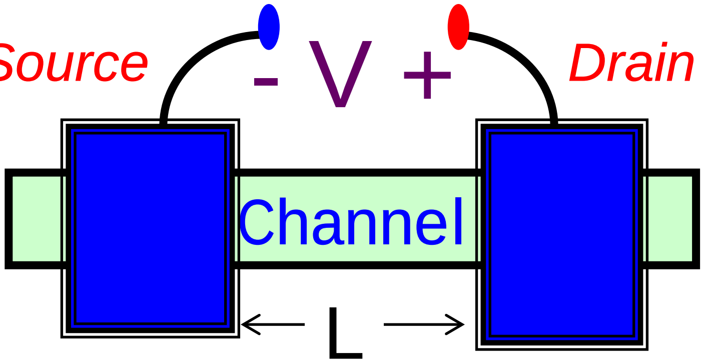


Supriyo Datta

Spring 2015

http://nanohub.org/groups/lnebook

New Perspective on Transport



Drude formula: $\dfrac{m}{nq^2\tau}$

$$\frac{V}{I} \equiv R = \frac{\rho}{A} L$$

0.1 mm

1984 → 10 µm

1 µ m

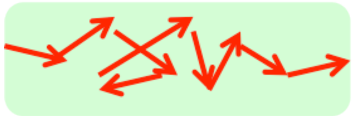
2014 → 0.1 µm

10 nm

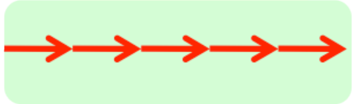
1 nm

Atoms → 0.1 nm

Diffusive



Ballistic



Clear

$$R = \overbrace{\frac{h}{q^2}\frac{1}{M}}^{R_B}\left(1 + \frac{L}{\lambda}\right)$$

$$\frac{h}{q^2} \approx 25\ K\Omega$$

q: Electronic charge (magnitude)

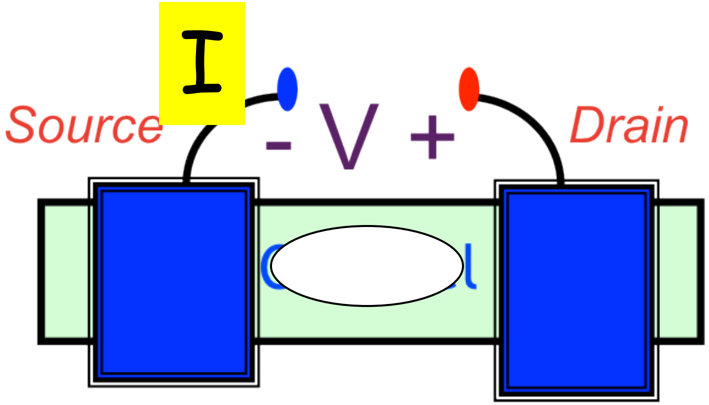
h: Planck's constant

λ : *Mean free path*

M: Number of "modes"

Where is the Resistance?

1. The new perspective
2. Energy band model



$$\frac{R_B}{2} \qquad R_B\frac{L}{\lambda} \qquad \frac{R_B}{2}$$

$$R_B + R_B\frac{L}{\lambda}$$

$$R = R_B\left(1+\frac{L}{\lambda}\right)$$

Resistance is associated with

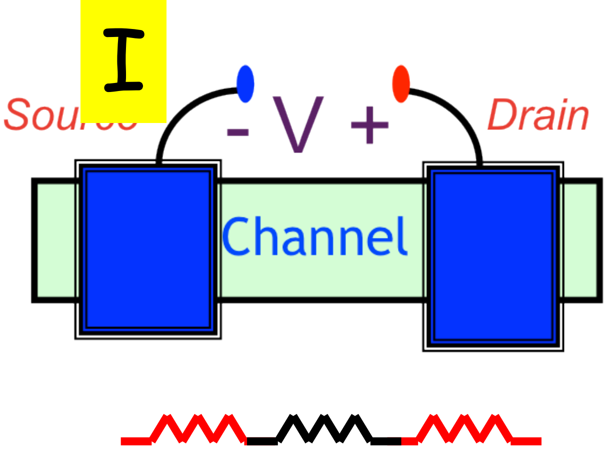
- ~~Joule Heating: I^2R~~
- Voltage drop: IR

M: Number of "modes"

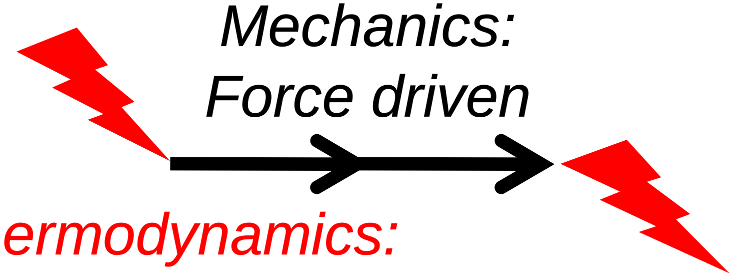
$$R_B = \frac{h}{q^2}\frac{1}{M}$$

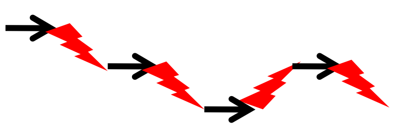
"Elastic Resistor"

1. The new perspective
2. Energy band model
3. What and where is the voltage?

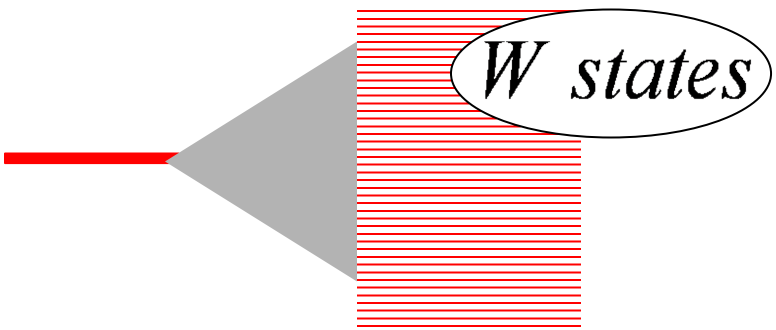


$$\frac{R_B}{2} \qquad R_B\frac{L}{\lambda} \qquad \frac{R_B}{2}$$





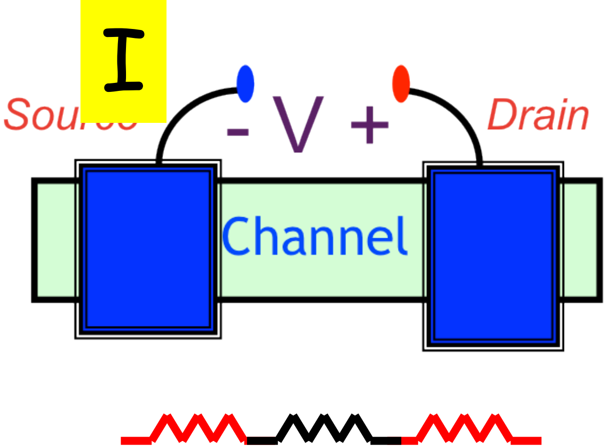
Usually all mixed up !!



$$S = k \ln W$$

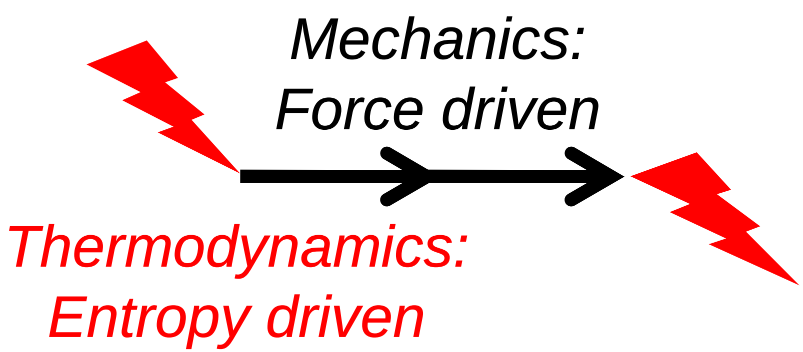
Landauer's Principle

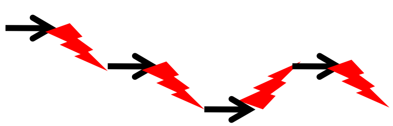
Longer Resistors



$$\frac{R_B}{2} \qquad R_B\frac{L}{\lambda} \qquad \frac{R_B}{2}$$

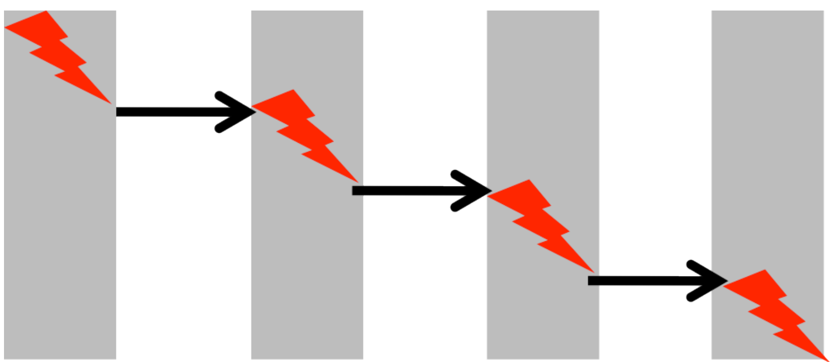
- Provides approximate physical picture in general
- Agrees with rigorous theory for low bias





Usually all mixed up !!

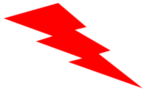
Long Resistors

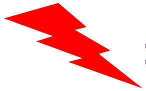


Rigorous theory

"Elastic Resistor"

Part A:
Semiclassical Transport

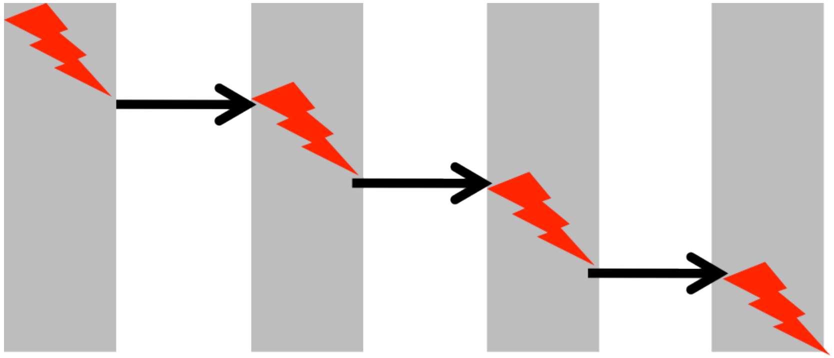
Newton +  = 

Schrodinger +  = NEGF

Part B:
Quantum Transport

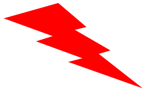
- *Provides approximate physical picture in general*
- *Agrees with rigorous theory for low bias*

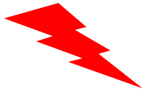
Long Resistors



Why Approximate Pictures

A: Semiclassical

Newton +  = 

Schrodinger +  =

B: Quantum NEGF

From Feynman Lectures, 2-1

" .. people.. say there is nothing which is not contained in the equations .. if I understand them mathematically, I will understand the physics ..

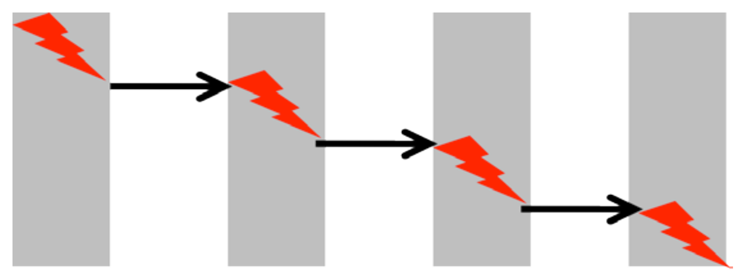
Only it doesn't work that way.

A physical understanding is completely unmathematical, imprecise and inexact .. but absolutely necessary for a physicist. "

Usual Physical Picture

$$J = \sigma F \rightarrow \sigma = \frac{nq^2\tau}{m}$$

A Different Physical Picture



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FUNDAMENTALS OF NANOELECTRONICS

Prerequisite: Calculus,

Elementary Differential Equations

Part B requires Matrix Algebra

First offered on nanoHUB-U,

Spring 2012

Text:

Lessons From Nanoelectronics:

A New Perspective on

Transport

World Scientific (2012)

II Edition 2015:

Manuscript will be available

to registered students

A. Basic Concepts:

Semiclassical Model

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

   Second law & information

From Semi-classical To Quantum

B. Quantum Model

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

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