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

\[ G = \frac{q^2 D}{2 t} \]

D: Density of states

Supriyo Datta

Spring 2015

http://nanohub.org/groups/inebook
The New Perspective

$\mu_1$ $\rightarrow$ $qV$ $\rightarrow$ $\mu_2$

$M$: Number of "modes"

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

Drude Formula

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

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

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

Supriyo Datta  

Spring 2015  

http://nanohub.org/groups/lnebook
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: $IR$

\[
R = R_B \left( 1 + \frac{L}{\lambda} \right) \quad G = \frac{G_B}{1 + \frac{L}{\lambda}}
\]
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)

Supriyo Datta  
Spring 2015  
http://nanohub.org/groups/Lnebook
1. The new perspective
2. Energy band model
3. What and where is the voltage?
4. Heat & electricity:
   Second law & information

Mechanics:
Force driven

Thermodynamics:
Entropy driven

\[ I \sim G(E) \times (f_1(E) - f_2(E)) \]

\[ S = k \ln W \]

“Elastic Resistor”

Supriyo Datta

Spring 2015

http://nanohub.org/groups/lnbook
Rigorous theory

Part A: Semiclassical Transport

Newton + Schrödinger = $E\psi = H\psi$

Part B: Quantum Transport

Provides approximate physical picture in general

Agrees with rigorous theory for low bias

“Elastic Resistor”

Long Resistors

Supriyo Datta

Spring 2015

http://nanohub.org/groups/inbebook
An Example

**NEGF**

Non–Equilibrium Green's Function

Supriyo Datta  
Spring 2015  
http://nanohub.org/groups/Inebook
Quantized conductance

$G_B \uparrow$

Sharvin Resistance

$G_B \uparrow$

Experiments 1988-present

Quantum Hall Effect (1980)

$R_{xy} \uparrow$

NEGF

Semiclassical

B-field (T) --->

Supriyo Datta

Spring 2015

http://nanohub.org/groups/Lnebook
Spin Transport

1. Schrödinger Equation
2. Contacting Schrödinger
3. NEGF Method
4. Spin Transport

B. Quantum (Q) Model

Similar to “Spin-flip Transistor”
Bauer et al. 2001

Supriyo Datta
Spring 2015

http://nanohub.org/groups/lnebook
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

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

B. Quantum (Q) Model
   1. Schrodinger Equation
   2. Contact-ing Schrodinger
   3. NEGF Method
   4. Spin Transport