

FUNDAMENTALS OF NANOELECTRONICS

B. Quantum Transport

1. Schrodinger Equation

Contact-ing Schrodinger →

3. Advanced Examples

4. Spin Transport

2.1. Introduction

2.2. Semiclassical Model

2.3. Quantum Model

2.4. NEGF Equations

2.5. Current Operator

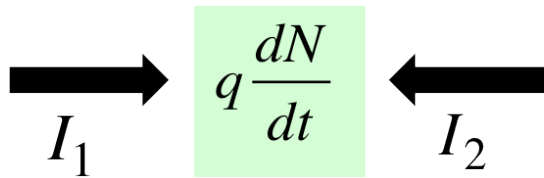
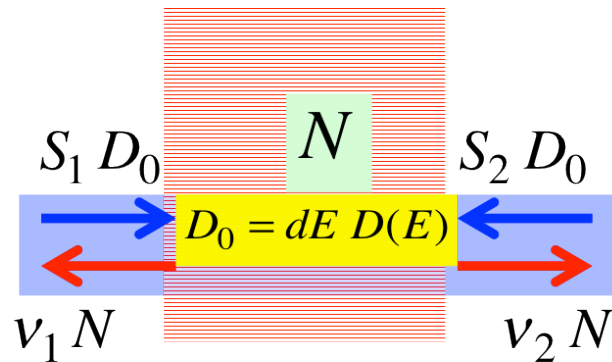
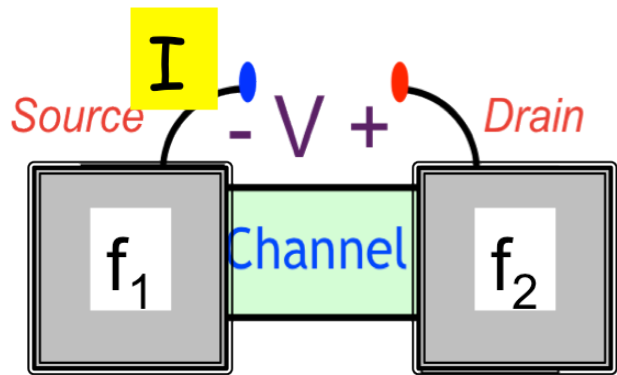
2.6. Scattering Theory

2.7. Transmission

2.8. Resonant Tunneling

2.9. Dephasing

2.10. Summing up ..



$$\frac{dN}{dt} = -(\nu_1 + \nu_2) N + (S_1 + S_2) D_0$$

Outflow

Inflow

2.3a Quantum Model

$$i\hbar \frac{d}{dt} \{\tilde{\psi}\} = [H] \{\tilde{\psi}\} \quad \{\tilde{\psi}\} = \{\psi\} e^{-iEt/\hbar}$$

$$i\hbar \times -\frac{iE}{\hbar} = E$$

$$E\{\psi\} = [H]\{\psi\}$$

$$+ [\Sigma_1 + \Sigma_2] \{\psi\} \quad \text{Outflow}$$

$$+ \{s_1\} \quad \text{Inflow}$$

$$s_1 + \Sigma_1 \psi + H\psi + \Sigma_2 \psi = \text{From boundary conditions}$$

$$i\hbar \frac{d}{dt} \tilde{\psi}^+ \tilde{\psi} = \tilde{\psi}^+ (\Sigma - \Sigma^+) \tilde{\psi}$$

$$-\tilde{s}^+ \tilde{\psi} + \tilde{\psi}^+ \tilde{s}$$

$$\left(i\hbar \frac{d}{dt} \tilde{\psi}^+ \right) \tilde{\psi} + \tilde{\psi}^+ \left(i\hbar \frac{d}{dt} \tilde{\psi} \right)$$

$$= - (H\tilde{\psi})^+ \tilde{\psi} + \tilde{\psi}^+ (H\tilde{\psi})$$

$$= -\tilde{\psi}^+ H^+ \tilde{\psi} + \tilde{\psi}^+ H \tilde{\psi}$$

$$= \tilde{\psi}^+ (H - H^+) \tilde{\psi}$$

2.3b Quantum Model

$$i\hbar \frac{d}{dt} \{ \tilde{\psi} \} = [H] \{ \tilde{\psi} \}$$

$$+ [\Sigma_1 + \Sigma_2] \{ \tilde{\psi} \}$$

Outflow

Σ

$$+ \{ \tilde{s} \}$$

Inflow

$$N = \tilde{\psi}^+ \tilde{\psi}$$

$$\{ \tilde{\psi} \} =$$

$$= \psi^+ \psi$$

$$\{ \psi \} e^{-iEt/\hbar}$$

$$s_1 + \Sigma_1 \psi + H\psi + \Sigma_2 \psi$$

$$i\hbar \frac{d}{dt} \tilde{\psi}^+ \tilde{\psi} = \tilde{\psi}^+ (\Sigma - \Sigma^+) \tilde{\psi} + (\tilde{\psi}^+ \tilde{s} - \tilde{s}^+ \tilde{\psi})$$

$$\frac{1}{q}(I_1 + I_2) \quad \xrightarrow{I_1} \quad q \frac{dN}{dt} \quad \xleftarrow{I_2}$$

$$\frac{dN}{dt} = -\tilde{\psi}^+ \frac{\Gamma_1 + \Gamma_2}{\hbar} \tilde{\psi} \quad \text{Outflow}$$

$$+ \frac{\tilde{\psi}^+ \tilde{s} - \tilde{s}^+ \tilde{\psi}}{i\hbar} \quad \text{Inflow}$$

$$\frac{dN}{dt} = -(\nu_1 + \nu_2) N \quad \text{Outflow}$$

$$+ (S_1 + S_2) D_0 \quad \text{Inflow}$$

2.3c Quantum Model

$$i\hbar \frac{d}{dt} \{\tilde{\psi}\} = [H] \{\tilde{\psi}\}$$

$$+ [\Sigma_1 + \Sigma_2] \{\tilde{\psi}\} \quad \text{Outflow}$$

$$\Sigma + \{\tilde{s}\} \quad \text{Inflow}$$

$$\Gamma \equiv i(\Sigma - \Sigma^+)$$

$$\Sigma = \Sigma_1 + \Sigma_2$$

$$N = \tilde{\psi}^+ \tilde{\psi}$$

$$= \psi^+ \psi$$

$$\{\tilde{\psi}\} =$$

$$\{\psi\} e^{-iEt/\hbar}$$

$$s_1 + \Sigma_1 \psi + H\psi + \Sigma_2 \psi = E\psi$$

$$\frac{I_1 + I_2}{q} = -\psi^+ \frac{\Gamma_1 + \Gamma_2}{\hbar} \psi \quad \text{Outflow}$$

$$+ \frac{\psi^+ s_1 - s_1^+ \psi}{i\hbar} \quad \text{Inflow}$$

$$\frac{s_1^+ G^A s_1 - s_1^+ G^R s_1}{i\hbar}$$

$$A = i[G^R - G^A]$$

$$s_1^+ \frac{A}{\hbar} s_1$$

$$\frac{dN}{dt} = -(\nu_1 + \nu_2) N \quad \text{Outflow}$$

$$+ (S_1 + S_2) D_0 \quad \text{Inflow}$$

2.3d Quantum Model

$$E\psi = (H + \Sigma)\psi + s_1$$

$$[EI - H - \Sigma]\psi = s_1$$

$$\psi = [G^R] \{s_1\},$$

$$G^R = [EI - H - \Sigma]^{-1}$$

$$\psi^+ = s_1^+ G^A, \quad G^A = [G^R]^+$$

$$\Gamma \equiv i(\Sigma - \Sigma^+)$$

$$\Sigma = \Sigma_1 + \Sigma_2$$

$$E\psi = s_1 + \Sigma_1 \psi + H\psi + \Sigma_2 \psi$$

2.3e Quantum Model

$$\frac{I_1 + I_2}{q} = -\psi^\dagger \frac{\Gamma_1}{\hbar} \psi - \psi^\dagger \frac{\Gamma_2}{\hbar} \psi + s_1^\dagger \frac{A}{\hbar} s_1 + s_2^\dagger \frac{A}{\hbar} s_2$$

$\frac{I_1}{q} \longrightarrow \longleftarrow \frac{I_2}{q}$

Outflow

Inflow

$$E\psi = (H + \Sigma)\psi + s_1$$

$$G^R = [EI - H - \Sigma]^{-1}$$

$$G^A = [G^R]^\dagger$$

$$A = i[G^R - G^A]$$

$$\Gamma \equiv i(\Sigma - \Sigma^\dagger)$$

$$\Sigma = \Sigma_1 + \Sigma_2$$

$$E\psi = s_1 + \Sigma_1\psi + H\psi + \Sigma_2\psi + s_2$$

$$I_1 + I_2 = -\nu_1 N - \nu_2 N$$

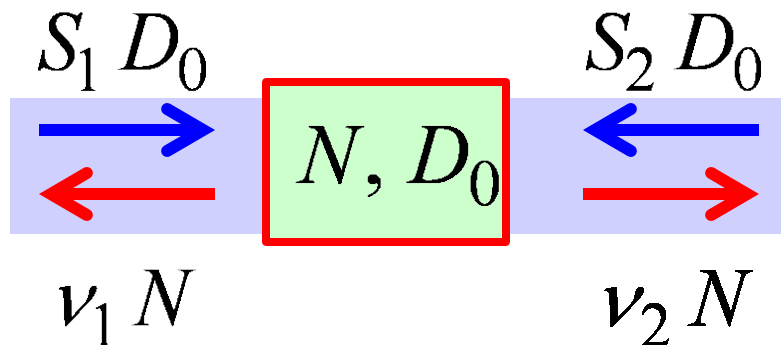
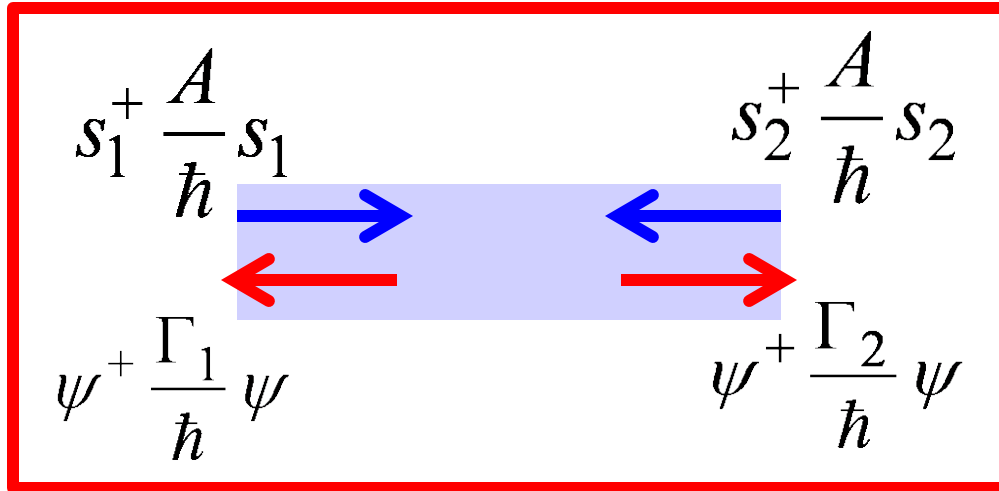
Outflow

Inflow

$$+ S_1 D_0 + S_2 D_0$$

Coming up next ..

$$E\psi = s_1 + \Sigma_1 \psi + H\psi + \Sigma_2 \psi + s_2$$



- 2.1. Introduction
- 2.2. Semiclassical Model
- 2.3. Quantum Model
- 2.4. NEGF Equations**
- 2.5. Current Operator
- 2.6. Scattering Theory
- 2.7. Transmission
- 2.8. Resonant Tunneling
- 2.9. Dephasing
- 2.10. Summing up ..