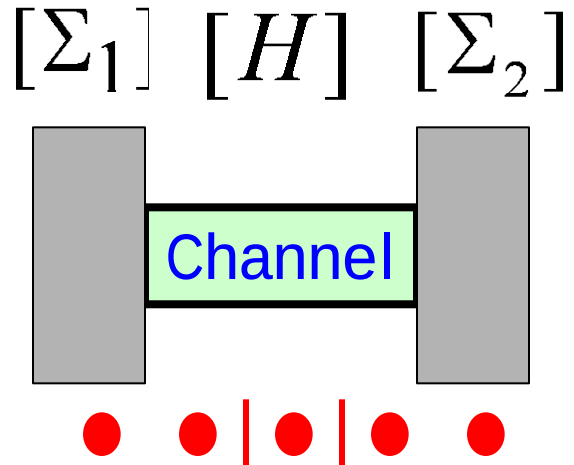
B. Quantum Transport

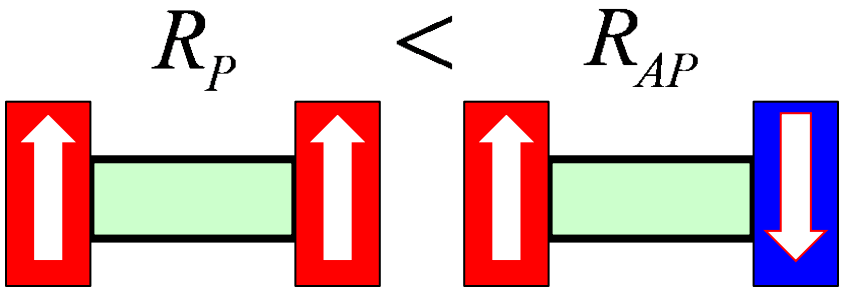
1. Schrodinger Equation
2. Contact-ing Schrodinger
3. More Examples

4. Spin Transport →

- 4.1. Introduction
- 4.2. Magnetic contacts
- 4.3. Rotating contacts
- 4.4. Vectors and spinors
- 4.5. Spin-orbit coupling
- 4.6. Spin Hamiltonian
- 4.7. Spin density/current
- 4.8. Spin voltage
- 4.9. Spin circuits
- 4.10. Summing up ..

4.2a Magnetic contacts





$$\Sigma_1 = -\frac{i}{2}[\gamma_1] \qquad H = [\varepsilon] \qquad \Sigma_2 = -\frac{i}{2}[\gamma_2]$$

$$\Gamma_1 = [\gamma_1] \qquad \Gamma_2 = [\gamma_2]$$

$$\Gamma = i[\Sigma - \Sigma^+]$$

$$G^R = [EI - H - \Sigma_1 - \Sigma_2]^{-1}$$

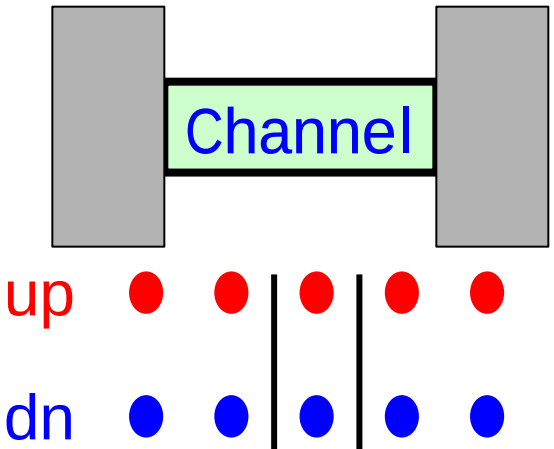
$$\bar{T}(E) = Trace[\Gamma_1 G^R \Gamma_2 G^A]$$

$$G^R = \left[E - \varepsilon + \frac{i}{2}(\gamma_1 + \gamma_2)\right]^{-1}$$

$$\rightarrow G^A = \left[E - \varepsilon - \frac{i}{2}(\gamma_1 + \gamma_2)\right]^{-1}$$

$$= \frac{\gamma_1 \gamma_2}{(E-\varepsilon)^2 + \left(\frac{\gamma_1 + \gamma_2}{2}\right)^2} \times 2$$

4.2b Magnetic contacts



$$\Gamma = i[\Sigma - \Sigma^+]$$

$$G^R = [EI - H - \Sigma_1 - \Sigma_2]^{-1}$$

$$\bar{T}(E) = Trace[\Gamma_1 G^R \Gamma_2 G^A]$$

$$\Sigma_1 = -\frac{i}{2}\begin{bmatrix}\gamma_{1u} & 0\\ 0 & \gamma_{1d}\end{bmatrix} \qquad H = \begin{bmatrix}\varepsilon & 0\\ 0 & \varepsilon\end{bmatrix} \qquad \Sigma_2 = -\frac{i}{2}\begin{bmatrix}\gamma_{2u} & 0\\ 0 & \gamma_{2d}\end{bmatrix}$$

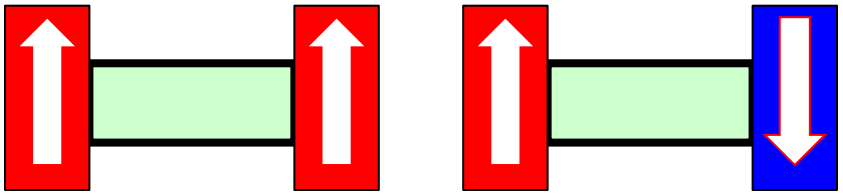
$$\Gamma_1 = \begin{bmatrix}\gamma_{1u} & 0\\ 0 & \gamma_{1d}\end{bmatrix} \qquad \Gamma_2 = \begin{bmatrix}\gamma_{2u} & 0\\ 0 & \gamma_{2d}\end{bmatrix}$$

$$= \frac{\gamma_{1u}\gamma_{2u}}{(E-\varepsilon)^2 + \left(\frac{\gamma_{1u}+\gamma_{2u}}{2}\right)^2} + \frac{\gamma_{1d}\gamma_{2d}}{(E-\varepsilon)^2 + \left(\frac{\gamma_{1d}+\gamma_{2d}}{2}\right)^2}$$

1 Level

$$\frac{\gamma_1\gamma_2}{(E-\varepsilon)^2 + \left(\frac{\gamma_1+\gamma_2}{2}\right)^2}$$

4.2c Magnetic contacts



α — α $\quad$ α — β

β — β $\quad$ β — α

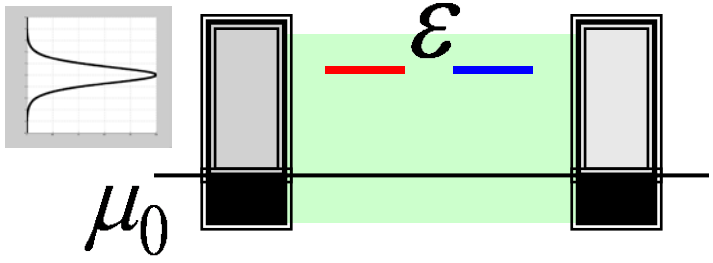
$$\Gamma = i\left[\Sigma - \Sigma^{+}\right]$$

$$G^{R} = \left[EI - H - \Sigma_1 - \Sigma_2\right]^{-1}$$

$$\bar{T}(E) = Trace\left[\Gamma_1 G^{R} \Gamma_2 G^{A}\right]$$

$$= \frac{\gamma_{1u}\gamma_{2u}}{(E-\varepsilon)^2 + \left(\frac{\gamma_{1u}+\gamma_{2u}}{2}\right)^2} + \frac{\gamma_{1d}\gamma_{2d}}{(E-\varepsilon)^2 + \left(\frac{\gamma_{1d}+\gamma_{2d}}{2}\right)^2}$$

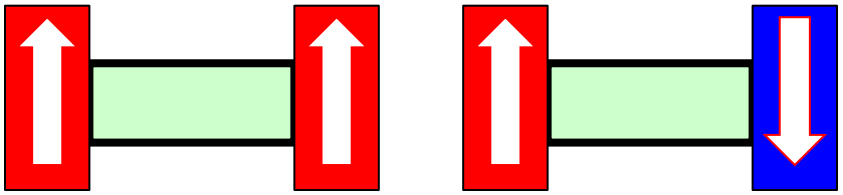
$$T_P \approx \frac{\alpha^2+\beta^2}{(\mu_0-\varepsilon)^2} \qquad T_{AP} \approx \frac{2\alpha\beta}{(\mu_0-\varepsilon)^2}$$



$$\approx \frac{\gamma_{1u}\gamma_{2u} + \gamma_{1d}\gamma_{2d}}{(\mu_0-\varepsilon)^2}$$

4.2d Magnetic contacts

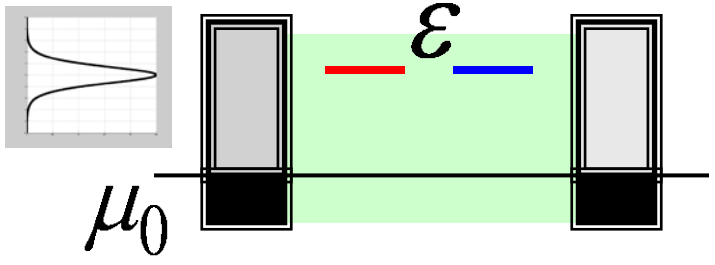
$$R_P < R_{AP}$$



α — α $\quad$ α — β

β — β $\quad$ β — α

$$T_P \approx \frac{\alpha^2+\beta^2}{(\mu_0-\varepsilon)^2} \qquad T_{AP} \approx \frac{2\alpha\beta}{(\mu_0-\varepsilon)^2}$$



$$TMR = \frac{R_{AP}}{R_P} - 1 = \frac{T_P}{T_{AP}} - 1$$

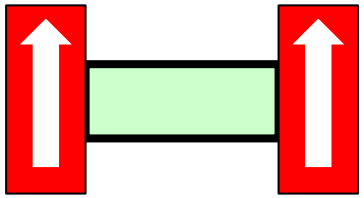
$$= \frac{\alpha^2+\beta^2}{2\alpha\beta} - 1$$

$$= 2\,\frac{(\alpha-\beta)^2}{(\alpha+\beta)^2-(\alpha-\beta)^2}$$

$$= \frac{2P^2}{1-P^2} \quad , \quad P \equiv \frac{\alpha-\beta}{\alpha+\beta}$$

Coming up next ..

$$\Gamma_1 = \begin{bmatrix} \alpha & 0 \\ 0 & \beta \end{bmatrix} \qquad \Gamma_2 = \begin{bmatrix} \alpha & 0 \\ 0 & \beta \end{bmatrix}$$



$$H = \begin{bmatrix} \varepsilon & 0 \\ 0 & \varepsilon \end{bmatrix}$$

$$\Gamma_1 = \begin{bmatrix} \alpha & 0 \\ 0 & \beta \end{bmatrix} \qquad \Gamma_2 = \begin{bmatrix} \beta & 0 \\ 0 & \alpha \end{bmatrix}$$