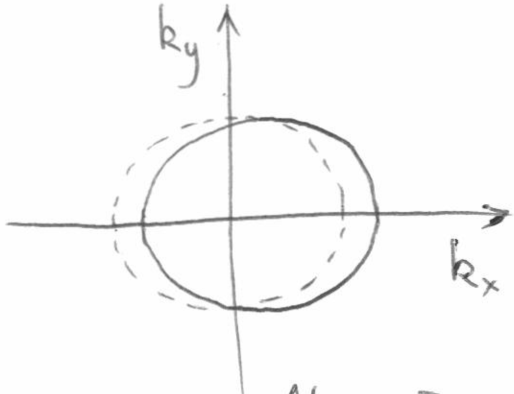
DIFFUSIVE TRANSPORT



$$\Delta k = \frac{eE_0\tau}{\hbar}$$

Depends on strength of the $\vec{E}$-field.

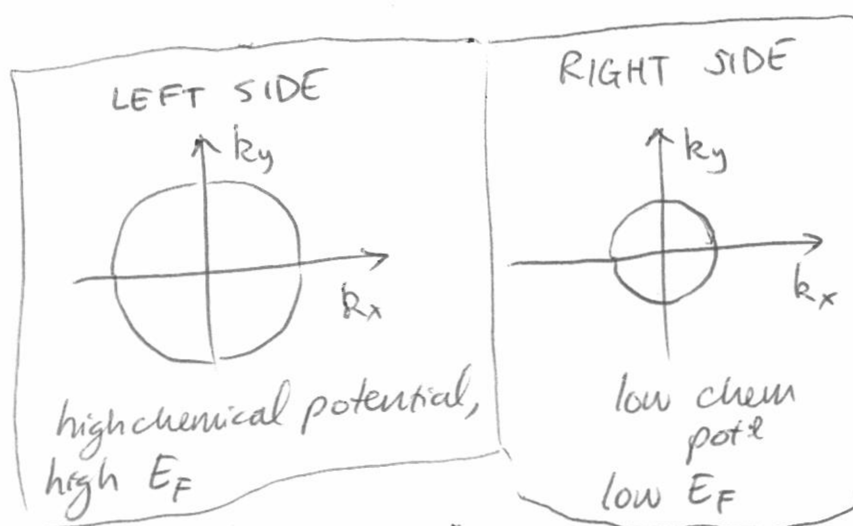
Electrons near the Fermi surface are constantly scattering ~~between~~ to different states.

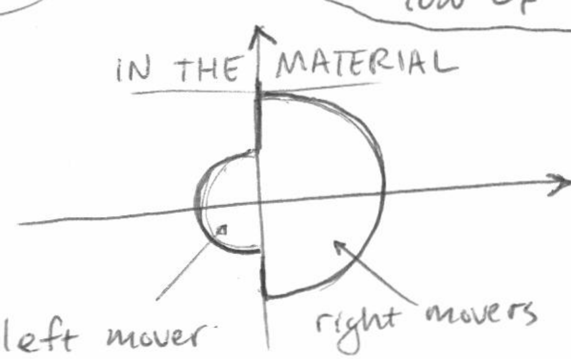
BALLISTIC TRANSPORT

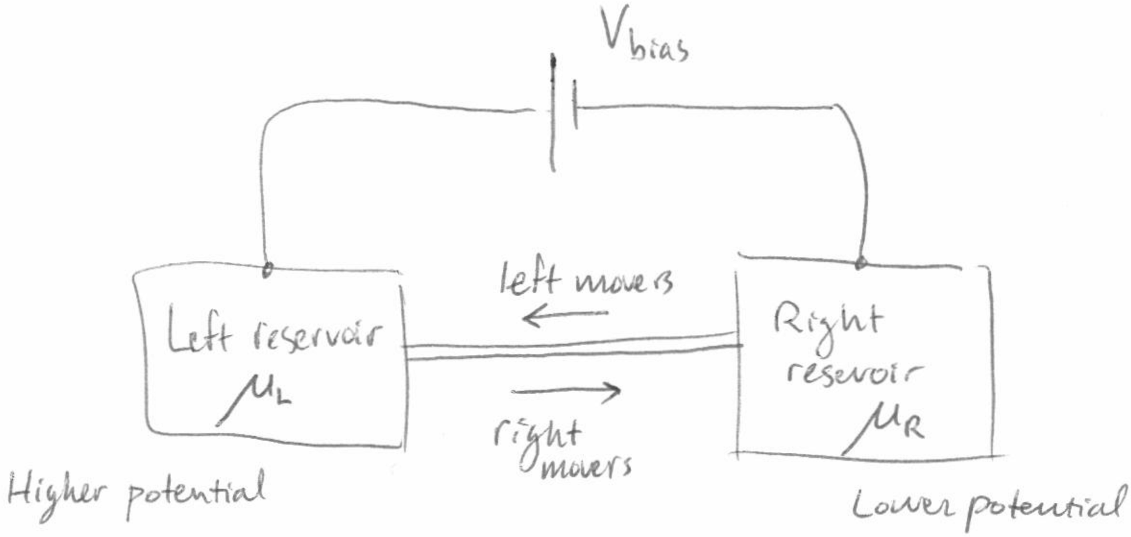
= No scattering (& no relaxation)

$\tau \longrightarrow \infty$

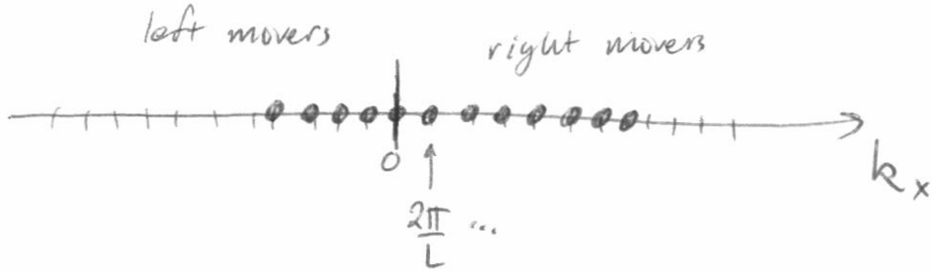
If a bias is applied to the material, the occupation function is now governed by the chemical potential on the left & right sides

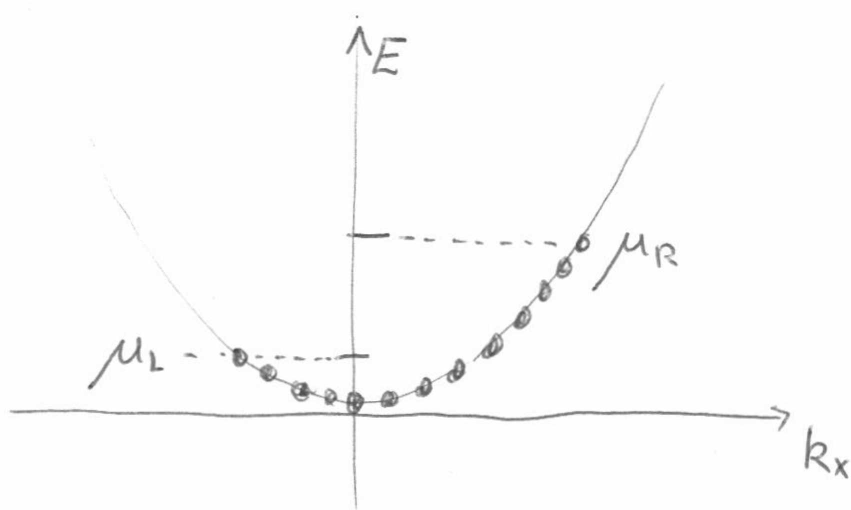




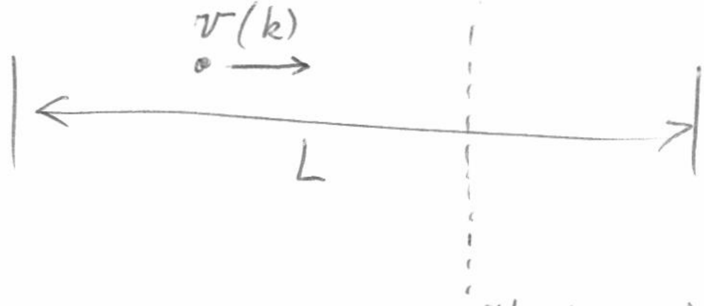


~~EXERCISE~~ Occupation of states in the CNT





Now calculate the current



will the electron cross the line?

Probability per unit time is $\frac{v}{L}$.

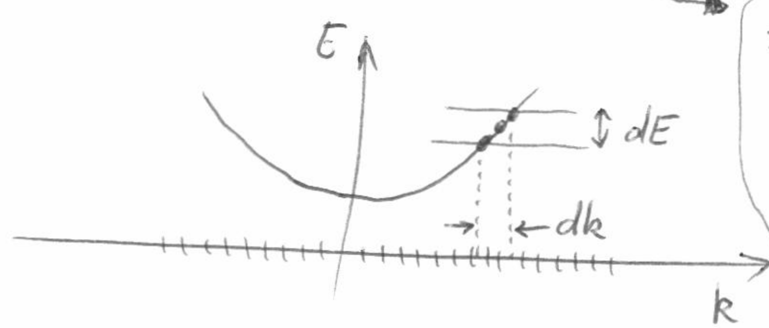
$$I = \sum_{\text{all states}} e\,\frac{v(k)}{L} \qquad \text{[charge per time]}$$

Convert this into an energy integral (for more convenient calculation)

Only consider the imbalanced charge motion:

$$I = \int_{\mu_L}^{\mu_R} \frac{e v}{L}\, \mathrm{DOS}(E)\, dE$$

$$= \int_{\mu_L}^{\mu_L + eV} \frac{e v}{L}\, \underbrace{2 \frac{L}{2\pi} \left(\frac{dE}{dk}\right)^{-1} dE}$$



\# of states

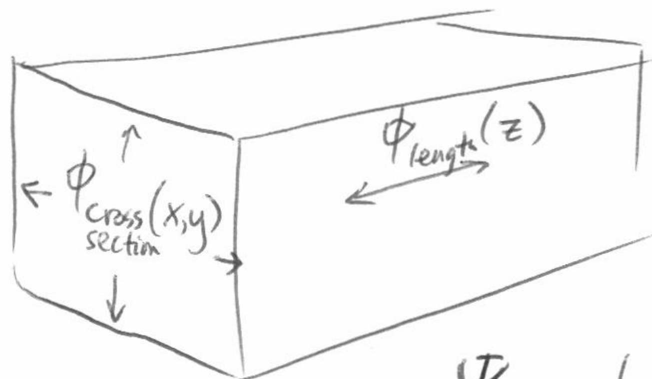
$$= 2 \cdot dk \Big/ \frac{2\pi}{L}$$

$$= 2 \cdot \frac{dE}{\text{slope}} \Big/ \frac{2\pi}{L}$$

$$= 2 \cdot \frac{L}{2\pi} \left(\frac{dE}{dk}\right)^{-1} dE$$

I chose the CNT example because CNTs are 1d...
Easy to analyze the # of states and their velocities.

To analyze a bigger material



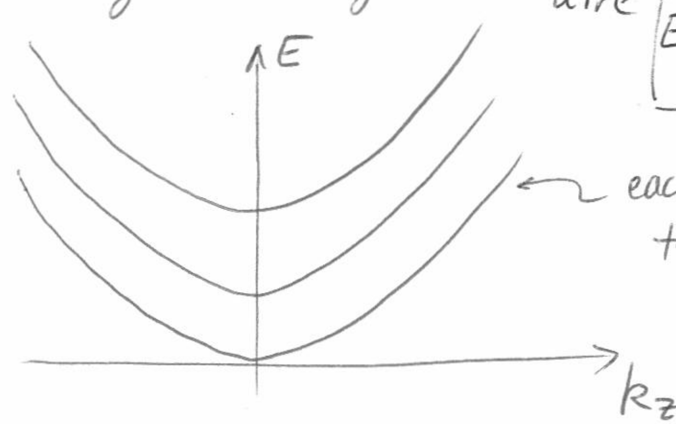
$$\Psi = \phi_{\substack{cross\\section}} \cdot \phi_{length}$$

[wavefn is seperable]

Each cross-sectional wavestate gives use a 1d channel along the length.

For free e^-s in a rectangular wire

$$\boxed{E = \frac{\hbar^2 k^2}{2m} = \frac{\hbar^2}{2m}\left(\frac{\pi^2 n_x^2}{L_x^2} + \frac{\pi^2 n_y^2}{L_y^2} + k_z^2\right)}$$



each curve corresponds to a different 1d channel, (or multiple channels if degeneracies exist).

If N channels are occupied, the ballistic conductance is $G = \frac{2e^2}{h} N$

Example of an exam question:

Show that the # of occupied cross-sectional wavestates in a metal is

$\approx$ # of atoms in the cross section.

CNTs have a pair of 1d channels, $N = 2$

$$G = \frac{4e^2}{h} \qquad \left(R = \frac{h}{4e^2} = 6.5\,k\Omega \right)$$

A macroscopic wire (1mm x 1mm)

$$\text{has} \quad N \sim \frac{(10^{-3})^2}{(3\times 10^{-10})^2} = 10^{13}$$

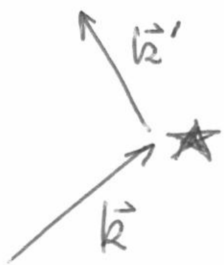
$$R_{ballistic} \approx \frac{10^4\,\Omega}{10^{13}} = 10^{-9}\,\Omega$$

ADD SCATTERING TO THE BALLISTIC SYSTEM

(Interesting regime where only 1 or 2 scattering events).

Our approach will depend on the type of scattering

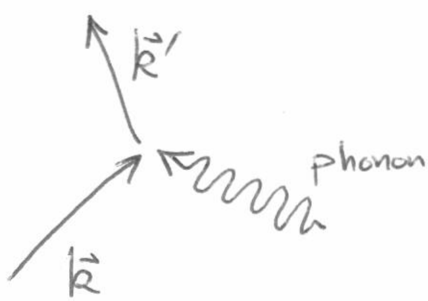
a) Elastic:



$$E(\vec{k}') = E(\vec{k})$$

Caused by a crystal defect like a missing atom or an impurity atom

b) Inelastic



$$E(\vec{k}') \neq E(\vec{k})$$

During elastic scattering, the phase of the wavefn is preserved.

During inelastic scattering, phase information is destroyed.