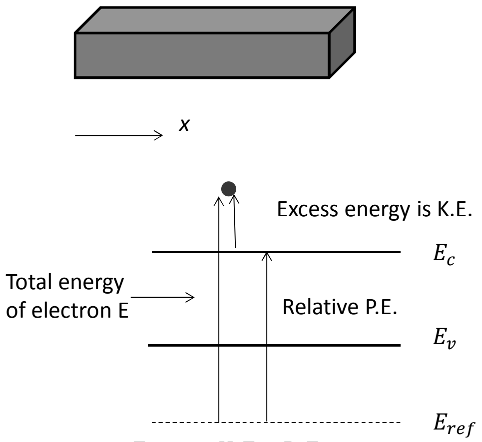
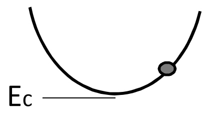
Band Diagrams



$\mathrm{E_{total}} = \mathrm{K.E.} + \mathrm{P.E.}$

$\mathrm{P.E.} = \mathrm{E_c} - \mathrm{E_{ref}}$

For conduction electrons



$E - E_c = \dfrac{p^2}{2m^*}$

Kinetic Energy

Band diagram tells us a lot of information!

Band Diagram Cont'd

For conduction electron

$\boxed{\text{P.E.} = -qV}$ **V, electrostatic potential**

$\boxed{V = \text{P.E.}/(-q) = (E_C - E_{ref})/(-q)}$

$\boxed{\mathcal{E} = -\nabla V}$

In 1D $$\mathcal{E} = -\frac{dV}{dx} = \frac{1}{q}\frac{dE_C}{dx} = \frac{1}{q}\frac{dE_V}{dx} = \frac{1}{q}\frac{dE_i}{dx}$$

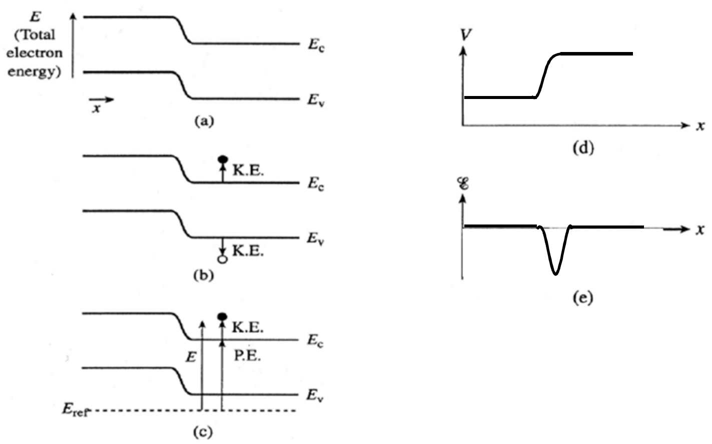
E_C, E_V, E_i differ only by a constant, and are always parallel with each other in the band diagram

Band Bending

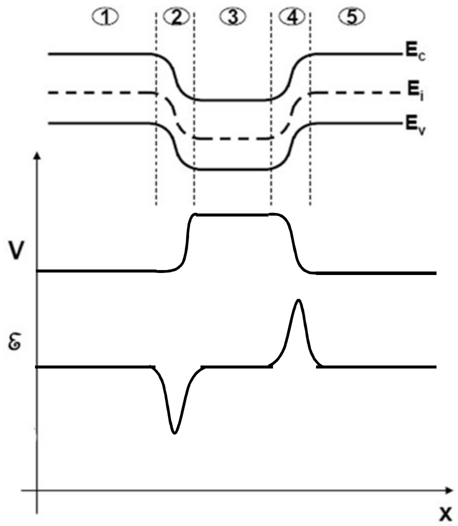
$V = P.E./(-q) = (E_C - E_{ref})/(-q)$

$\mathcal{E} = -\nabla V$

If there is electric field inside the material....

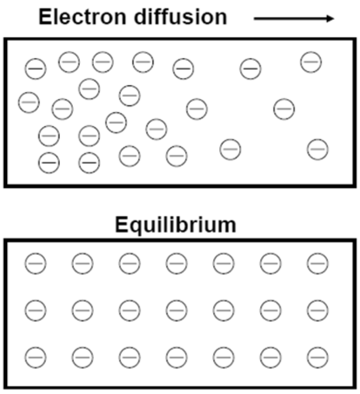


Example

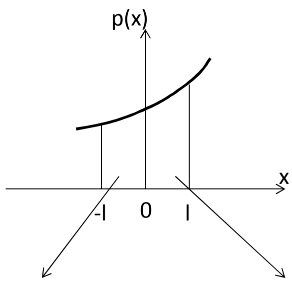


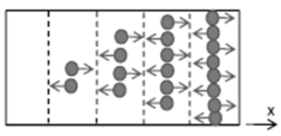
Diffusion

Carriers flow from higher to lower concentration



Fick's Law





$$J = \left[\frac{ql}{2}\left(\frac{p(0)+p(0)-\frac{dp}{dx}l}{2}\right) - \frac{ql}{2}\left(\frac{p(0)+p(0)+\frac{dp}{dx}l}{2}\right)\right] / \frac{l}{v_{th}}$$

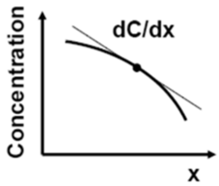
$$= -q\frac{lv_{th}}{2}\frac{dp}{dx} = -qD\frac{dp}{dx}$$

Diffusion Current

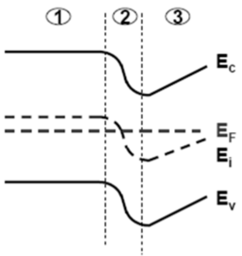
Diffusion process described by

· Fick's law: flux given by $F=-D\nabla\eta$
· Diffusion constant, D
· Diffusion process dependent on material properties

Diffusion current given by diffusion constant and concentration gradient



Example



$$n = n_i e^{(E_F - E_i)/k_B T}$$

$$p = n_i e^{(E_i - E_F)/k_B T}$$

Based on the band diagram above, fill in the blank with “<”, “>”, “+”:

Region 1:	$J_{D,n}$ ____ 0	$J_{D,p}$ ____ 0
Region 2:	$J_{D,n}$ ____ 0	$J_{D,p}$ ____ 0
Region 3:	$J_{D,n}$ ____ 0	$J_{D,p}$ ____ 0

Einstein Relationship

At equilibrium, $J_n = 0$ and $J_p = 0$, and $\boxed{\frac{dE_f}{dx} = 0 \text{ at equilibrium}}$

$$J_n = q\mu_n n\mathcal{E} + qD_n \frac{dn}{dx} = 0 \qquad n = n_i \exp\left(\frac{E_f - E_i}{kT}\right)$$

$$q\mu_n n_i \exp\left(\frac{E_f - E_i}{kT}\right)\frac{1}{q}\frac{dE_i}{dx} = -\frac{q}{kT} D_n n_i \exp\left(\frac{E_f - E_i}{kT}\right)\left(\frac{dE_f}{dx} - \frac{dE_i}{dx}\right)$$

Constants for diffusion and drift related (can calculate diffusion constants from μ)

$$\boxed{\frac{D_n}{\mu_n} = \frac{kT}{q}} \qquad \boxed{\frac{D_p}{\mu_p} = \frac{kT}{q}}$$

Summary

Total current in a semiconductor:

$$\boxed{\begin{aligned} J_N &= J_{N|drift} + J_{N|diff} = qn\mu_n\mathcal{E} + qD_N \frac{dn}{dx} \\ J_P &= J_{P|drift} + J_{P|diff} = qn\mu_p\mathcal{E} - qD_p \frac{dp}{dx} \end{aligned}}$$

$$\boxed{J = J_N + J_P}$$