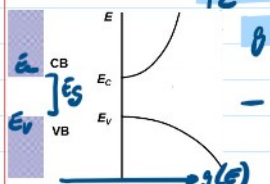
Density of states, Fermi Levels

Thursday, November 5, 2020 6:15 PM

Density of States

- How many states @ what Energies $g(E)$

$$g_c(E) = \frac{m_e^{*3/2}}{\pi^2 \hbar^3}\sqrt{2(E-E_c)}$$
↳ CB edge

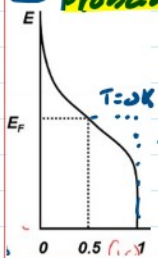


$$g_v(E) = \frac{4\pi(2m_h^*)^{3/2}}{h^3}\sqrt{(E_v-E)}$$

- $g(E) \rightarrow$ tells if states exist & if full.

Fermi Dirac

- Probability e^- fills given state

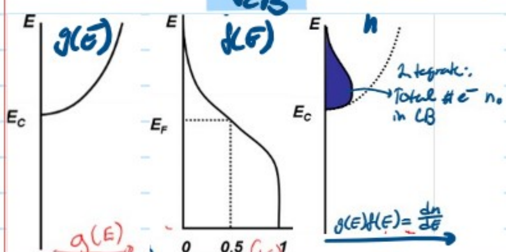


$$f(E) = \frac{1}{1+\exp\left(\frac{(E-E_F)}{kT}\right)}$$
→ E_F = Fermi level
k = Boltzmann const
T = Temp (K)

- 1 = low energy (fully occupied)
0 = high energy

Counting e^-

- $\# e^-$ $n = \int_{CB}^{Top\,CB} g_c(E) f(E)\, dE$



$\# e^-$/Volume: $\frac{dn}{dE} = f(E)g(E)$

- when $E-E_F \gg kT$:

Boltzmann Distribution $f(E) \sim \exp[-(E-E_F)/kT]$

If $kT \ll (E_c - E_F)$ $\quad f(E) \sim \exp[-(E-E_F)/kT]$

$$n_0 = \int_{E_C}^{Top} \frac{4\pi(2m_e^*)^{3/2}}{h^3}(E-E_C)^{1/2}\exp[-(E-E_F)/kT]\,dE$$

$$N_c = 2\left(\frac{2\pi m_e^* kT}{h^2}\right)^{3/2}$$

↳ if $E_c - E_F \gg kT$ → N_c = CB effective density of states

$$n_0 = N_c \exp\left(\frac{-(E_c-E_F)}{kT}\right) = (N_D^+ - N_A^-)$$

Counting Holes

$$p_0 = \int_{Bottom\,VB}^{E_v} g_v(E)(1-f(E))\,dE$$ → occurs when no e^- in VB

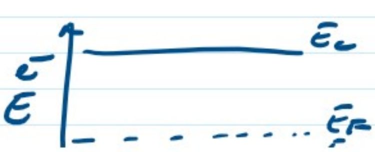
$$N_v = 2\left(\frac{m_h^* kT}{2\pi\hbar^2}\right)^{3/2}$$

$$p_0 = N_v \exp\left(-\frac{(E_F-E_v)}{kT}\right) = \frac{n_i^2}{n_0}$$

Doping & Fermi level

- n-doping = ↑ Fermi level, n_0 ↑ & p_0 ↓

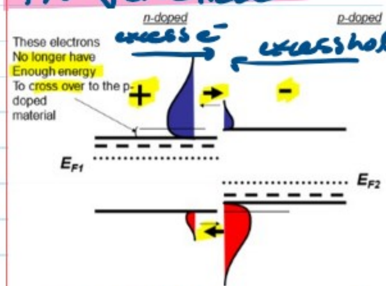
- p-doping = ↓ Fermi level ...

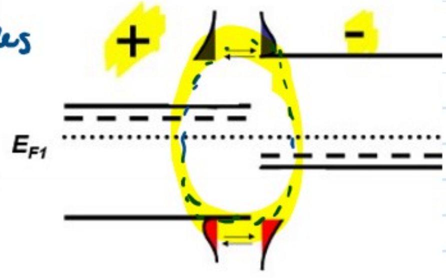


- n-doping = ↑ Fermi level, n_o ↑ as p_o ↓
- p-doping = ↓ Fermi level, p_o ↑ as n_o ↓
- Fermi level = midpoint b/w CB & VB + factor

$$E_F = \frac{E_v + E_c}{2} + \frac{kT}{2}\ln\left(\frac{N_v}{N_c}\right) = \frac{E_v + E_c}{2} + \frac{3kT}{4}\ln\left(\frac{m_h^*}{m_e^*}\right)$$
$$= \frac{E_g}{2} + \frac{3}{4}kT\ln\left(\frac{m_h^*}{m_e^*}\right)$$

PN Junction

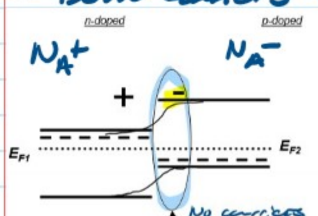


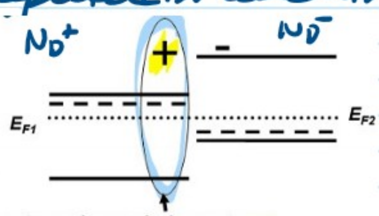


- equilibrium reached when $E_{F1} = E_{F2}$

Depletion Region

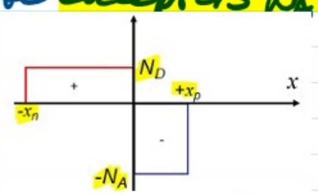
- e^- enter, holes leave
- e^- recombine w/ holes
- Both carriers depleted in concentration



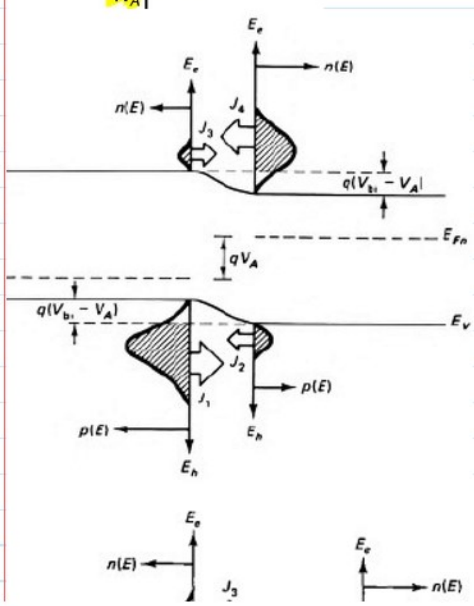


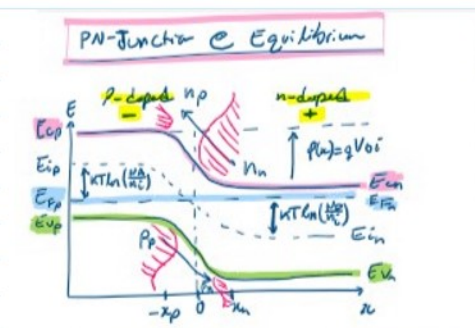
net (-) charge due to acceptors N_A^-

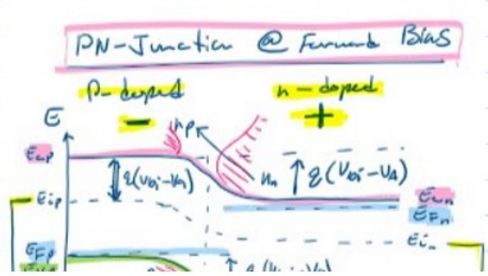
net (+) charge due to donors N_D^+

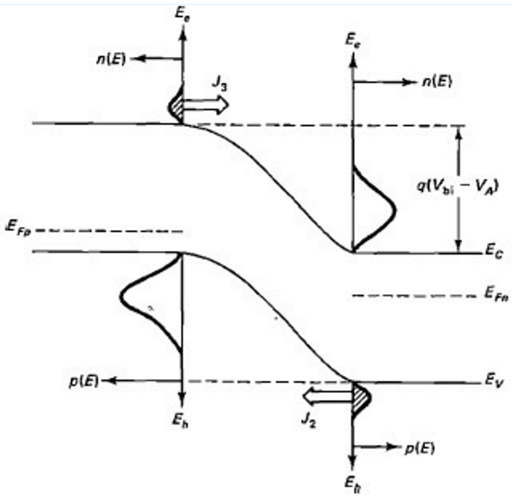


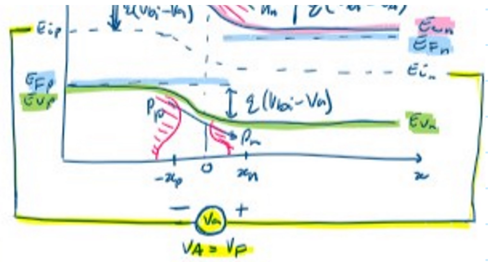
- PE of e^- in depletion region $U(x)$ due to $V(x)$:
  $U(x) = V(x)q$











PN-Junction @ Reverse Bias