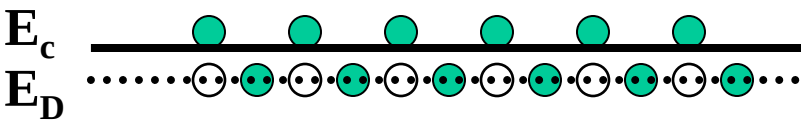
Lecture 6

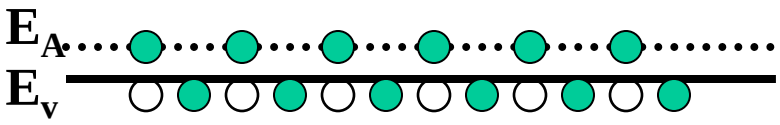
Partial Ionization, Intrinsic Energy and Parameter Relationships

Reading:

(Cont'd) Notes and Anderson[2] sections from lecture 4

Partial Ionization Case





$$N_A^- = \frac{N_A}{1 + g_A\, e^{(E_A - E_f)/kT}}$$

$$N_D^+ = \frac{N_D}{1 + g_D\, e^{(E_f - E_D)/kT}}$$

$g_A = 4$ for Si, GaAs, Ge and most semiconductors

$g_D = 2$ for Si, GaAs, Ge and most semiconductors

For 10^{14} cm^{-3} B in Si:

$$N_A^- = 0.9998 N_A$$

For 10^{17} cm^{-3} B in Si:

$$N_A^- = 0.88 N_A$$

For 10^{17} cm^{-3} P in Si:

$$N_D^+ = 0.94 N_D$$

Charge Neutrality

Partial Ionization Case

$$\left(p - N_A^-\right) = \left(n - N_d^+\right)$$

$$p - \frac{N_A}{1 + g_A\, e^{(E_A - E_f)/kT}} = n - \frac{N_D}{1 + g_D\, e^{(E_f - E_D)/kT}}$$

$$N_v e^{(E_v - E_f)/kT} - \frac{N_A}{1 + g_A\, e^{(E_A - E_f)/kT}} = \ldots$$

$$\ldots \quad N_c e^{(E_f - E_c)/kT} - \frac{N_D}{1 + g_D\, e^{(E_f - E_D)/kT}}$$

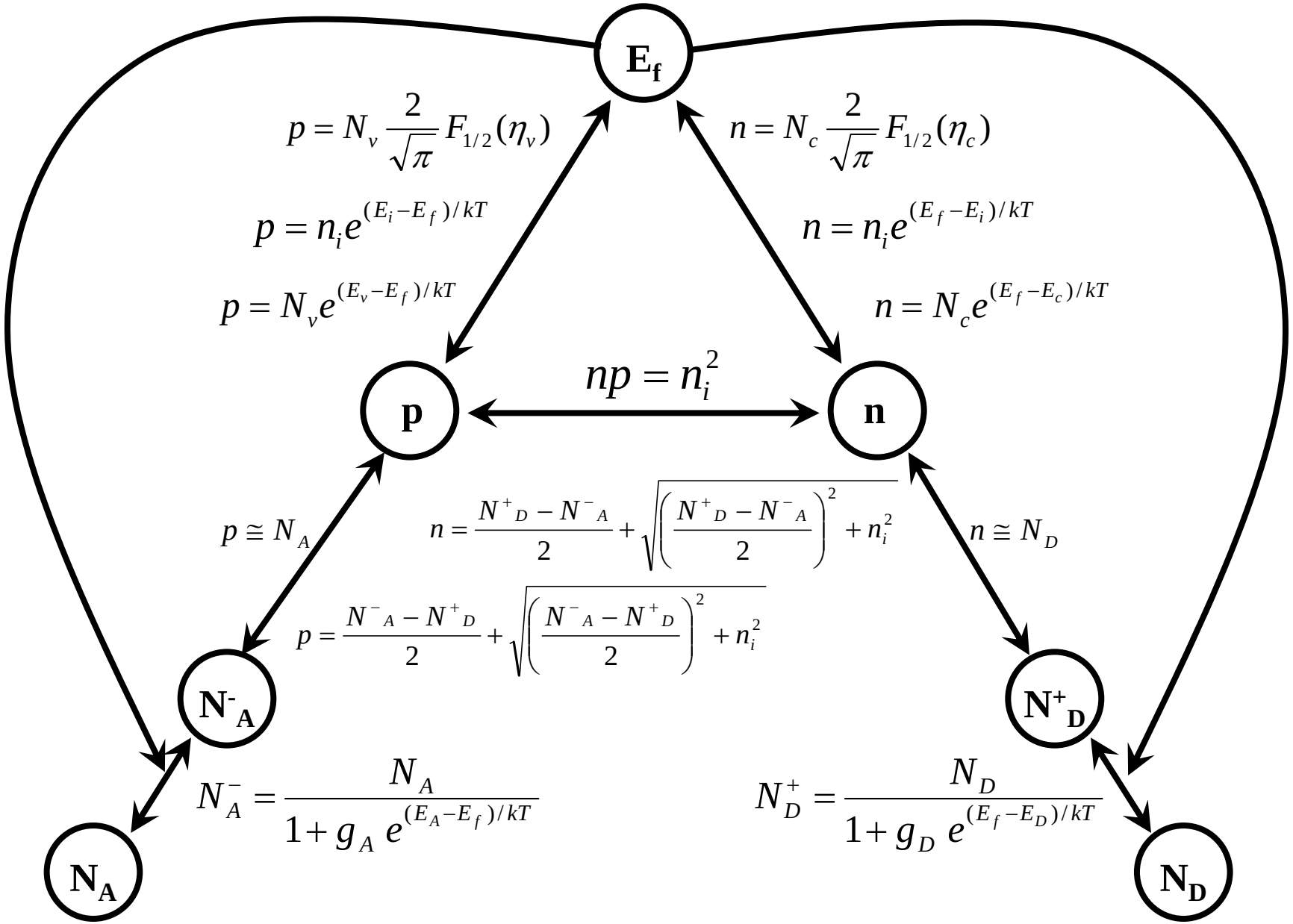
What are the Degeneracy Factors

The degeneracy factors account for the possibility of electrons with different spin, occupying the same energy level (I.E. a true statement of the Pauli Exclusion principle is that no electron with the same quantum numbers (energy and spin) can occupy the same state).

g_D is then =2 in most semiconductors.

g_A is 4 due to the above reason combined with the fact that there are actually 2 valence bands in most semiconductors. Thus, 2 spins x 2 valance bands makes g_A=4

Relationships between Parameters



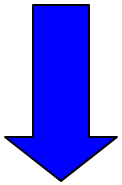
Where is E_i?

Since we started with descriptions of intrinsic materials then it makes sense to reference energies from the intrinsic energy, E_i.

Intrinsic Material:

$$n = N_c e^{(E_f - E_c)/kT} = N_v e^{(E_v - E_f)/kT} = p$$

$$N_c e^{(E_i - E_c)/kT} = N_v e^{(E_v - E_i)/kT}$$



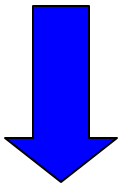
$$E_i = \frac{E_c + E_v}{2} + \frac{kT}{2}\ln\left(\frac{N_v}{N_c}\right)$$

Where is E_i?

Intrinsic Material:

But,

$$\frac{N_v}{N_c} = \left(\frac{m_p^*}{m_n^*}\right)^{3/2}$$



$$E_i = \underbrace{\frac{E_c + E_v}{2}}_{\text{Letting } E_v=0,\ \text{this is } E_g/2 \text{ or ``Midgap''}} + \underbrace{\frac{3kT}{4}\ln\left(\frac{m_p^*}{m_n^*}\right)}_{\text{-0.007 eV for Si @ 300K (0.6\% of } E_G \text{)}}$$

Where is E_i?

Extrinsic Material:

$$n = n_i e^{(E_f - E_i)/kT} \qquad p = n_i e^{(E_i - E_f)/kT}$$

Solving for $(E_f - E_i)$

$$E_f - E_i = kT \ln\left(\frac{n}{n_i}\right) = -kT \ln\left(\frac{p}{n_i}\right)$$

or for $N_D >> N_A$ *and* $N_D >> n_i$

$$E_f - E_i = kT \ln\left(\frac{N_D}{n_i}\right)$$

or for $N_A >> N_D$ *and* $N_A >> n_i$

$$E_f - E_i = -kT \ln\left(\frac{N_A}{n_i}\right)$$

Where is E_i?

Extrinsic Material:

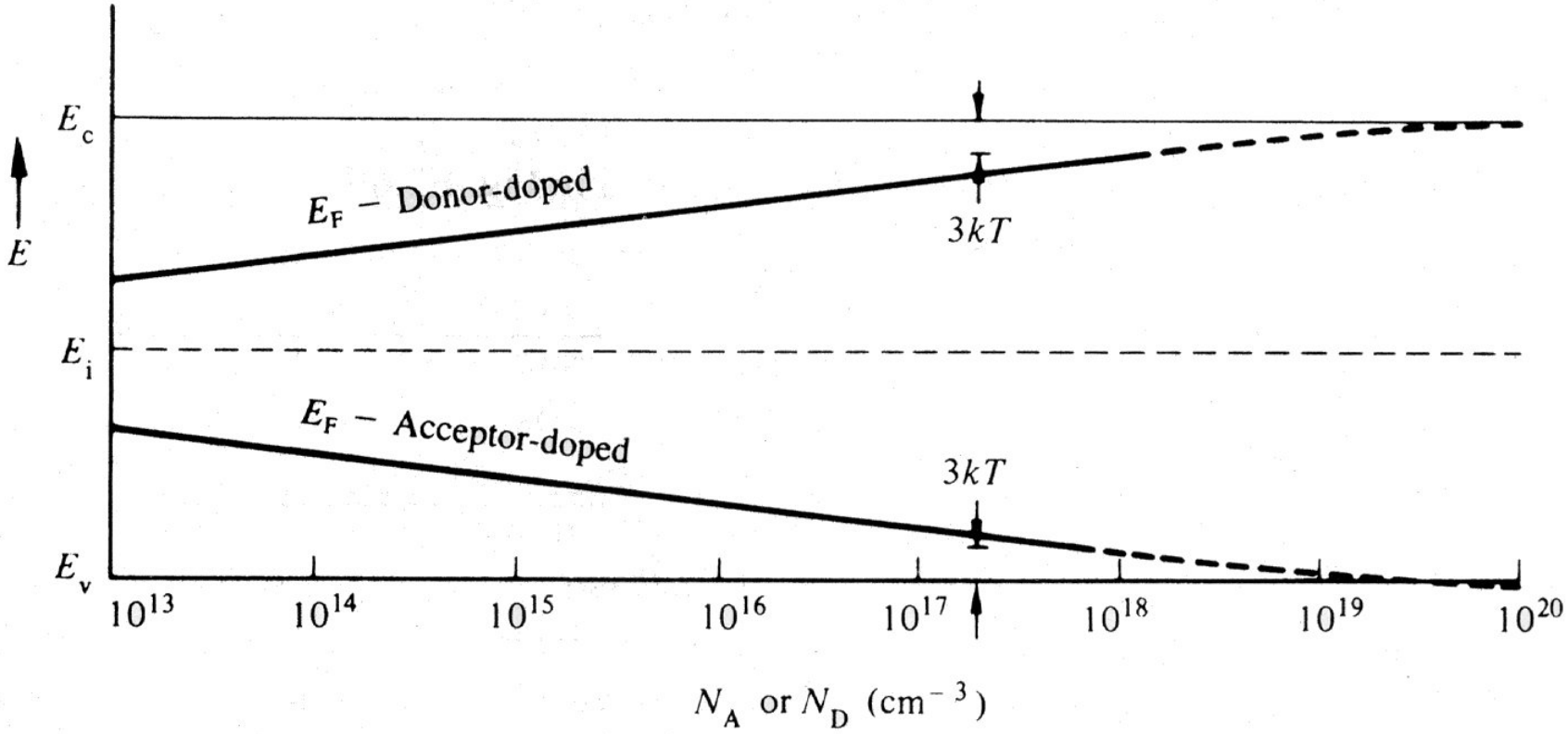


Figure 2.21 Fermi level positioning in Si at 300 K as a function of the doping concentration. The solid E_F lines were established using Eq. (2.38a) for donor-doped material and Eq. (2.38b) for acceptor-doped material ($kT = 0.0259$ eV, and $n_i = 10^{10}/cm^3$).

Note: The fermi-level is pictured here for 2 separate cases: acceptor and donor doped.