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Charge-carrier density in Semiconductors

- Density of states
  - Number of available states per unit energy interval per unit volume.

$$D(E) \propto \sqrt{(E-E_c)}$$

$$D(E) = K \sqrt{(E-E_c)} \quad eV^{-1}\,cm^{-3}$$

Constant

$$D(E=E_c) = 0$$

- What is the probability of energy-state of energy E at temperature T is filled with the electrons (holes) ?

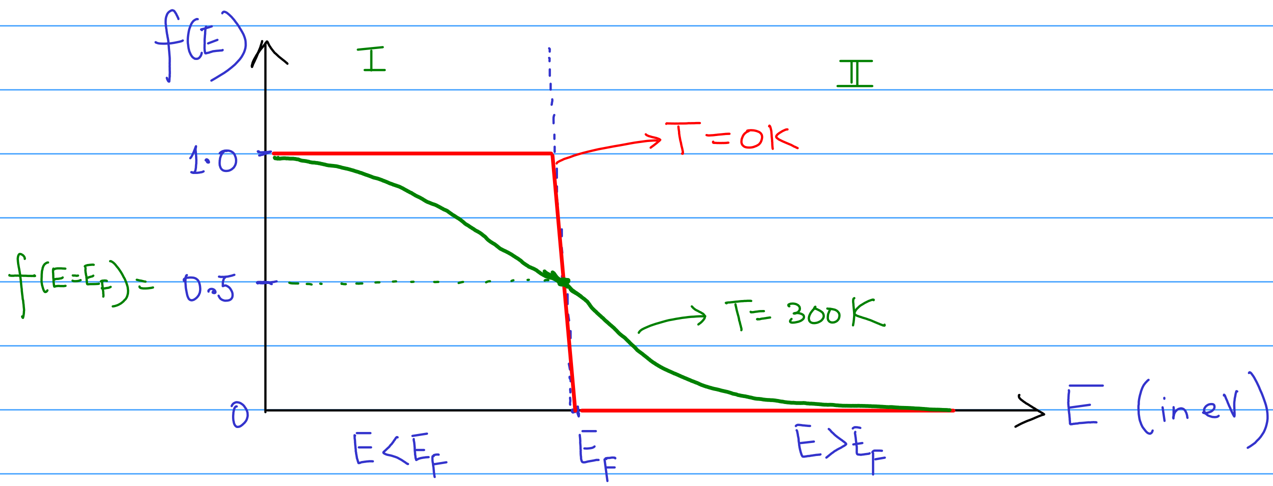
$\Rightarrow$ The electrons (holes) are categorized as "FERMIONS" and they follow Fermi-Dirac statistics.

$$\boxed{f(E) = \frac{1}{1 + \exp\left(\frac{E-E_F}{k_B T}\right)}}$$

here, E_F is termed as "FERMI-ENERGY"

$f(E)$ = Probability that an available energy state at energy E and at Temp T is occupied with the electron.

$$f(E) = \frac{1}{1 + \exp\left[\frac{E - E_F}{k_B T}\right]}$$



i) <u>at $T \to 0K$</u>

a) $E < E_F$

$$\underbrace{\exp\left[\frac{-(E_F - E)}{k_B T}\right]}_{\to 0}$$

$$f(E) \to 1$$

b) $E > E_F$

$$\exp\left(\frac{E - E_F}{k_B T}\right) \to \infty$$

$$f(E) \to 0$$

ii) <u>at $T = 300K$</u>

$k_B T = 25\,meV$

a) $E < E_F$

$$\exp\left(\frac{-(E_F - E)}{k_B T}\right)$$

Vary 'E' from 0 to E_F

b) $E = E_F$

$$f(E = E_F) = \frac{1}{1 + e^0} = \frac{1}{2}$$

c) $E > E_F$ $\exp\left(\frac{E - E_F}{k_B T}\right)$

- Now, we know the DOS in CB and how the electrons occupy the available energy-states.

Therefore, we can calculate the electron density in the conduction band at temp 'T' as

$$n = \int_{E_C}^{\infty} \underbrace{f(E)}_{\text{Probability of occupancy}} \cdot \underbrace{D(E)}_{\text{Number of electrons in CB in cm}^{-3}} \, dE$$

$$n = \int_{E_C}^{\infty} \frac{1}{1 + \exp\left(\frac{E - E_F}{k_B T}\right)} \cdot K\sqrt{E - E_C} \cdot dE$$

"FERMI-INTEGRAL"

Approximate Sol^n:

$$n = N_c \, e^{-(E_c - E_F)/k_B T} \quad (\text{in cm}^{-3})$$

where, N_c = effective density of energy states

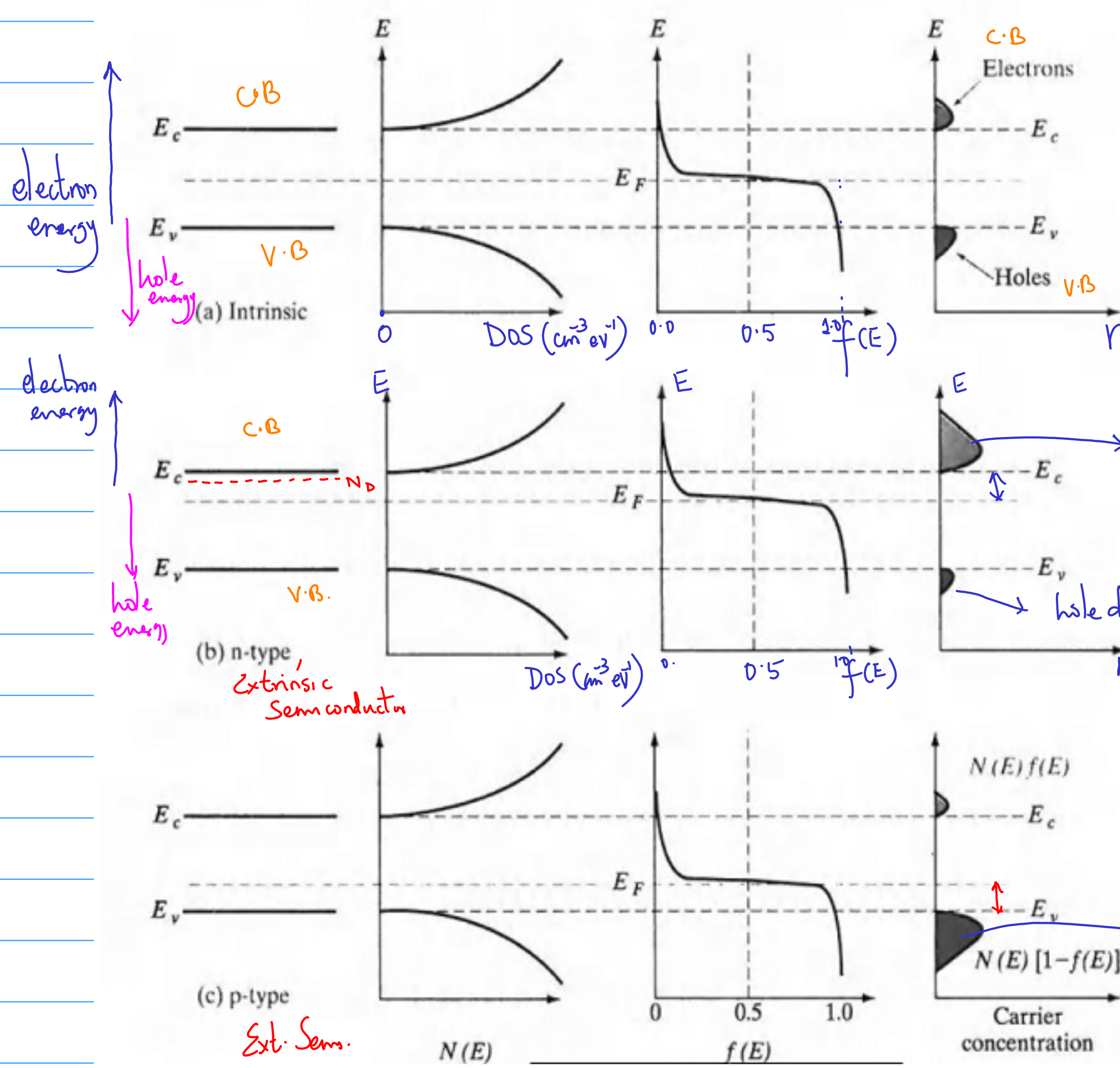
$$N_c = 2\left(\frac{2\pi m_e^* k_B T}{h^2}\right)^{3/2} \sim 10^{19} \text{ cm}^{-3}$$

Density of charge-carriers in Intrinsic & Extrinsic Semiconductors

$n = \int_{E_c}^{\infty} f(E) \cdot DOS \, dE$

$n = N_c e^{-(E_c - E_F)/k_B T}$

$n = p = n_i$



$n = N_c e^{-(E_c - E_F)/k_B T}$

$n >> p$

$p >> n$