# Written Assignment - 2 for Mod. 2 & 3

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Q1) Derive an exp. for fermi energy of intrinsic semi-conductor and explain the variation of Fermi energy with temperature for n-type and p-type semiconductor.

Ans:- The carrier concentration of electron in intrinsic semiconductor :-

$$n = 2\left(\frac{2\pi m_e^* kT}{h^2}\right)^{3/2} e^{\left(\frac{E_F - E_C}{kT}\right)}$$

where $m_e^*$ = effective mass of electron

$E_F$ = fermi energy level.

$E_C$ = energy of conduction band.

$k$ = Boltzmann's constant. = $8.617 \times 10^{-5}$ eV/K

$T$ = temperature in absolute scale.

$h$ = Planck's constant = $6.626 \times 10^{-34}$ J sec.

The carrier concentration of holes in intrinsic semiconductor

$$p = 2\left(\frac{2\pi m_h^* kT}{h^2}\right)^{3/2} e^{\left(\frac{E_V - E_F}{kT}\right)}$$

where $m_h^*$ = effective mass of hole.

$E_V$ = energy of valence band.

PTO

For intrinsic semiconductor;

no. of electrons = no. of holes

i.e. $$2\left(\frac{2\pi m_e^* kT}{h^2}\right)^{3/2} e^{\left(\frac{E_F - E_C}{kT}\right)} = 2\left(\frac{2\pi m_h^* kT}{h^2}\right)^{3/2} e^{\left(\frac{E_V - E_F}{kT}\right)}$$

$$\Rightarrow (m_e^*)^{3/2} e^{\left(\frac{E_F - E_C}{kT}\right)} = (m_h^*)^{3/2} e^{\left(\frac{E_V - E_F}{kT}\right)}$$

$$\Rightarrow e^{\left(\frac{E_F - E_C}{kT}\right)} = \left(\frac{m_h^*}{m_e^*}\right)^{3/2} e^{\left(\frac{E_V - E_F}{kT}\right)}$$

$$\Rightarrow e^{(2E_F/kT)} = \left(\frac{m_h^*}{m_e^*}\right)^{3/2} \cdot e^{\left(\frac{E_V + E_C}{kT}\right)}$$

$$\Rightarrow 2E_F/kT = \frac{3}{2}\log\left(\frac{m_h^*}{m_e^*}\right) + \left(\frac{E_V + E_C}{kT}\right)$$

[Taking $\log_e$ on both sides]

$$\Rightarrow E_F/kT = \frac{3}{4}\log\left(\frac{m_h^*}{m_e^*}\right) + \frac{E_V + E_C}{2kT}$$

$$\Rightarrow E_F = \frac{3}{4}kT\log\left(\frac{m_h^*}{m_e^*}\right) + \frac{E_V + E_C}{2}$$

$\because$ $m_h^* = m_e^*$ so,

$$\boxed{E_F = \frac{E_V + E_C}{2}}$$ [As $\log(1) = 0$]

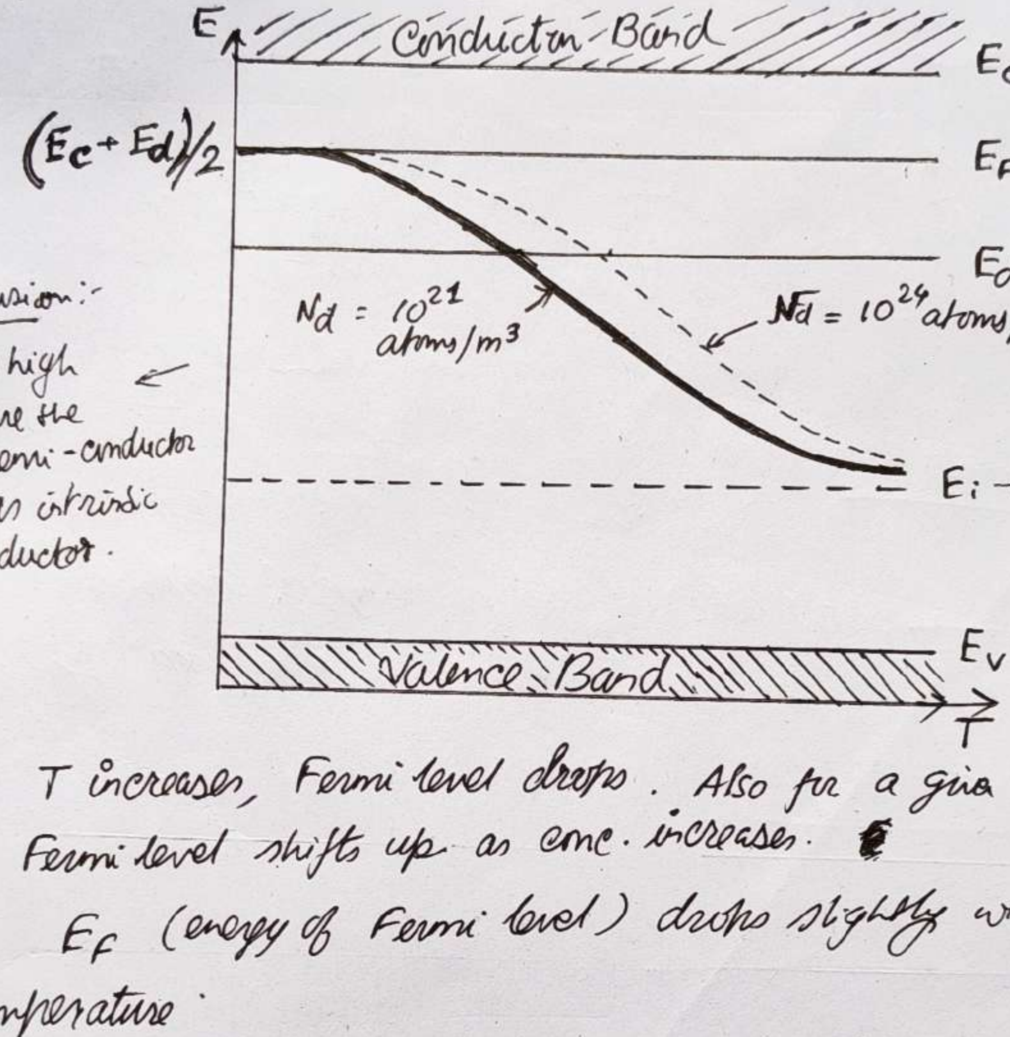
Thus, the fermi energy level is located half way between the valence band and conduction band and its position is independent of temperature for an intrinsic semiconductor.

## Fermi energy for N-type semiconductor

The fermi energy for n-type semiconductor is :-

$$E_F = \frac{E_C + E_D}{2}$$

// movement of fermi energy level as temperature increases.
graph



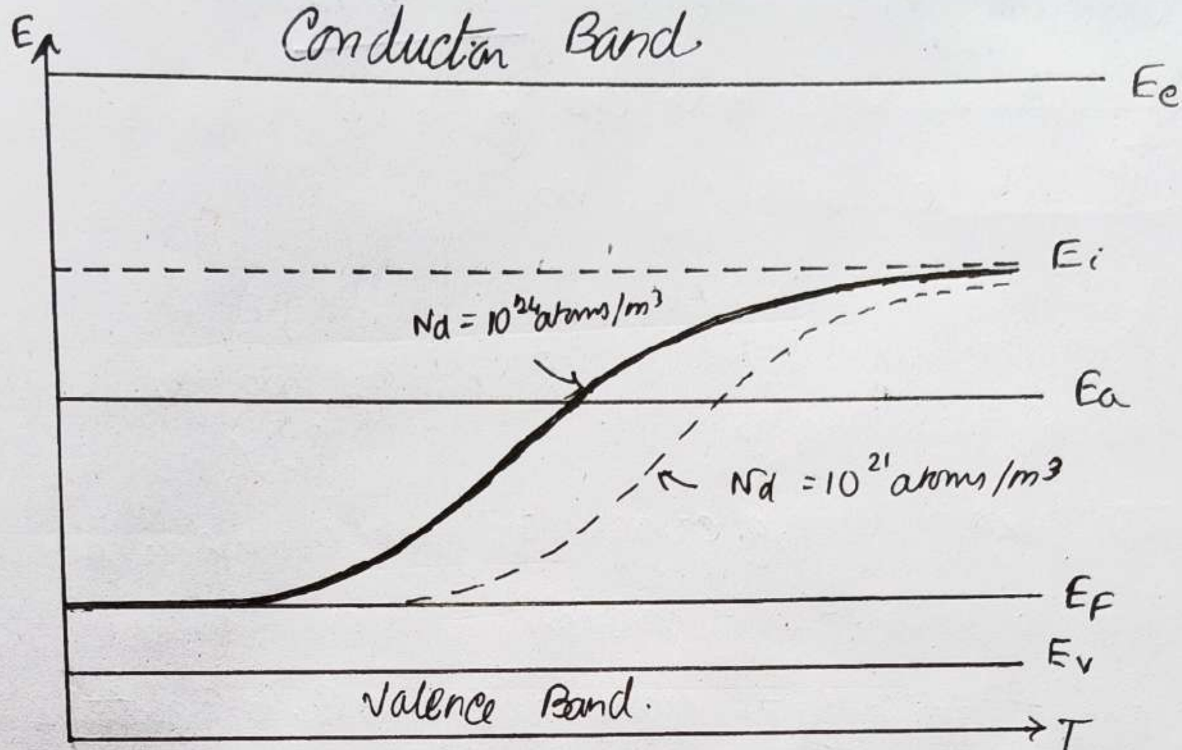

Conclusion:- At very high temperature the n-type semi-conductor behaves as intrinsic semi-conductor.

- As T increases, Fermi level drops. Also for a given temperature, the Fermi level shifts up as conc. increases.
- The $E_F$ (energy of Fermi level) drops slightly with increase in temperature.
- As temperature is increased, more & more donor atoms are ionised. For a particular temperature, all the donor atoms are ionised.
- With further increase in temperature, e-h pairs generate due to breaking of covalent bonds & the material tends to behave in intrinsic manner. The fermi level gradually moves towards the intrinsic fermi level F.

Fermi energy level of p-type semiconductor is :-

$$E_F = \frac{E_v + E_a}{kT}$$

at OK. the Fermi level is exactly at the middle of the acceptor level on the top of the VB.




For a particular temperature all the acceptor atoms are ionized. Further increase of ~~the~~ temperature results in generation of e⁻-hole pair due to breaking of covalent bonds & the material tend to behave in intrinsic manner.

The Fermi-level gradually moves towards the intrinsic Fermi level.

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