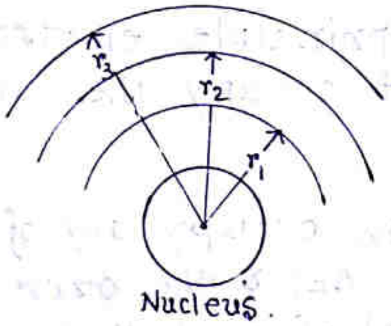
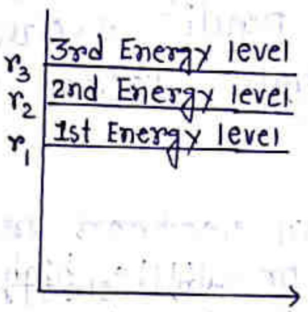
Semiconductor diodes.

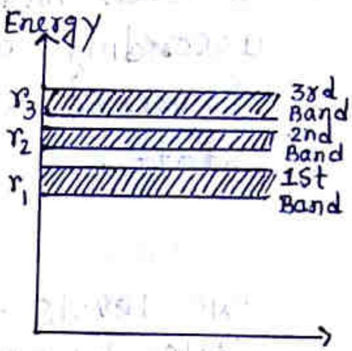
Semiconductor are a class of materials whose electrical conductivity lies between that of a conductor & of an insulator.

▨ Energy Band

The range of energies possessed by an electron in a solid is known as energy band.







▨ Valence Band.

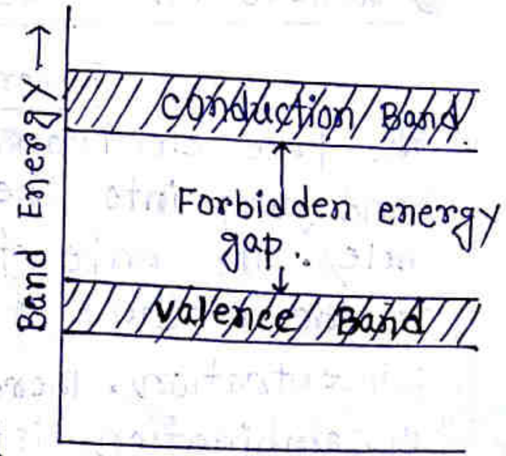
The range of Energies possessed by valence electrons is known as valence band.

▨ Conduction Band

The range of energies possessed by conduction band electrons is known as conduction band. Basically all electrons in the conduction are free electron.

▨ Forbidden energy gap (E_g)

The Separation between conduction band & valence band on the energy level diagram is known as forbidden energy gap.

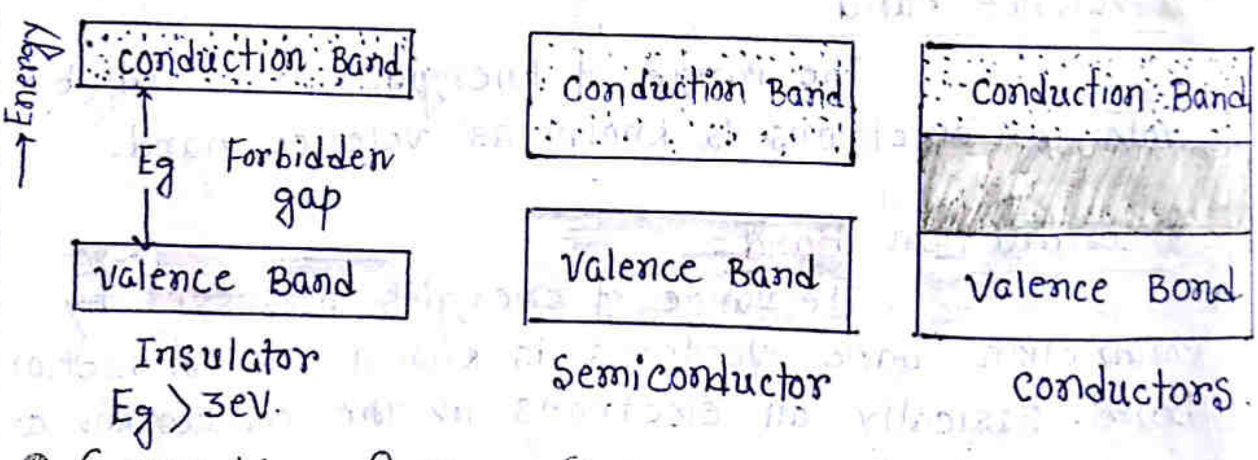


At room temperature. Si $\overset{E_g}{\rightarrow}$ 1·12 eV
& Ge → 0·72 eV.

Energy Band structure in Solid (Band Theory).

An electron is an isolated atom can have only certain discrete energies. Now two identical atoms with single valence electrons are slowly brought close to each other until their electrons shell begin to overlap. The electron-ion and electron-electron interaction start to take place, the atomic orbitals start overlapping. These interaction cause splitting of each individual energy level into two because according to pauli's exclusion principle electrons from a single system can not occupy the same state.

An electron may now occupy any of the two levels - one little higher $(E+\Delta E)$ & the other a little lower $(E-\Delta E)$ than that (E) of the individual isolated atom.



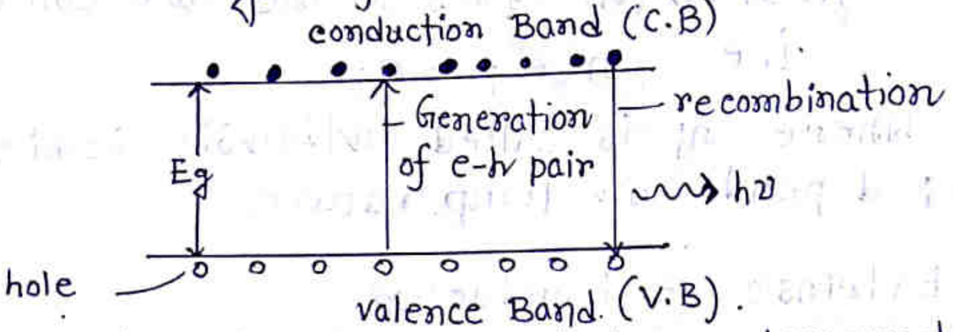
Generation & Recombination of Electrons & holes.

Recombination is the process in which the free electrons the free electrons in the conduction band jump into the valence band to combine with holes. The rate of recombination is proportional to the product of electron concentration & hole concentration. There is a process opposite to this recombination is known as Generation.

In recombination, the minimum energy released in form EM radiation is equal to the band gap. Eg. If ν is the frequency of emitted EM radiation,

$$E_g = h\nu = \frac{hc}{\lambda}$$

Where h planck's constant, $c = 3\times10^8$ m/s velocity of light & λ is wavelength of the radiation.



*Note
[At 0 K all electrons lies in V.B, But at room temperature (300K) maximum electrons reside at C.B]

problem-

The bandgap of a specimen of gallium arsenide - phosphide is 1·98 eV. Determine the wavelength of the EM radiation that is emitted upon direct recombination of electrons & holes in this sample. What is the colour of the emitted radiation?

If λ is the wave length

we know that,

$$E_g = h\nu = \frac{hc}{\lambda}$$

$$\text{or, } \lambda = \frac{hc}{E_g}$$

$1\mathring{A} = 10^{-8}$ cm
$= 10^{-10}$ m

$$= \frac{6{\cdot}625\times10^{-34}\times3\times10^{8}}{1{\cdot}98\times1{\cdot}6\times10^{-19}}\ \text{m}$$

$$= 625\ \text{nm}.$$

$1\text{nm} = 10^{-9}$m

As λ is in red region of the visible light the colour of EM radiation is red.

Intrinsic Semiconductor.

A Semiconductor is an extremely pure form is known as intrinsic semiconductor.

In thermal equilibrium the rate of generation & recombination of e-h pairs become equal, for an intrinsic semiconductor electron concentration (n) equals to the hole concentration (p)

i.e $n = p = n_i$

where n_i is called intrinsic semiconductor. n_i depends on temperature.

Extrinsic Semiconductor

The characterstic of intrinsic semiconductors can be changed drastically by adding small percentage of impurity atoms. Then the resulting semiconductor is known as Extrinsic semiconductor.

This type of semiconductors are two type.

a) n type (As, Sb) & b) p type (B, Al)
pentavalent tri-valent

Direct & indirect band-gap semiconductor.

The energy of a free electron is,

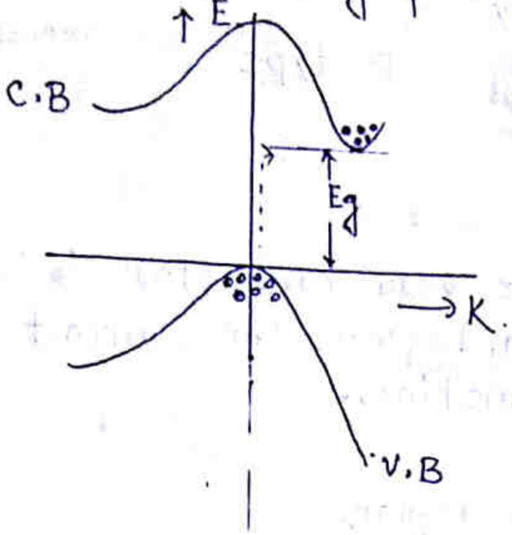
$$E = \frac{p^2}{2m_0}$$

p → momentum
m_0 → Free electron mass

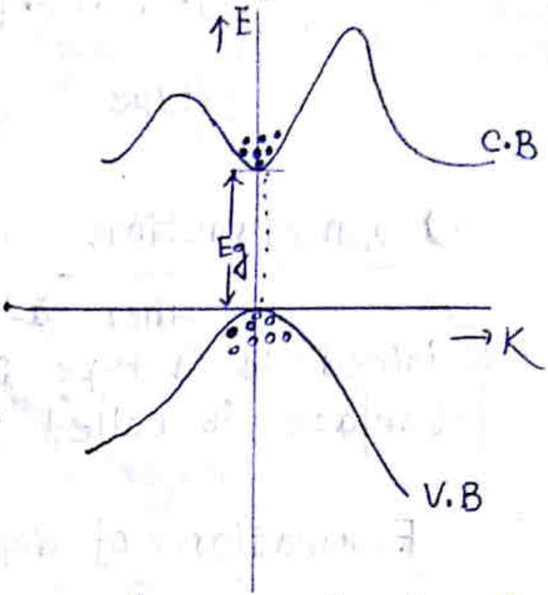
or, $$E = \frac{\hbar^2 K^2}{2m_0} \quad [p = \hbar K]$$

K → wave vector
$\hbar \rightarrow h/2\pi$, h → planck constant

On the basis of energy band structures, semiconductors can be classified as direct & indirect band-gap.



Si – Indirect B.G.



GaAs → Direct B.G.

n-type Semiconductor

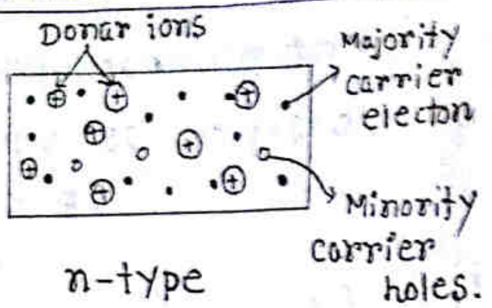
When a small amount of pentavalent impurity (As, Sb) is added to a pure semiconductor is known as n-type semiconductor.

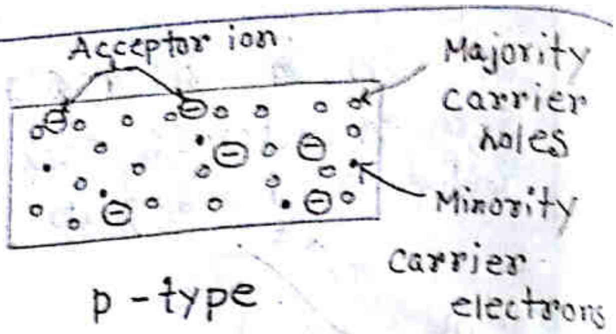
In a n-type semiconductor electrons are majority carrier & holes are minority carrier.

p-type Semiconductor

When a small amount of tri-valent (B, Al) is added to a pure Semiconductor, is called p-type Semiconductor.

In a p-type semiconductor holes are majority carrier & electrons are minority carrier



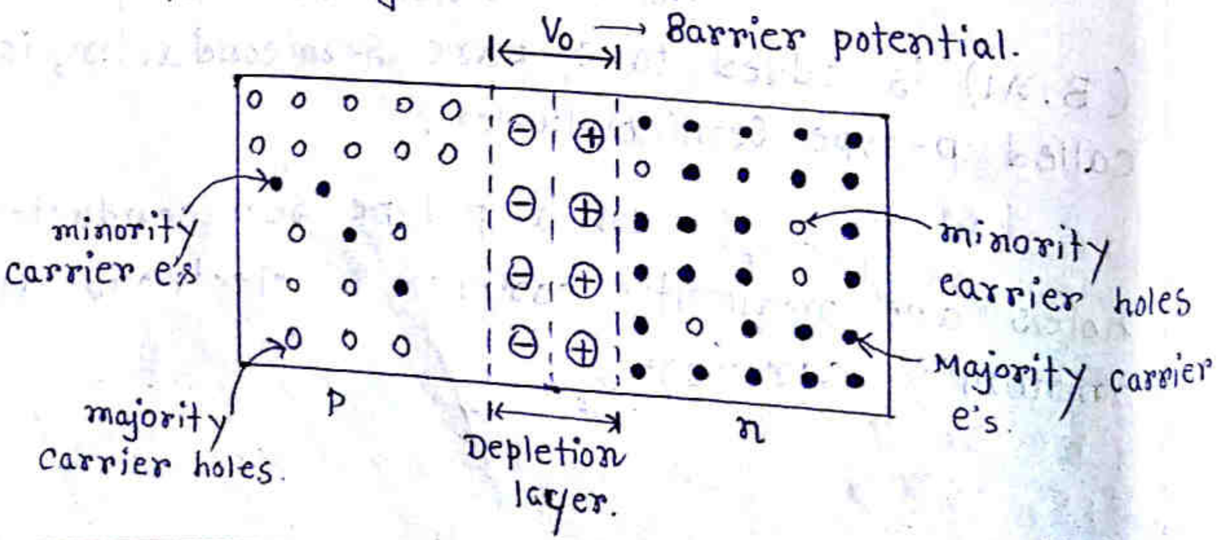


p-n junction

When a p-type semiconductor is Suitab joined to n type semiconductor, the contact of surface is called p-n junction.

Formation of depletion region

At the instant of pn junction formation, the free electrons near the junction in the n region begin to diffuse across the junction into the p region where they combine with holes near the junction. The result is that n region loses free electrons as they diffuse into the junction. This creates a layer of negative charges (pentavelent ions) near the junction. As the electrons move across the junction, the p region loses holes as the electrons & holes combine. The result is that there is a layer of negative charges (trivalent ions) near the junction. These two layers of positive & negative charges from the depletion region.



Variation of the width of depletion region.

i) Forward biasing :- The forward biasing voltage V exerts a force on the holes of p-side and electrons in the n side of the junction, driving them towards the junction. As a result the width of the depletion region is reduced.

ii) Reverse biasing :- The reverse biasing voltage V pulls the holes in the p side and electrons in the n-side away from the junction. Thus the width of the junction increase.

iii) Doping concentration :- The value of width of depletion region decreases with increase in doping concentration.

- The barrier potential can not be measured by connecting a voltmeter - Explain.

To show the reading a small amount of current must flow through the circuit. It causes Joule heating in the circuit. Since there is no external source of energy it must cause simultaneous cooling of the p-n junction. But according to 2nd law of thermodynamics it is not possible to derive work by cooling a body below its equilibrium temperature. Thus no current can pass through the circuit & the voltmeter shows zero reading

Actually the barrier potential is balanced by the metal-to-Semiconductor contact potentials in the circuit.

▨ Height of potential barrier across p-n junction (V_b)

The required height of the potential barrier :

$$V_b = \frac{KT}{e} \ln \frac{N_a N_d}{n_i^2}$$

where K Boltzman constant

T Absolute temperature

e · Electronic charge.

N_a = Donor impurity concentration

N_d = Acceptor impurity concentration.

& n_i = Intrinsic carrier concentration.

At room temp. (300 K)

: $\frac{KT}{e} = 0.026 eV$

For Ge, crystal

$n_i = 2.5 \times 10^{19}/m^3$

$N_a = N_d = 10^{22}/m^3$

& $V_b = 0.3V$

Ge & Si → range of V_b 0.5 V to 0.7 V.

▨ Width of Depletion region. (W)

The value of W, depends on the concentration of impurity atoms on both side of the p-n junction.

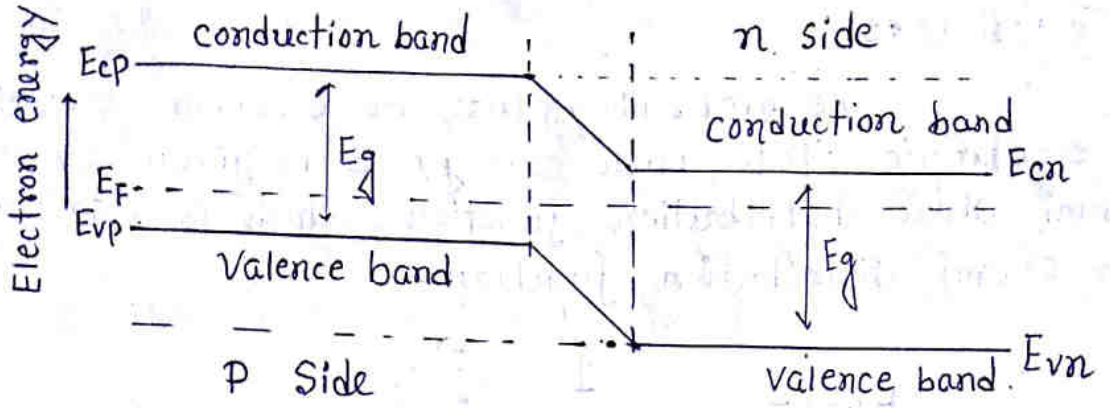
$$W = \left[\frac{2\epsilon KT}{e^2}\left(\frac{1}{N_a} + \frac{1}{N_d}\right) \ln \frac{N_a N_d}{n_i^2}\right]^{1/2}$$

Here ϵ is permittivity of the medium.

▨ Energy band diagram of p-n junction :-

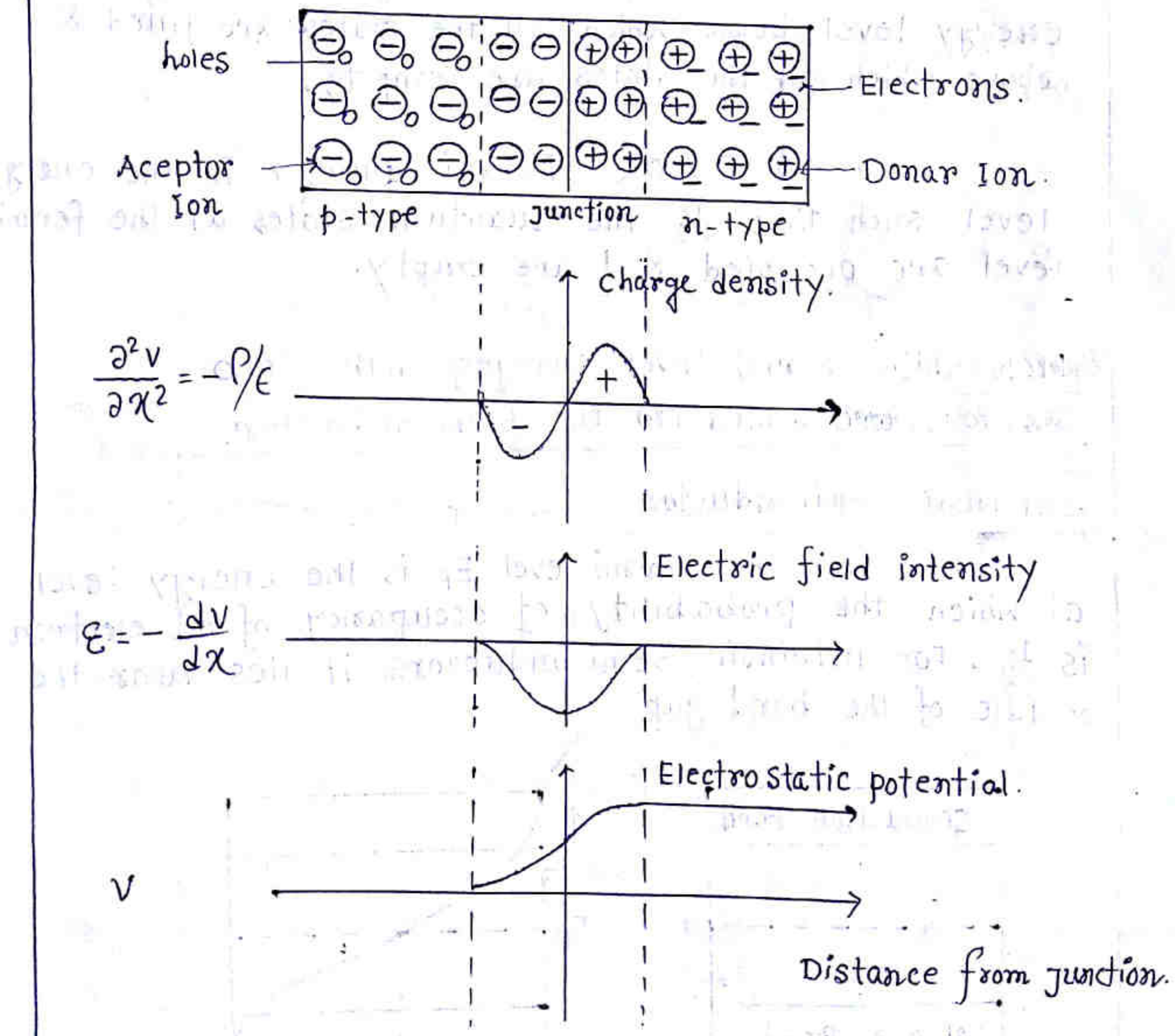
For an n-type semiconductor, Fermi level E_F lies near the conduction band edge E_C while for p type semiconductor it lies near the valence band edge. When p-n junction is formed, E_F attains a constant value through out the system.

At this situation the conduction band edge E_{cp} of p side will be at a higher level than the conduction band edge E_{cn} of n-side. Similarly E_{vp} is greater than E_{vn}.



[Energy band dia. of an open ckt p-n jn].

- Sketch the variation of the space charge, Electric field & the potential as a function of the distance across the junction of a open ckt p-n junction.



$$\frac{\partial^2 V}{\partial x^2} = -\rho/\epsilon$$

$$\mathcal{E} = -\frac{dV}{dx}$$

A schematic diagram of p-n junction.

Fermi level.

The probability that an electron occupies an electronic state with energy E is given by the Fermi-Dirac distribution function, which is also called the Fermi distribution function.

$$F(E) = \frac{1}{1 + e^{(E-E_F)/KT}}$$

Where K is Boltzman constant, T absolute temperature & E_F is the Fermi energy level.

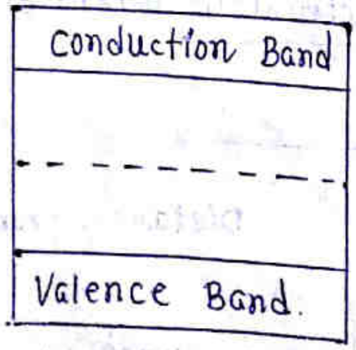
At T=0K, Fermi energy is the highest energy level below which all the states are filled & above which all the states are empty.

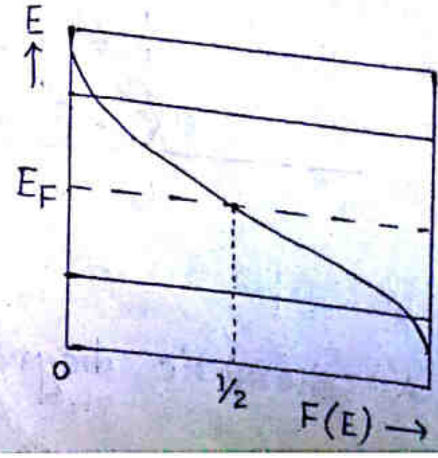
& At T≠0K, Fermi energy is the energy level such that, ½ the quantum states at the fermi level are occupied & $\frac{1}{2}$ are empty.

How does Fermi level changes with donors & acceptors are added to the semiconductor.?

Intrinsic Semiconductor

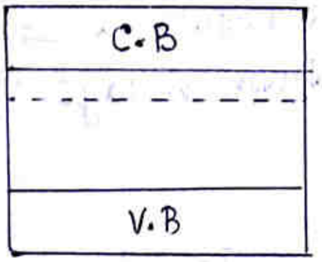
The Fermi level E_F is the energy level at which the probability of occupancy of an electron is ½. For intrinsic semiconductors it lies near the middle of the band gap.

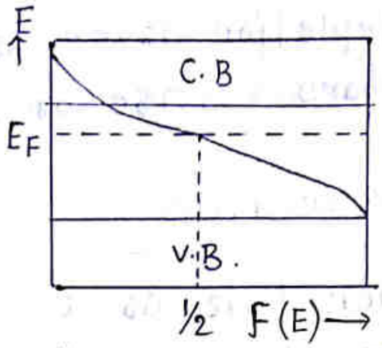


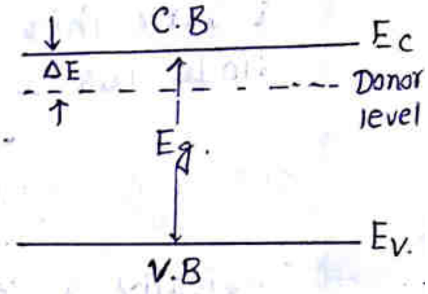


n type Semiconductor. (EX. Sc.).

with the addition of donor atom, free electrons from the donor atoms fill the states near the conduction band also it becomes difficult for the electrons in the valence band to cross the band gap. Hence the number holes in V.B decreases. Fermi level moves towards C.B for n-type Sc.

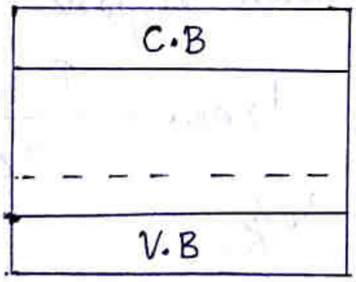


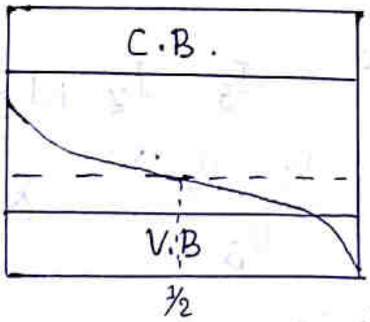


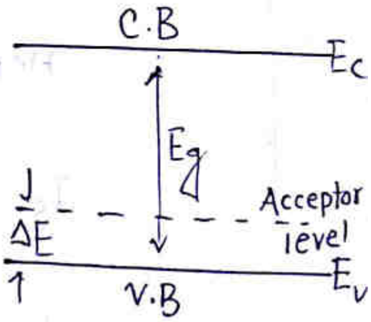


p-type Semiconductor. (Ex. Sc).

With addition of acceptor electrons moves in the acceptor level (E_c), hence holes increases in V.B., further excess holes enhances the rate of recombination with electrons, number of free electron decreases in C.B.. So E_F level moves towards the V.B.







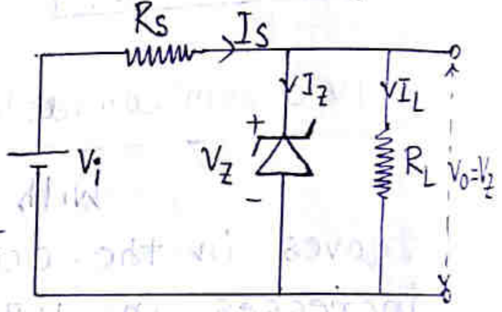
But when temperature rises both n-type & p-type Sc. becomes essentially intrinsic due to more more generation of electron-hole pairs. Hence E_F moves towards the middle.

Zener diode

A zener diode is special type of diode that is designed to operate in the reverse breakdown region. An ordinary diode operated in this region will usually be destroyed due to excessive current.

A zener diode is heavily doped to reduce the reverse breakdown voltage. This cause a very thin depletion layer. As a result, a zener diode has a sharp reverse breakdown voltage V_Z.

voltage regulator device.



Basically a zener diode as a voltage regulator device. In the break down region the voltage across the zener diode is almost independent current through it. The zener diode maintains a constant output voltage $V_0 = V_Z$ independent variation in load resistance R_L or the variation of input voltage V_i $(>V_Z)$ so long as the diode remains in the breakdown region.

Here $I_S = I_Z + I_Z$. , $I_{Z\,max} = \frac{P_{Z\,max}}{V_Z}$.

$$I_S = \frac{V_i - V_Z}{R_S} \quad \& \quad I_L = V_0/R_L$$

R_S calculation :-

$$R_{S\,min} = \frac{V_{i\,max} - V_Z}{I_{Zm}}.$$

$$\& \quad R_{S,max} = \frac{V_{i\,min} - V_Z}{I_{L\,max}}.$$

R_L calculation

$$R_{L\,min} = \frac{V_Z}{I_{L\,max}}$$

$$\& \quad R_{L\,max} = \frac{V_Z}{I_{L\,min}}$$

Avalanche breakdown

Thermally generated minority carriers flowing down the junction barrier acquire energy from the applied potential. They are always undergoing collisions with the crystal ions. when the reverse voltage is high, these collisions may become so violent that electrons are knocked out of the covalent bonds & new electrons-hole pairs are generated. As these carriers are generated in the midst of high field, they rapidly Separate out and cause further pair generation through further collisions. This cumulative process is known as avalanche multiplication. It results in a large reverse current & the diode is said to be operating in the avalanche breakdown region.

Zener breakdown

when both sides of a p-n junction are heavily doped, the width of the depletion region becomes very small with relatively small reverse-bias voltge the electric field at the junction may become very high. The strong force exerted by this field on a bound electron may tear the electron out of its covalent bond.

The new electron-hole pair thus created increases the reverse current. This process is called Zener breakdown.