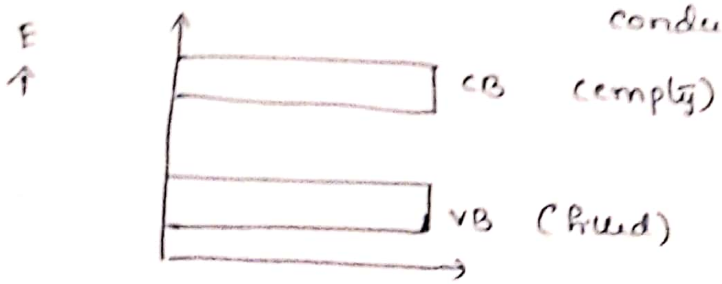
Semi conductors

Electrical conductivity / resistivity values are in b/w conductors & insulators → Semi conductors.

In terms of band gap → the materials for which the band gap b/w valence band and conduction is < 2 eV



- These materials have some unique electrical characteristics due to which they have several applications.
- The electrical prop. of these materials are extremely sensitive to the presence of small conc. of impurities.

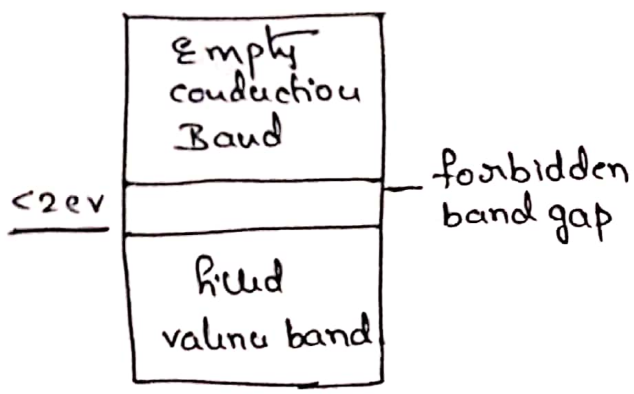
Semi conductors.

Intrinsic (pure form) ↓ The electrical behaviour is based on the electronic structure inherent in the pure material

Extrinsic (Impure form) ↓ The electrical properties are dictated by the impurity atoms.

Intrinsic Semiconductors

These are characterized by the e^- band structure as shown in fig.



- At 0K, a completely filled valence band, separated from an empty conduction band by a relatively narrow forbidden band gap (< 2ev).

Semiconducting Materials (Types)

① Elemental semiconductors – Silicon – Si – 1.1 ev
Germanium – Ge – 0.7 ev

Both are found in $\boxed{\text{Group IV A}}$ in periodic Table.

$\boxed{\text{Covalently bonded}}$

② Compound semiconductors –

$\boxed{\text{III – V compounds}}$ → They also display intrinsic behavior
→ one such group is formed b/w elements of III A & V A

Ex: GaAs (Gallium Arsenide) (1.42ev)
InSb (Indium Antimonide) (0.17ev)

$\boxed{\text{II – VI compounds}}$ → this group is formed b/w Group II B and VI A

Ex: CdS (cadmium sulphide) (2.40 ev)
ZnTe (Zinc Telluride) (2.26 ev)

- For these materials – atomic bonding is ionic &
– magnitude of energy band gap is more.
→ At 0 k they become more insulative.

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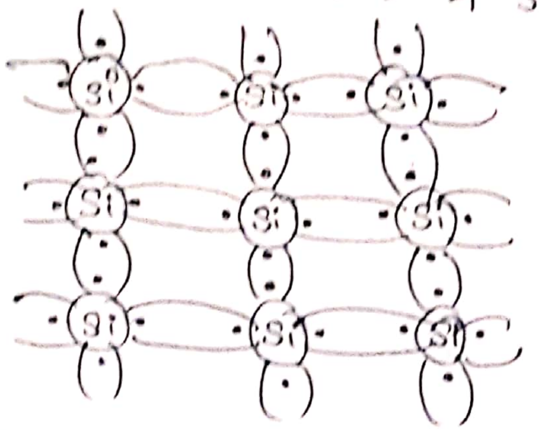
Intrinsic semiconductors structure

Si - 14 - $1s^2 2s^2 2p^6 3s^2 3p^2$



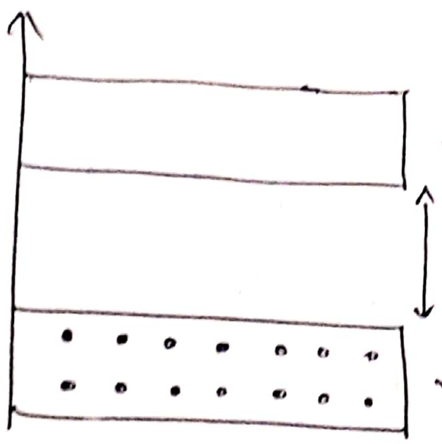
All are bonded in strong covalent bonds

If T ↑ the → e^- become free from the covalent bond and leaves a hole in the covalent bond.

($E = kT$)

This concept can be understood more clearly from the band energy bands structure.

(Boltzmann constant $k = 1.38 \times 10^{-23}$)



C·B (Empty)

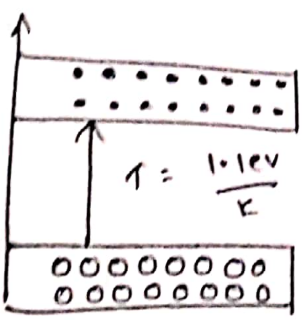
1.1 ev. $\Rightarrow$ $E = kT \Rightarrow 1.1\,ev = kT$

$\Rightarrow T = \dfrac{1.1\,ev}{1.38 \times 10^{-23}}$

$\Rightarrow T =$ ____

VB completely filled

If we supply the temp. (electric field) the e^- moves into conduction band by leaving one hole in v.B.



CB

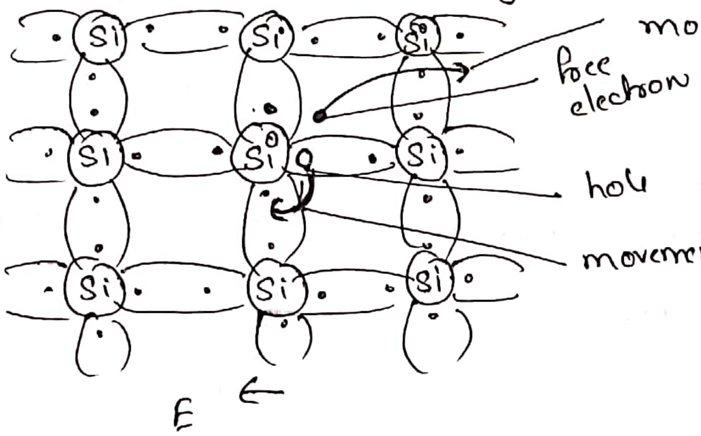
$T = \dfrac{1.1\,ev}{k}$

V.B

" A missing e^- from the valence band as a +vely charged particle called a hole "

- Hole — $+1.6 \times 10^{-19}$ col. (opp. charge of e^- but equal in magnitude)

- In presence of electric field, equal no. of free e^- & holes are created in conduction and valence bands.
- They move in opposite directions.
- These are scattered by lattice imperfections.



Intrinsic conductivity

In intrinsic semiconductors, there are two types of charge carriers (free e^-s & holes).

Hence Here, the conduction is due to free e^-s & as well as holes.

Hence The conductivity expression is as follows.

$$\sigma = n|e|\mu_e + p|e|\mu_h$$

n - no. of free e^-s / m3 p - no. of holes / m3

e - charge of e^- e - charge of hole.

μ_e - mobility of e^- μ_h - mobility of holes

" $\boxed{\mu_h < \mu_e}$ → Magnitude of Mobility of holes is always less than the mobility of e^-

for intrinsic semiconductors

Every e^- promoted across the band gap leaves behind a hole in the valence band

$\therefore n = p = n_i$ (no. of free e^- = no. of holes)

where n_i – Intrinsic carrier concentration.

At room temp.

$$\sigma = n_i|e|\mu_e + n_i|e|\mu_h$$

$$\boxed{\sigma = n_i|e|(\mu_e + \mu_h)}$$

Extrinsic Semiconductors

- All sc commercial semiconductors are extrinsic
- i.e electrical behaviour of sc is determined by impurities
- The introduction of the impurities in the sc is even in small conc. then also they introduces excess of e^-/holes.

Ex:- An impurity concentration of one atom in 10^{12} is sufficient to render silicon extrinsic at room temp

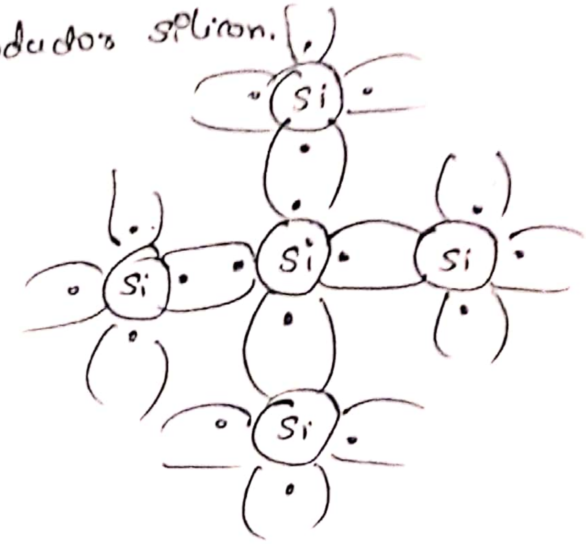
Two types of extrinsic S.C

1. N-type Extrinsic S.C
2. P-type "

n-type of semiconductor:

- To know the extrinsic semiconductor behaviour, let us consider elemental semiconductor silicon.

- si has four e⁻, each of which covalently bonded with one of four adjacent si atoms.



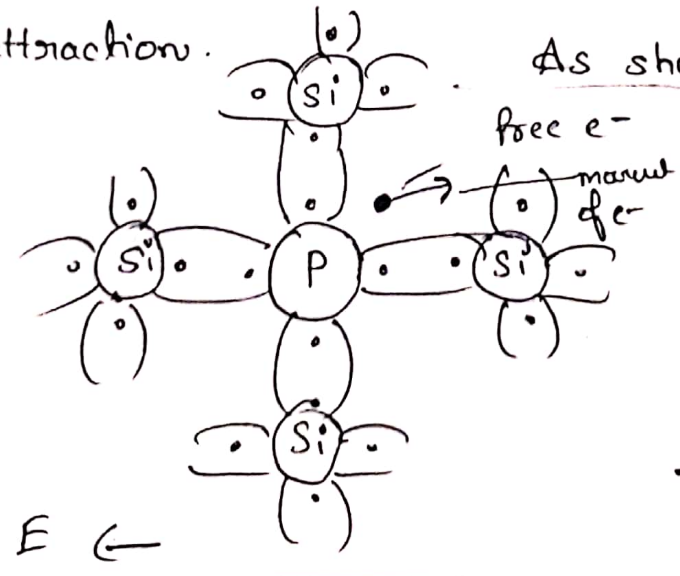
- Now, an impurity of with 5 e⁻ (valency e⁻) is added as substitutional impurity

↓

(VA Group elements - P, As & Sb).

- only four of valence e⁻s of these impurity atoms can participate in bonding b'coz there are four possible bonds with neighboring atoms.

- The extra non-bonding e⁻ is loosely bound to the region around the impurity atom by a weak electrostatic attraction. As shown in figure.

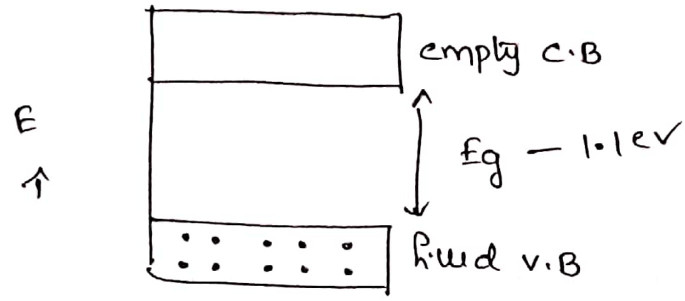


- The B.E of this e⁻ is very small (0.01ev) & it is easily removed from the impurity atom

- It becomes a free (or) conducting e⁻ - N-type

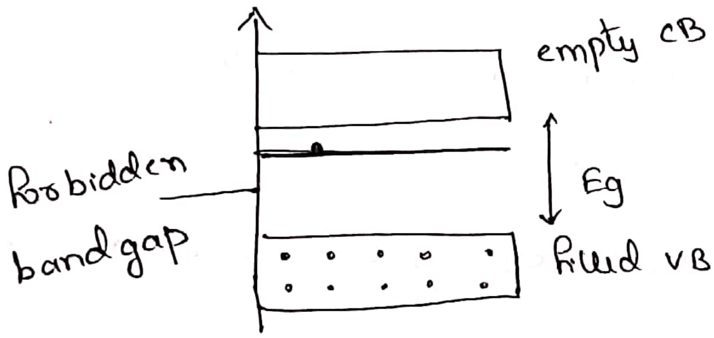
This can be easily understood from electron band model scheme.

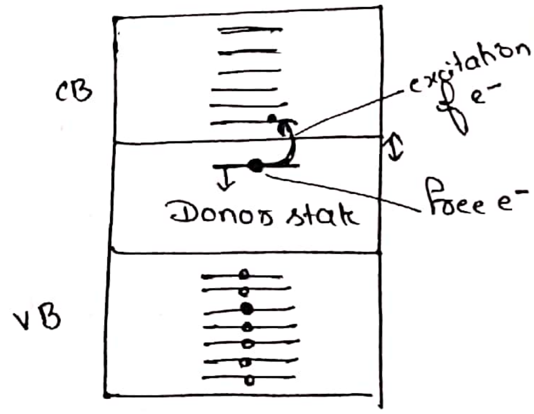
<u>pure si</u>



<u>for doped si</u>

for each loosely bound e⁻s, there exists a single energy level or energy state, which is located <u>within the forbidden band gap</u> <u>just below the conduction band.</u>





- The e⁻ B.E corresponds to the energy required to excite the e⁻ from one of these impurity states to a state within the conduction band.
- Each excitation event supplies or donates a single e⁻ to the conduction band.
- An impurity of this type is known as <u>donor</u>
- <u>Since each donor e⁻ is excited from an impurity level, no corresponding hole is created within the valence band.</u>

* At room temperature, the thermal energy available is sufficient to excite large no. of e^-s from donor states.

(In addition - some valence - conduction band transitions occur but to a negligible degree).

- Thus the no. of e^-s in the conduction band far exceeds the no. of holes in the valence band ($n >> p$)

- Hence conductivity expression becomes.

$$\boxed{\sigma \cong n e \mu_e}$$

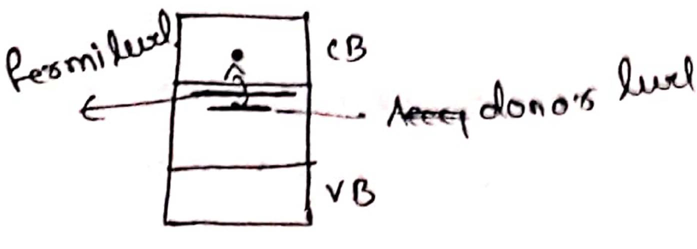
e^-s are majority charge carriers by virtue of their density (concentration).

holes " minority "

Hence a material of this type is known as n-type semiconductor.

* for n-type semiconductors

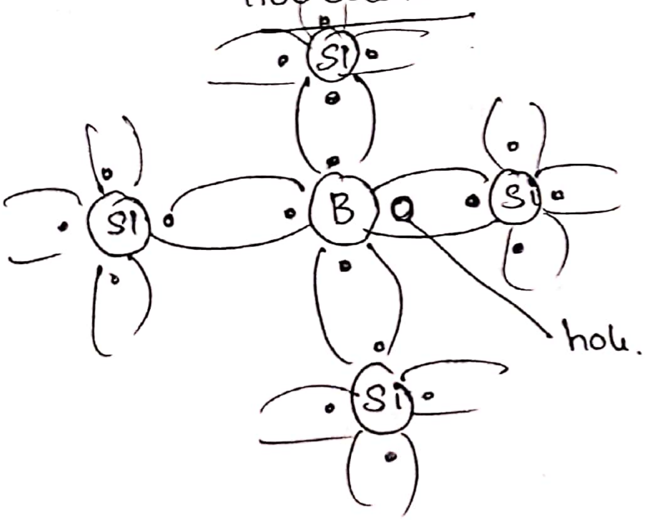
The Fermi energy level is shifted upward in the band gap, to within the vicinity of the donor states, its exact position is a function of both temperature & donor concentration.



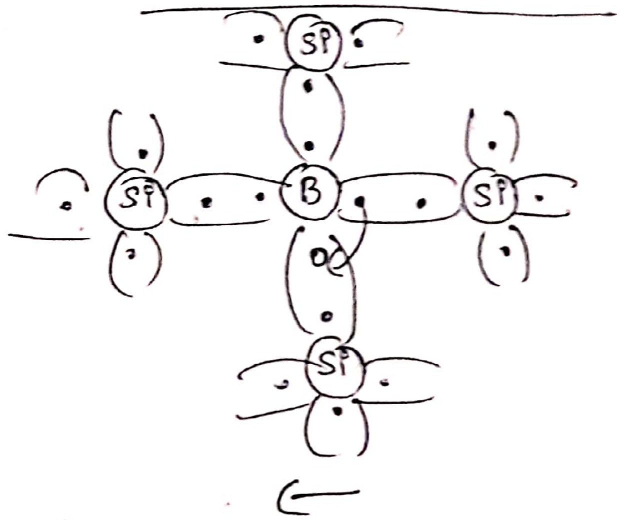
P-type Extrinsic Semiconductor

- An opposite effect is produced by the addition of trivalent substitutional impurities such as Aluminium, Boron & gallium (III A group elements of periodic table) to silicon or germanium.
- One of the covalent bonds around each of these atoms is deficient in an electron.
- Such deficiency may be viewed as a hole that is weakly bound to the impurity atom.
- This hole is moved from the impurity atom by the transfer of an e- from an adjacent bond as shown in fig.
- In essence, the e^- and the hole exchange positions.
- A moving hole is considered to be in an excited state and participates in the conduction process.

Hole creation



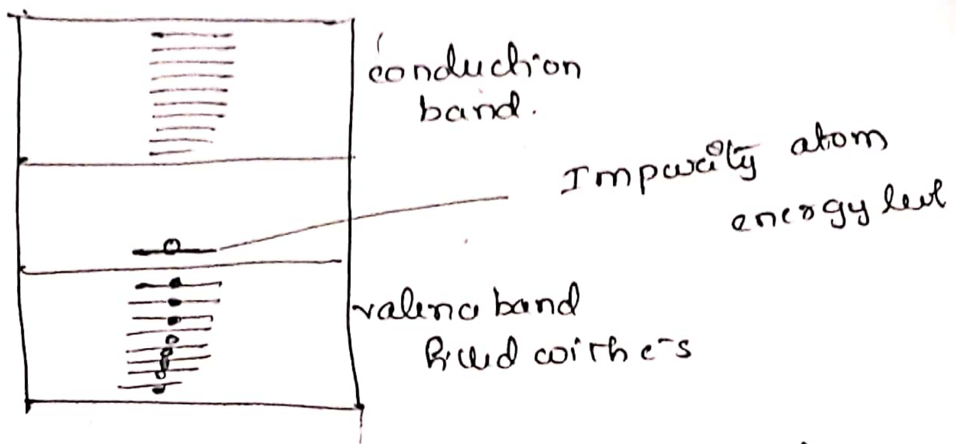
E is applied movement of hole



Movement of hole from one covalent bond to other

Extrinsic excitations, in which holes are generated may also be represented using the band model.

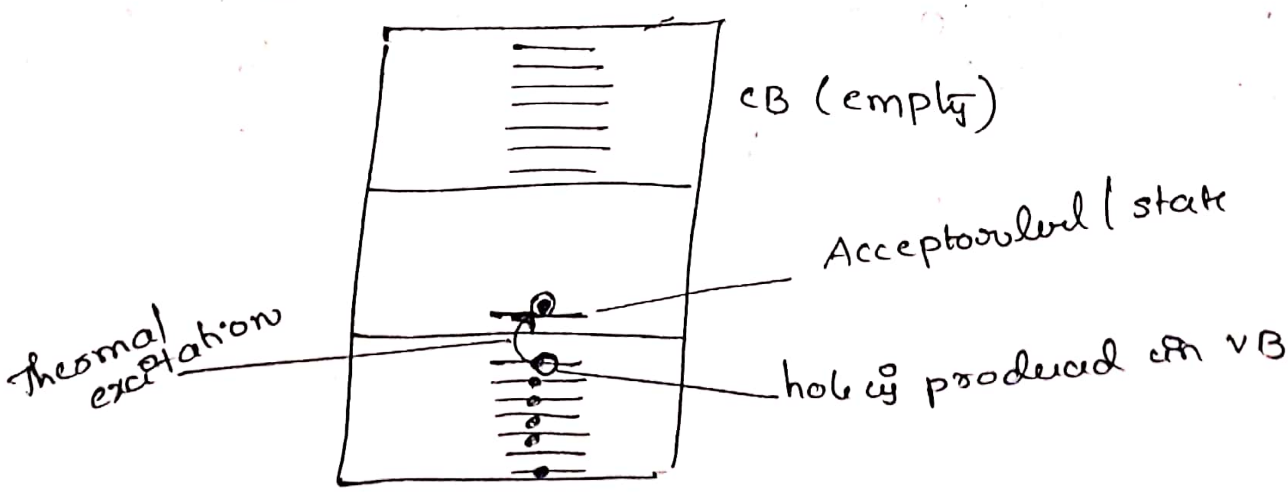
→ Each trivalent impurity atom of this type introduces an energy level within the band gap, which is above & very close to the top of the valence band.



- A hole is imagined to be created in the valence band by the thermal excitations of an e⁻ from the valence band into this impurity e⁻ state

with such a transition only one carrier is produced

* a hole in a valence band
* A free e⁻ is not created in either the impurity level or the conduction band



- An impurity of this type is called an acceptor, because it is capable of accepting an e^- from the valence band, leaving behind a hole.

- The energy level within the bandgap introduced by this type of impurity is called an acceptor state

conductivity

For this type of extrinsic conduction, holes are present in much higher concentrations than e^-s $(p >> n)$

These type of materials are known as p-type because +vely charged particles are primarily responsible for electrical conduction.

- Holes are majority charge carriers
- e^-s are minority "

$$\boxed{\therefore \quad \sigma = p|e|\mu_p}$$

For p-type semiconductors, the Fermi level is positioned within the band gap & near to the acceptor level.

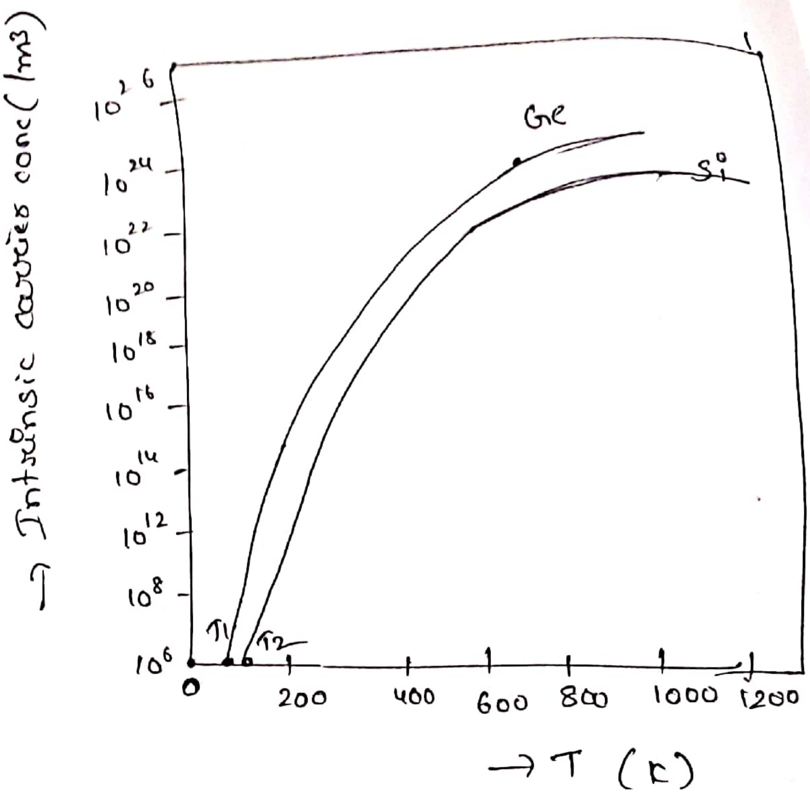
* The process of adding impurities to increase the conductivity is known as doping

* At high Temp also → electrical conductivities are obtained in extrinsic semiconductors.

* Most of these materials are designed for use in electronic devices to be operated in ambient conditions.

Temperature Dependence of carrier concentration effects :-

For intrinsic semiconductors



- Above figure is plotted b/w log of intrinsic carrier concentration 'n_i' & temperature for both 'Si' & 'Ge'.
- From graph following observations were made

Ge → carrier conc. starts at one temp T_1

Si → " " other temp T_2

B'coz of band gap diff.

Ge – 0.67 eV $\Rightarrow$ $KT = E_g = 0.67\,eV = \frac{0.67 \times 1.6 \times 10^{-19}}{1.38 \times 10^{-23}}$

= some value.

7768

Si – 1.11 eV $\Rightarrow$ $KT = E_g$

$\Rightarrow \frac{\cancel{0.67}\,1.11 \times 1.6}{1.38} \times 10^4$

$T = 12869\,K$