ENERGY BAND THEORY

* According to Bohr Model of an atom, each orbit of electrons has fixed amount of energy associated with it. The ēs moving in a particular orbit possess the energy of that orbit. This is the case of a single isolated atom.

* However, an atom in a solid is greatly influenced by the closely packed neighbouring atoms. Due to which, the ē in any orbit of such an atom can have a range of energies rather than a single energy. This is known as energy band.

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

* For instance, ēs in the first orbit can have slightly different energies which form a band - 1st energy band & those ēs in the 2nd orbit have range of energy forming 2nd energy band and so on.

VALENCE BAND : The range of energies possessed by valence electrons in a solid is known as valence band.

The ēs in the outermost orbit of an atom are known as valence ēs. Valence band has ēs of highest energy which may be completely or partially filled.

[The maximum energy possessed by free ēs at absolute zero is called fermi energy]

fermi level is the highest energy level that an ē can occupy in the valence band at absolute zero.

[All states lower to fermi level are filled and all other levels above fermi level are empty at absolute zero]
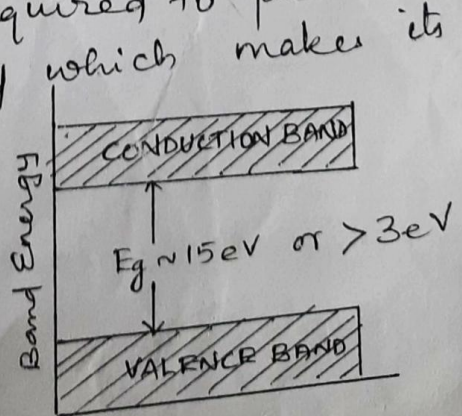
CONDUCTION BAND : The range of energies possessed by conduction band $\bar{e}$'s is known as conduction band. It is the next allowable energy band. All electrons in the conduction band are free electrons.

* There may or may not be electrons in the conduction band. It depends on the structure of the material.

* If a substance has empty conduction band, it will not have free $\bar{e}$'s for conduction as in the case of insulators.

FORBIDDEN ENERGY GAP : The separation between conduction band and valence band on the energy level diagram is known as forbidden energy gap.

Classification of solids on the basis of Energy bands. [From top of valence band to the bottom of conduction band].
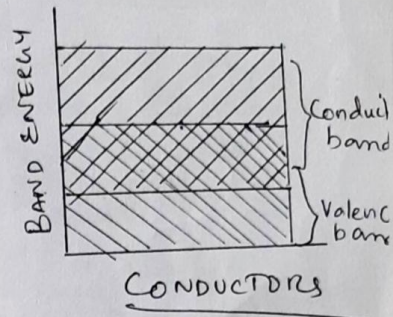
<u>Insulators</u> : In terms of energy band, the valence band is completely filled while the conduction band is empty. Also, the energy gap b/w valence and conduction band is very large ($\approx 15eV$). For this reason, for an insulator large amount of energy is required to push the valence $\bar{e}$'s to the conduction band which makes its conductivity extremely small.

Band Energy

CONDUCTION BAND

$E_g \sim 15eV$ or $> 3eV$

VALENCE BAND

Current through as there allow the passage of ē's available in them. In terms of energy band, the valence band and the conduction band overlap each other or they are closely placed. Due to this overlapping, the ē's in the valence band are easily available for conduction in the conduction band. This easily explains the high conductivity of conductors on the basis of energy band.

SEMI CONDUCTORS : Semiconductors (eg: Silicon, Germanium) are those substances whose conductivity lies b/w Conductors & insulators.
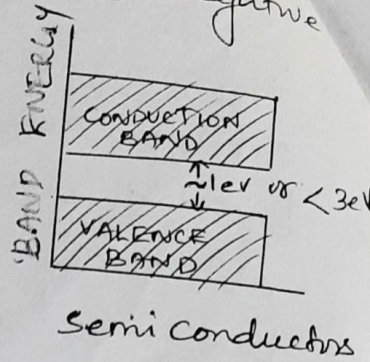

CONDUCTORS

In terms of energy band, the valence band is partly filled and Conduction band is partly empty. Further, the energy gap is very small ($< 3eV$).

Therefore, smaller electric field or thermal energy may be sufficient to push the ē's from the valence band to the Conduction band.

* At low temp., valence band is completely filled and Conduction band completely empty so that a semiconductor behaves as an insulator at these temperatures.

* At room temp, very few ē's (1 out of 10^{10}) cross over to conduction band imparting little conductivity to the semi conductor. (for Si, ionisation energy is $1.1 eV$ and Ge it is $0.7 eV$)

* As the temp. is increased, more and more e⁻ jump to Conduction band and hence its cond. increases. This shows that conductivity increases with increase in temp — ie Semiconductor has negative temperature coefficient of resistance.
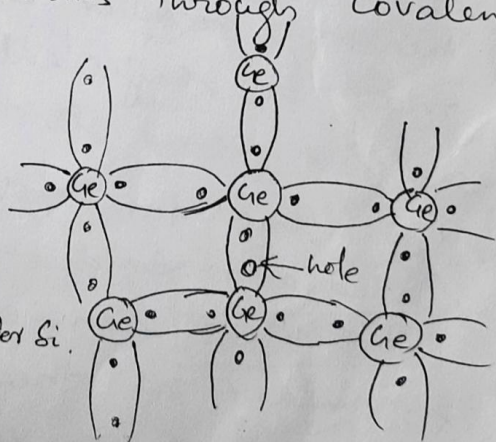
The conductivity of a semiconductor can be increased by

(i) increasing the temp.

(ii) by adding a suitable impurity (Gallium, arsenic etc)

BAND ENERGY

CONDUCTION BAND

$\simeq$ 1ev or < 3eV

VALENCE BAND

Semi conductors

Bonding of Ge or Si atoms in Germanium or Silicon Crystals.

Ge and Si are commonly used semiconductor whose 2-D arrangement of atoms is shown in fig. As they are tetravalent, these atoms complete the stable octeet. configuration by sharing their valence e⁻s with the neighbouring atoms through covalent bonds.
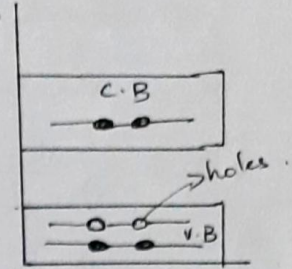
* At absolute zero, the Conduction band of S.C is empty while valence band is completely filled.

The band gap is 0.7eV for Ge and 1.1eV for Si.

* when the temp. is raised some of the covalent bonds are broken setting some of the e⁻s free to move the Conduction band. These free e⁻s can constitute

Ge Ge Ge Ge Ge Ge

hole

a tiny electric current if a p.d. is applied across the S.C. Crystal.

* As each $\bar{e}$ enter into the conduction band, it leaves a vacant space in the valence band which is called a 'hole'.

A vacancy of an $\bar{e}$ with an effective +ve charge is called a hole.

* As a p.d. is applied, the free $\bar{e}$s move constituting electric current. At the same time, hole current also flows due to ~~flows~~ movement of holes. when an electron moves from one site of covalent bond to another, under a p.d., the hole moves exactly in opp. direction. Therefore, thermal energy creates hole-electron pairs. $n_e = n_h = n_i$. (number density of $\bar{e}$s, holes = no. density of intrinsic charge carriers).

* hole current is due to the movement of valence
  Eventhough
  electrons, the hole can be considered as a site
  (virtual charge).
  of positive charge which moves in a direction opp.
  to that of $\bar{e}$s. "In fact, hole current is the most signi-
  ficant concept in S.C. physics."

Intrinsic Semi Conductor

A semiconductor in an extremely pure form is known as intrinsic S.C. .

* In an intrinsic S.C., even at room temp, $\bar{e}$-hole pairs are created. when a p.d. is applied across it, the conduction is by both free $\bar{e}$s in the conduction band & holes in the valence band. The total current is the sum of hole current & $\bar{e}$ current.

Extrinsic Semi Conductor:

The conductivity of a S.C. is very less at room temperature. Its conductivity can be increased by adding suitable impurities to it. The deliberate addition of impurities to an pure S.C. is called doping. The resulting S.C. is called extrinsic S.C.
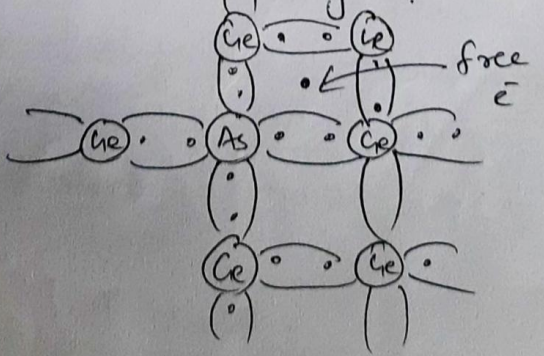
[* when a pentavalent impurity is added to the S.C., large no. of free ēs are produced while adding, & a trivalent impurity results in large no. of holes] Depending on the type of impurity added S.C. are classified into

(i) n-type S.C. (ii) p-type S.C.

n-type S.C

when a small amount of pentavalent impurity is added to a pure S.C., it is known as n-type S.C.

→ when a pentavalent impurity like Arsenic, Antimony are added to an intrinsic S.C. large no. of free ēs are & added to the lattice sites. They donate large no. of free ēs to the S.C. crystal as shown in fig

Arsenic added to the crystal site, engages in covalent bond with other Ge atoms while the fifth one is free as shown in fig. Therefore for each arsenic atom added, one free $\bar{e}$ will be available in the crystal. The addition of pentavalent impurity has produced a no. of conduction $\bar{e}$'s in the conduction band. These $\bar{e}$'s can move randomly ?cos the ionisation energy needed to free them is v. small (∼0.01

* Thermal energy of room temp. still generates a few $\bar{e}$-hole pairs plus the no. of free $\bar{e}$'s by the pentavalent impurity which predominates over holes hence called n-type S.C.
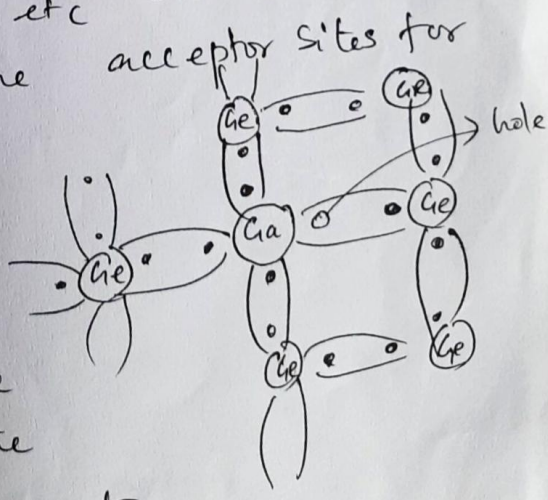
* There is additional energy level of free $\bar{e}$'s due to donor impurities — donor energy level which lies just below lowest energy level E_c.

P-type semiconductor

When a small amount of trivalent impurity is added to a pure S.C., it is called impurity is added to a pure S.C.

* The addition of trivalent impurity like Boron, Indium, Al, Gallium etc creates holes in the crystal sites which are acceptor sites for $\bar{e}$'s.

* Gallium which is trivalent has its three of its electrons engage in covalent bonds with three other Ge atoms while the fourth bond has a vacant space or hole.

* The missing ē leaves an acceptor site,
ie for each Ga atom added creates a
hole.

* Thus addition of trivalent impurity
creates a large no. of holes and they outnumber
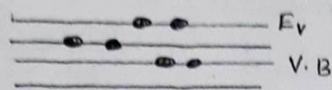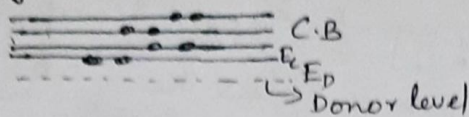the conduction ē's created by thermal
energy & hence the name p-type S.C.
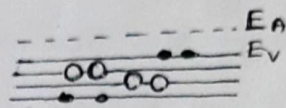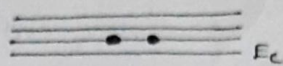

fig (i)
Energy band diagram
of n-type S.C. at T>0k

fig (ii)
Energy band diagram of
p-type S.C. at T>0k

* The acceptor impurity atom is short of
one ē & hence becomes a negative ion
while a donor impurity atom donates one
ē to the crystal & becomes +ve ion.

* The energy band diagram is modified
due to doping. There is an additional energy
level due to acceptor impurities — acceptor
energy level E_A which lies slightly above
the highest energy level in valence band E_v.
~~The Ele~~ By applying a small amount of
thermal energy, the holes from level E_A come
down to valence band (but the actual process
is movement of ē's from valence band to
E_A leaving behind holes)

[In thermal equilibrium, the total no. of holes & ē's per
unit vof. (no. density) is $n_e n_h = n_i^2$]