SEMICONDUCTOR

In its crystalline structure, every Si or Ge atom tends to share one of its four valence electrons with each of its four nearest neighbour atoms, and also to take share of one electron from each such neighbour.

These shared electron pairs are referred to as forming a covalent bond or simply a valence bond.

Intrinsic Semiconductors

As the temperature increases, more thermal energy becomes available to these electrons and some of these electrons may break–away (becoming free electrons contributing to conduction).

The thermal energy effectively ionises only a few atoms in the crystalline lattice and creates a vacancy in the bond

This vacancy with the effective positive electronic charge is called a hole. The hole behaves as an apparent free particle with effective positive charge.

In intrinsic semiconductors, the number of free electrons, ne is equal to the number of holes, nh.

That is $n_e = n_h = n_i$ where ni is called intrinsic carrier concentration.

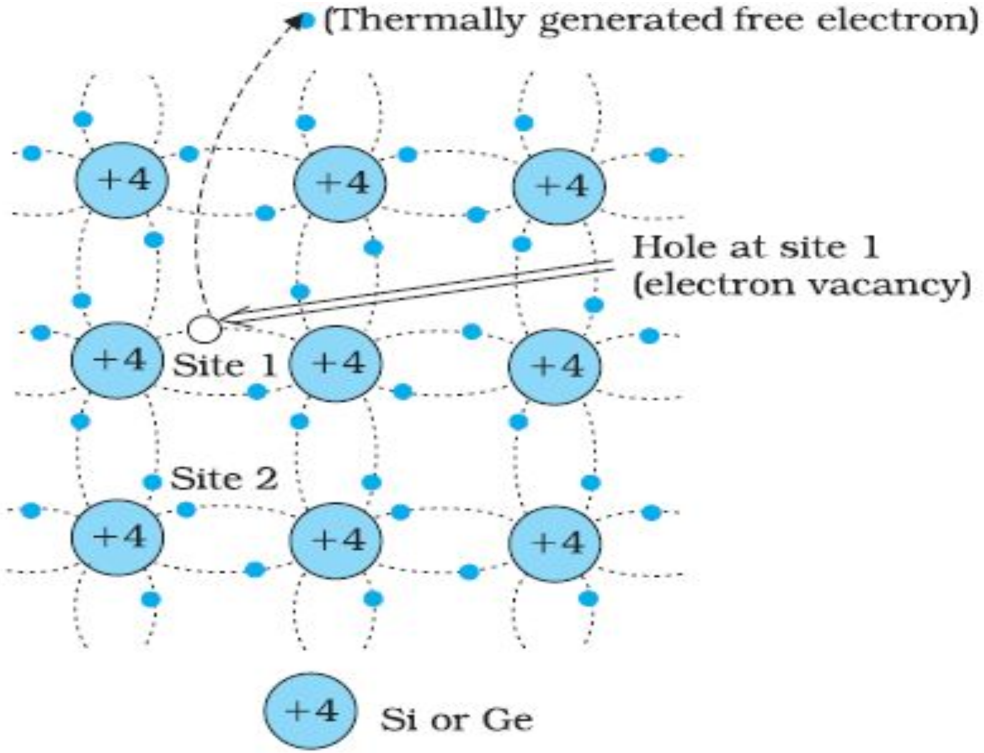
The free electron moves completely independently as conduction electron and gives rise to an electron current, Ie under an applied electric field.

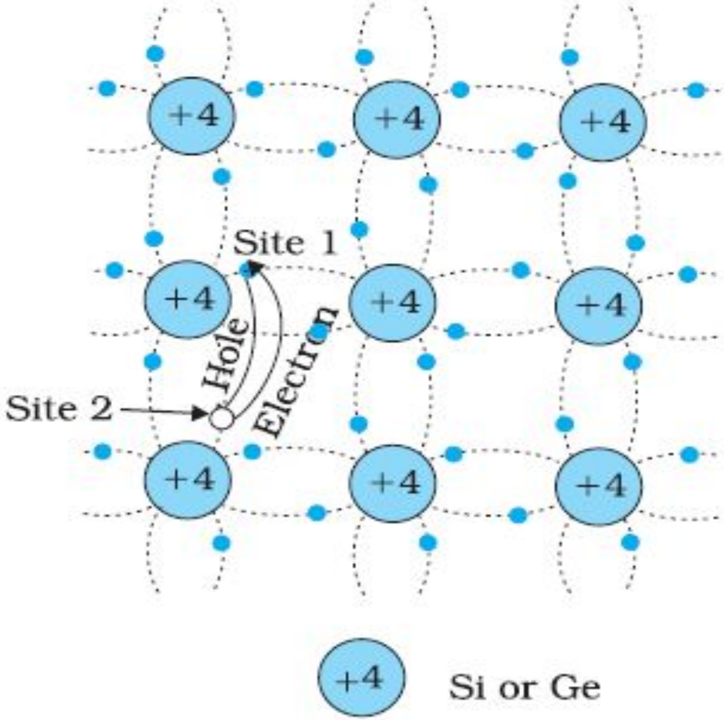
Under the action of an electric field, these holes move towards negative potential giving the hole current, I_h.

The total current, I is

thus the sum of the electron current I_e and the hole current I_h:

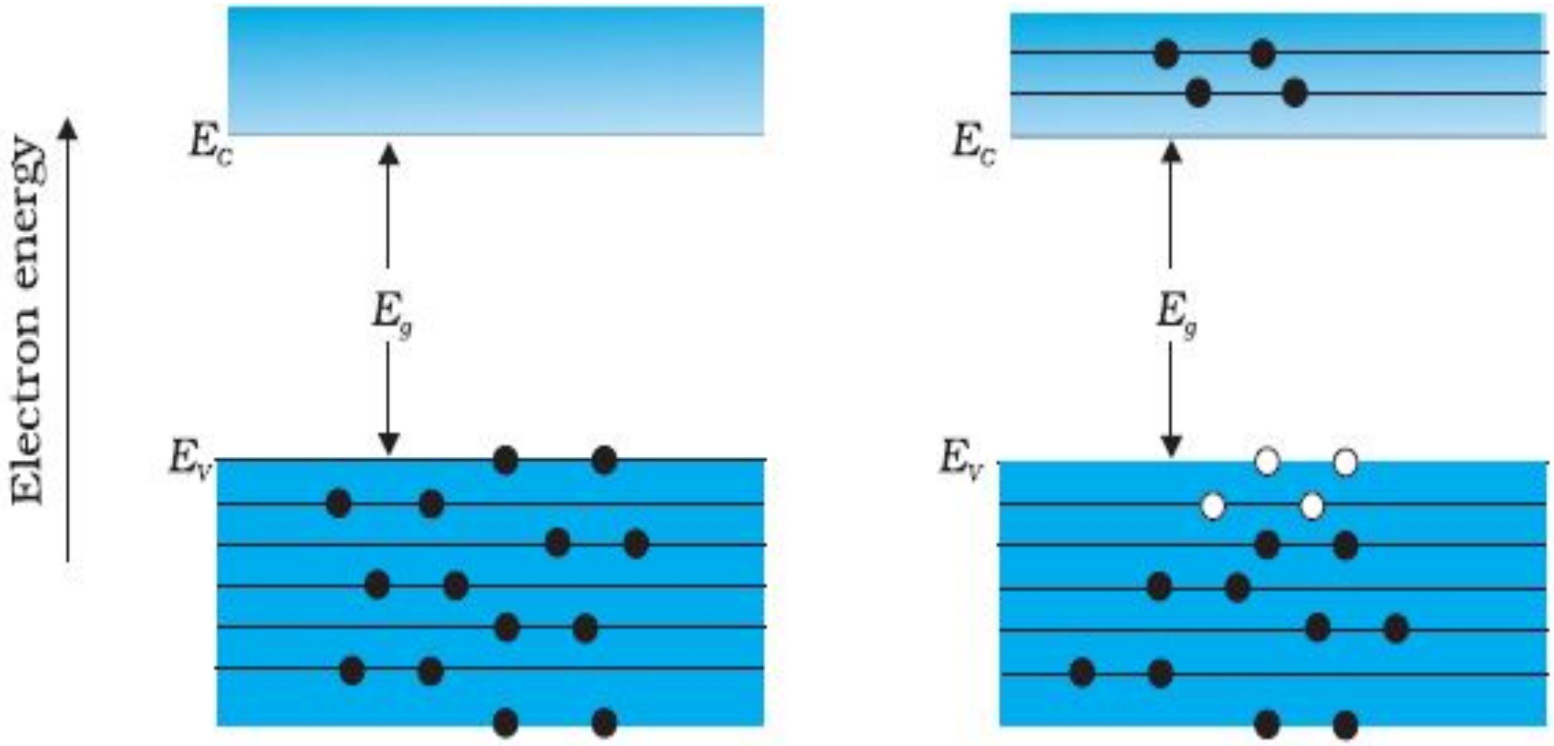
$$I = I_e + I_h$$


(Thermally generated free electron)
+4
Hole at site 1
(electron vacancy)
Site 1
Site 2
Si or Ge


Site 1
Hole
Electron
Site 2
+4
Si or Ge

It may be noted that apart from the process of generation of conduction electrons and holes, a simultaneous process of recombination occurs in which the electrons recombine with the holes.

At equilibrium, the rate of generation is equal to the rate of recombination of charge carriers. The recombination occurs due to an electron colliding with a hole



(a)

(b)

An intrinsic semiconductor will behave like an insulator at $T = 0$ K

It is the thermal energy at higher temperatures

($T > 0K$),

which excites some electrons from the valence band to the conduction band.

Here, some electrons are shown in the conduction band. These have come from the valence band leaving equal number of holes there.

EXTRINSIC SEMICONDUCTOR

When a small amount, say, a few parts per million (ppm), of a suitable impurity is added to the pure semiconductor, the conductivity of the semiconductor is increased manifold. Such materials are known as extrinsic semiconductors or impurity semiconductors.

The deliberate addition of a desirable impurity is called doping and the impurity atoms are called dopants. Such a material is also called a doped semiconductor.

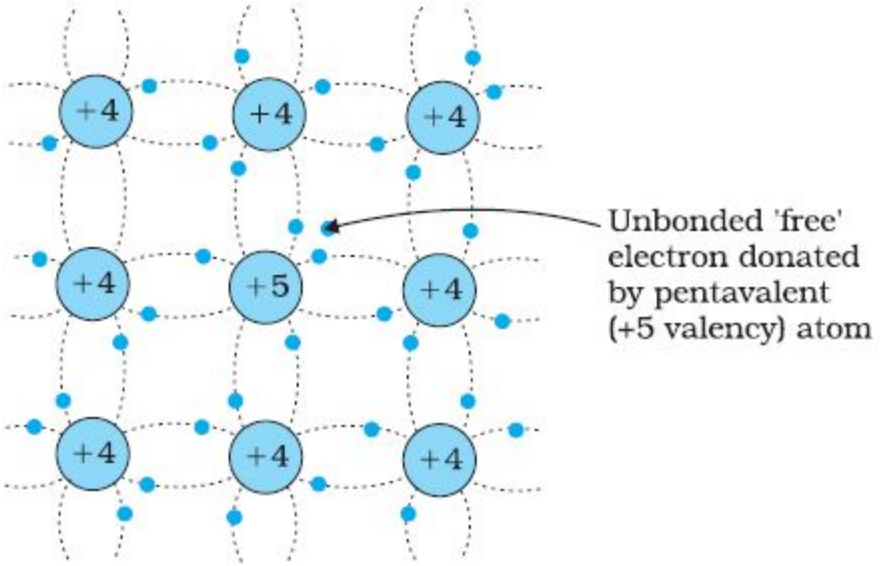
There are two types of dopants used in doping the tetravalent Si or Ge:

(i) Pentavalent (valency 5); like Arsenic (As), Antimony (Sb), Phosphorous (P), etc.

(ii) Trivalent (valency 3); like Indium (In), Boron (B), Aluminium (Al), etc.

(i) n-type semiconductor

Thus, with proper level of doping the number of conduction electrons can be made much larger than the number of holes.



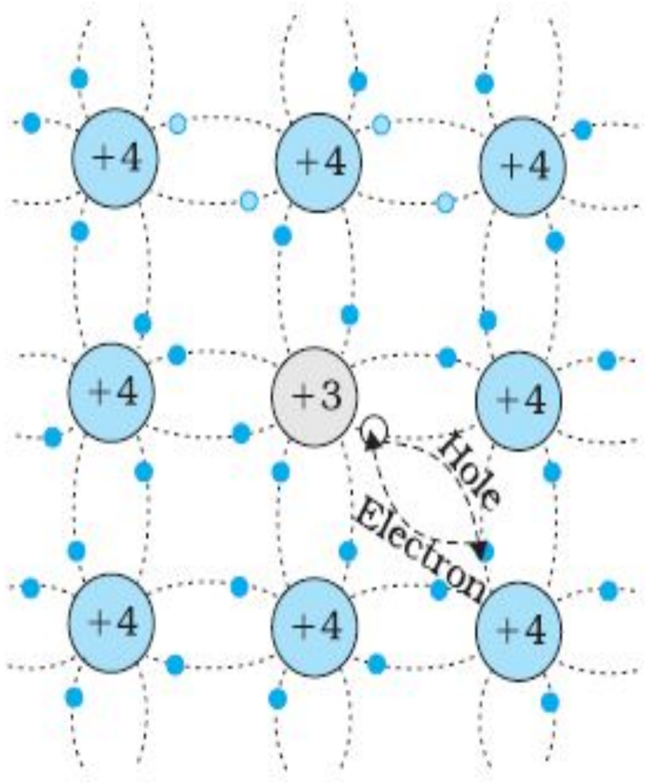
Hence in an extrinsic semiconductor doped with pentavalent impurity, electrons become the majority carriers and holes the minority carriers.

These semiconductors are, therefore, known as n-type semiconductors. For n-type semiconductors,

we have, $n_e >> n_h$

p-type semiconductor

This is obtained when Si or Ge is doped with a trivalent impurity like Al, B, In, etc.



The dopant has one valence electron less than Si or Ge and, therefore, this atom can form covalent bonds with neighbouring three Si atoms but does not have any electron to offer to the fourth Si atom.

So the bond between the fourth neighbour and the trivalent atom has a vacancy or hole

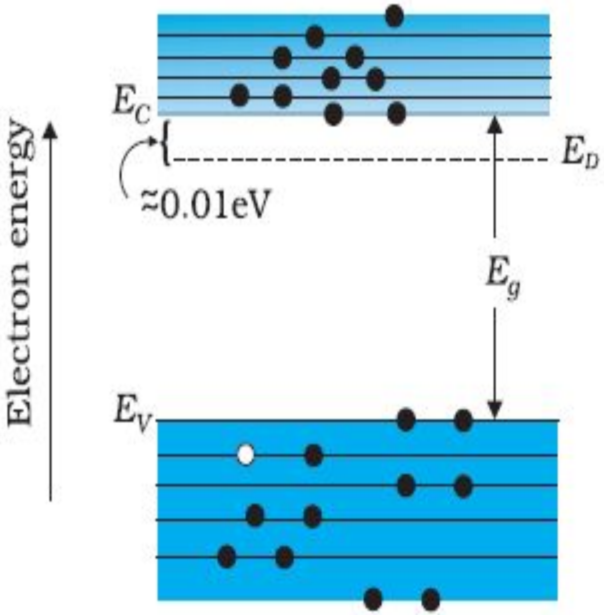
It is obvious that one acceptor atom gives one hole. These holes are in addition to the intrinsically generated holes while the source of conduction electrons is only intrinsic generation.

Thus, for such a material, the holes are the majority carriers and electrons are minority carriers. Therefore, extrinsic semiconductors doped with trivalent impurity are called p-type semiconductors

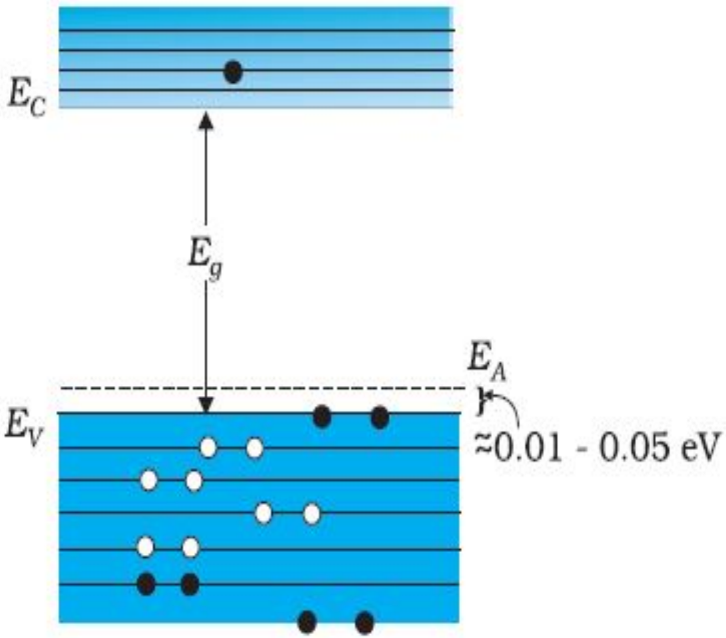
The electron and hole concentration in a semiconductor in thermal equilibrium is given by

$$n_e n_h = n_i^2$$

The p - type and n- type semiconductors are electrically neutral



(a) $T > 0K$
one thermally generated electron-hole pair + 9 electrons from donor atoms



(b) $T > 0K$

The semiconductor’s energy band structure is affected by doping. In the case of extrinsic semiconductors, additional energy states due to donor impurities (E_D) and acceptor impurities (E_A) also exist.

In the energy band diagram of n-type Si semiconductor, the donor energy level E_D is slightly below the bottom E_C of the conduction band and electrons from this level move into the conduction band with very small supply of energy.