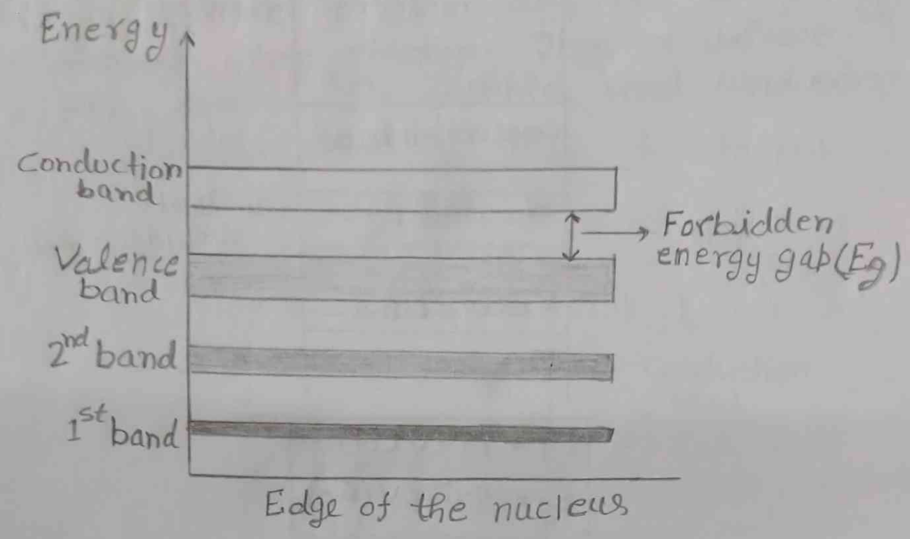
Energy Bands :-

The energy levels of electrons in each orbit merge into each other to form an energy band.

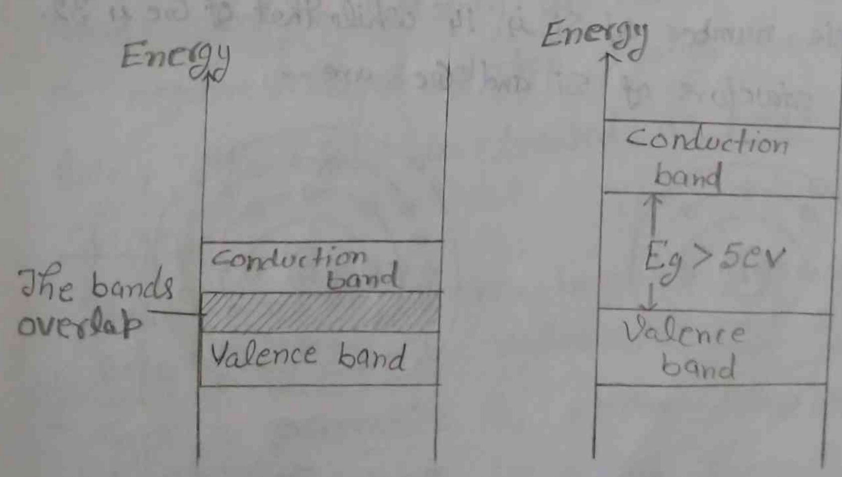
- The energy levels of valence electrons merge into each other to form a valence band. When a valence electron absorbs energy, it becomes free electron. The energy levels of all the free electrons merge into each other to form a conduction band.
- An energy band which separates the conduction band and the valence band is called forbidden energy gap (E_g).



Energy Band Diagram

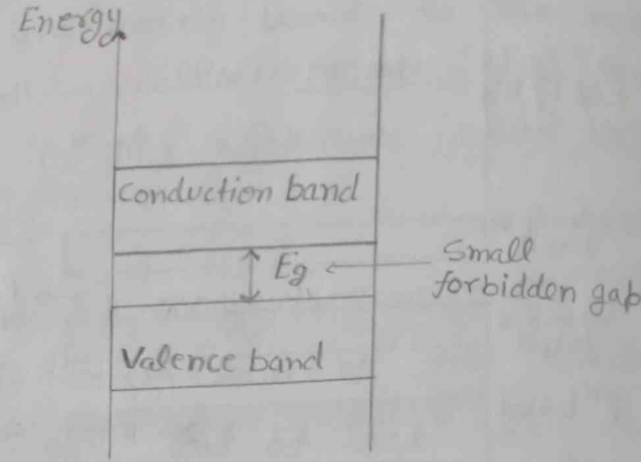
Classification based on Energy Band Diagram:-

Based on energy gap(E_G), the materials are classified as conductors, insulators and semiconductors.



(a) Conductor (b) Insulator

diagram

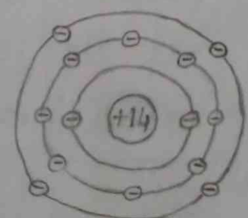


$E_g = 1.1\ eV\ (Si)$
$E_g = 0.67\ eV\ (Ge)$

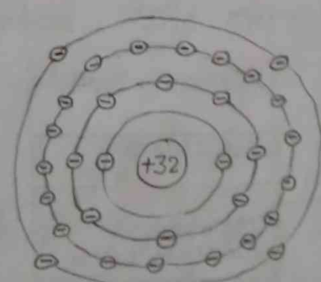
(c) Semiconductor

Structure of Silicon & Germanium :-

There are two important semiconductor materials, silicon (Si) and germanium (Ge). These two atoms has four electrons in a valence shell. The atomic number of Si is 14 while that of Ge is 32. The structure of Si and Ge are –



Si



Ge

no. of shells = 3 no. of shells = 4

outermost shell is valence shell

Why silicon is most widely used ?

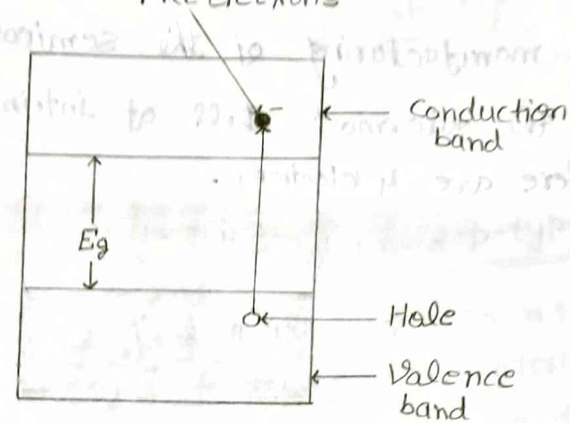
Looking at the structure of silicon and germanium atom, it can be seen that valence shell of silicion is 3^{rd} shell while valence shell of germanium is 4^{th} shell. Hence valence electrons of germanium are at larger distance from nucleus than valence electrons of silicon. Hence valence electrons of germanium are more loosely bound to the nucleus than those of silicon. Thus valence electrons of germanium can easily escape from the atom, due to very small additional energy imparted to them. So at high temperature, germanium becomes unstable than silicon and and hence silicon is widely used as semiconductor material.

Why semiconductors have negative temperature coefficient ?

At absolute zero temperature, there are no free electrons in the semiconductors. Hence the semiconductors behave as perfect insulators. As temperature increases, the electrons acquire thermal energy and some are available as free electrons in the conduction band. Due to the increased number of free electrons, the resistance of the semiconductor material decreases as the temperature increases. As temperature increases, the energy gap in the semiconductors decreases, hence more number of electrons can cross the gap and move from valence band to conduction band, as temperature increases. At high temperature, the conductivity of semiconductors is very high and resistance decreases to very low value. This characteristics is called negative temperature coefficient of semiconductors.

Concept of Electron-Hole Pairs :-

When a valence electron absorbs the energy, it becomes free electron. Thus a valence electron leaves the valence band and enters the conduction band.



Generation of electron-hole pair

When a valence electron drifts from the valence band, a vacancy is created in the valence band. Such a vacancy is called a <u>hole.</u> As negative charged electron leaves behind a hole, the hole is treated as <u>positively charged.</u>

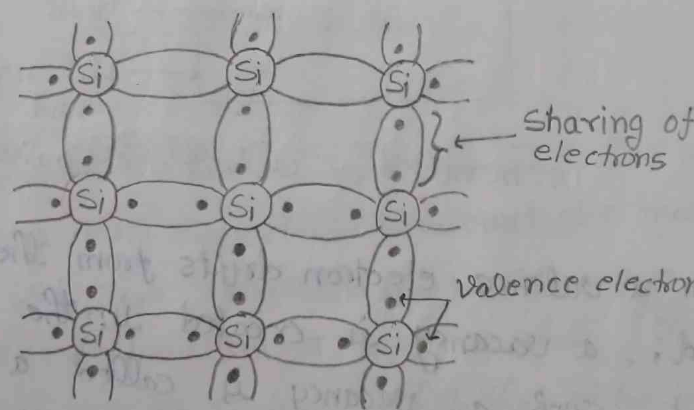
Thus when an electron becomes free, a hole gets generated in valence band.

- Such a generation of electron-hole pairs due to temperature is called <u>thermal generation</u> in semiconductors.

Intrinsic Semiconductor:-

A sample of semiconductor in its purest form is called an intrinsic semiconductor. The conductivity of such intrinsic semiconductor is very poor and practically can not be used for manufacturing of the semiconductor devices.

- In the outermost shell of intrinsic semiconductor, there are 4 electrons.



Crystalline structure of Si

- Such atoms have a crystalline structure in which 4 electrons of one atom share the 4 electrons of an adjacent atom, forming covalent bonds. This is shown in above fig.
- Hence the outermost shells of all the

atoms are completely filled with 8 electrons and are very stable. Thus all these electrons are tightly bound to the nucleus.

- Hence there are no free electrons and the conductivity of such intrinsic materials is very poor. Infact at absolute zero temperature, intrinsic semiconductors behave as insulators.

* Concentration of free e^- and holes will always be equal in an intrinsic semiconductor.

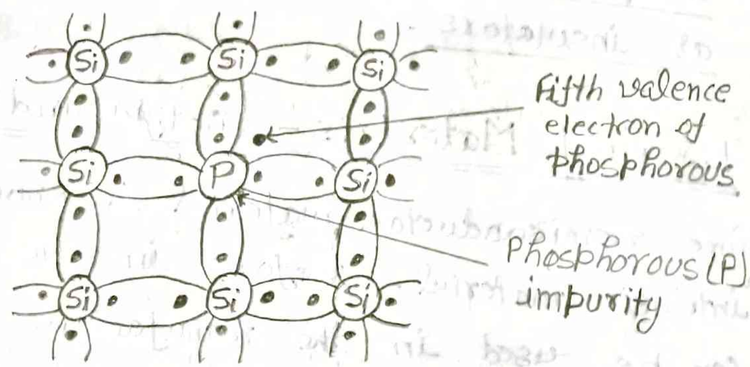
Extrinsic Materials - (n-type and p-type) :→

Pure semiconductor material is known as intrinsic material. Before intrinsic material can be used in the manufacture of a device, impurity atoms must be added to improve its conductivity. The process of adding the atoms is termed doping.

Two different types of doping are possible- donar doping and acceptor doping. Donar doping generates free electrons in the conduction band. Acceptor doping produces holes in the material. After doping, the semiconductor material is known as extrinsic material.

n-type Material –

The n-type is created by introducing those impurity elements that have five valence electrons (pentavalent), such as - P, As & Sb. The effect of such impurity elements is indicated in following fig –



n-type material formation

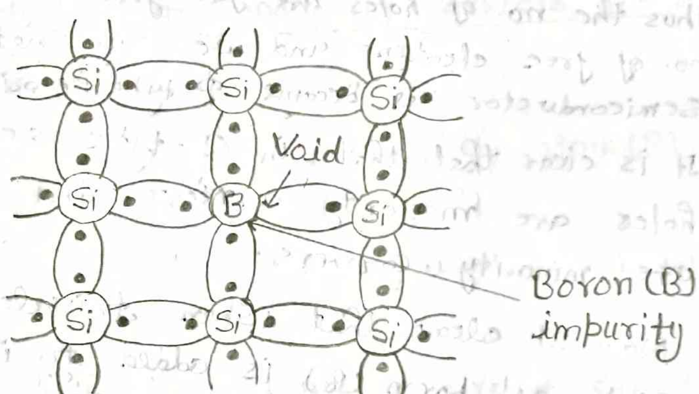
- 4 of 5 valence electrons form covalent bonds with four adjacent silicon atom.

The fifth electron is in excess and is loosely bound to phosphorous atom. This fifth electron requires very little energy to free itself from the phosphorous atom.

And this energy is so small that at room temperature almost <u>all such electrons become free.</u>

p- type Material →

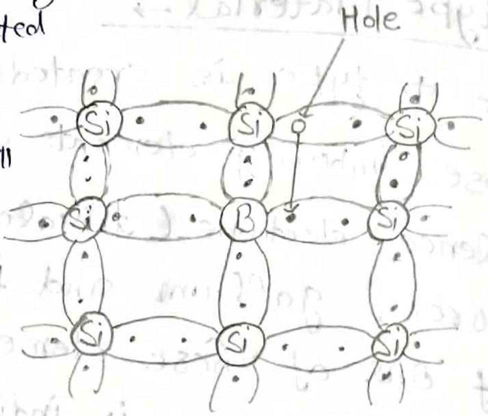
The p-type is created by introducing those impurity elements that have three valence electrons (trivalent) such as - boron, gallium and indium. The effect of one of these elements, boron, on a base of silicon is indicated as -



- Boron atom has only three valence electrons. These three valence electrons form covalent bonds with the three adjacent silicon atoms. Fourth adjacent Si atom is unable to form a covalent bond. As shown in above fig.
- There is chances that one covalent bond b/w two Si atom is broken and the electron jumps to occupy the vacancy around boron atom and hence a covalent bond is established b/w boron and Si atom.

- In this process two things happen.

First a vacancy is created in the adjacent Si atom which is called as hole. It is clear that hole will be positively charged.



- Second Boron with 3 valence electrons was earlier neutral but now because it has accepted one extra electron so this B atom is now -Ve charged.

- Thus the no. of holes are far greater than the no. of free electrons and we say that semiconductor has become P-type (positively type)
It is clear that that in P-type semiconductor holes are majority carriers and free electron are minority carriers.

- Now it clear that when trivalent impurity such as boron (B) is added to intrinsic semiconductor material, we get
  * A hole
  * And a negatively charged immobile ions

Note - Trivalent impurity such as boron acceps one electron that is why such type of impurity is called as Acceptor impurity.

1.5.2 Conduction in n-type Material

- In intrinsic semiconductor, the number of free electrons and holes is same. But when pentavalent impurity is added in large extent, the number of free electrons becomes very high compared to the number of holes.
- Thus if voltage is applied, the current is mainly because of free electrons which are large in number. Hence the free electrons are called **majority carriers** in n-type material. While there is small current due to less number of holes. Hence the holes are called **minority carriers** in n-type material.
- This is shown in the Fig. 1.5.2.

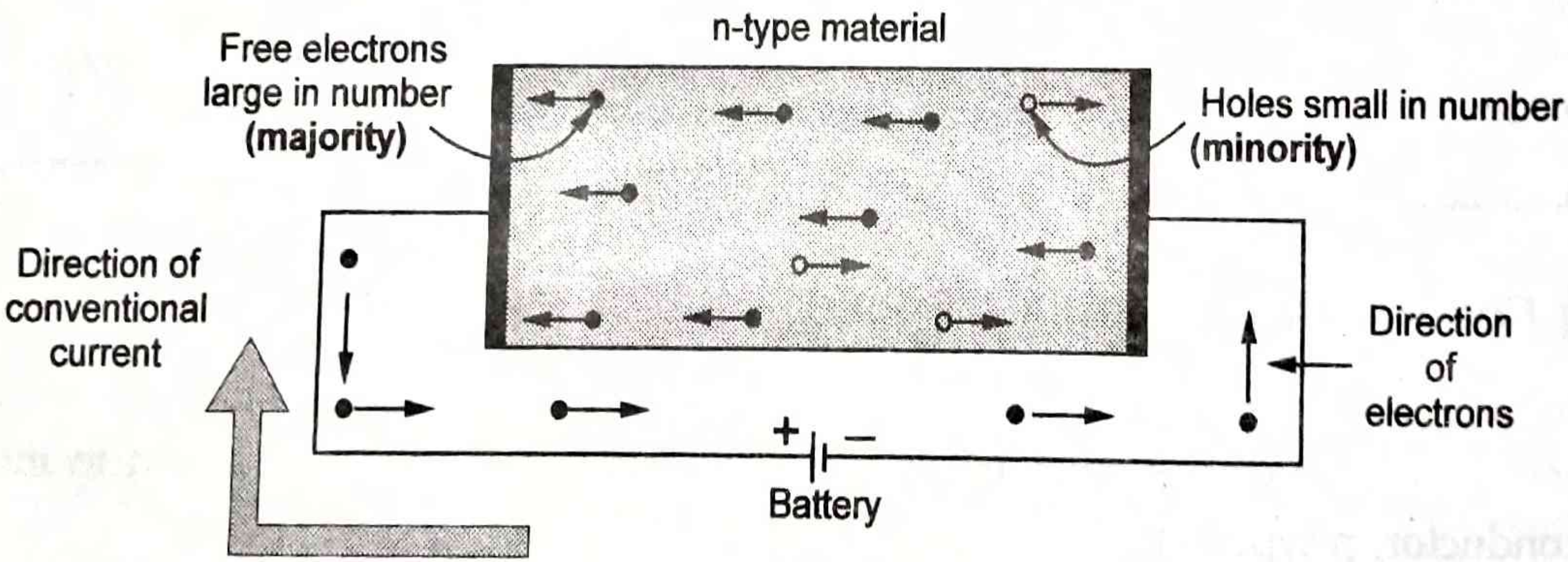


Fig. 1.5.2 Conduction in n-type material

1.5.4 Conduction in p-type Material

- When large trivalent impurity is added to silicon or germanium, the number of holes becomes very high as compared to free electrons.
- Thus if voltage is applied, the holes which are large in number move towards negative of battery and mainly responsible for the current. Hence the hole are called **majority carriers** in p-type material while there is small current due to the movement of less number of free electrons. Hence the free electrons are called **minority carriers** in p-type material.
- This is shown in the Fig. 1.5.4.

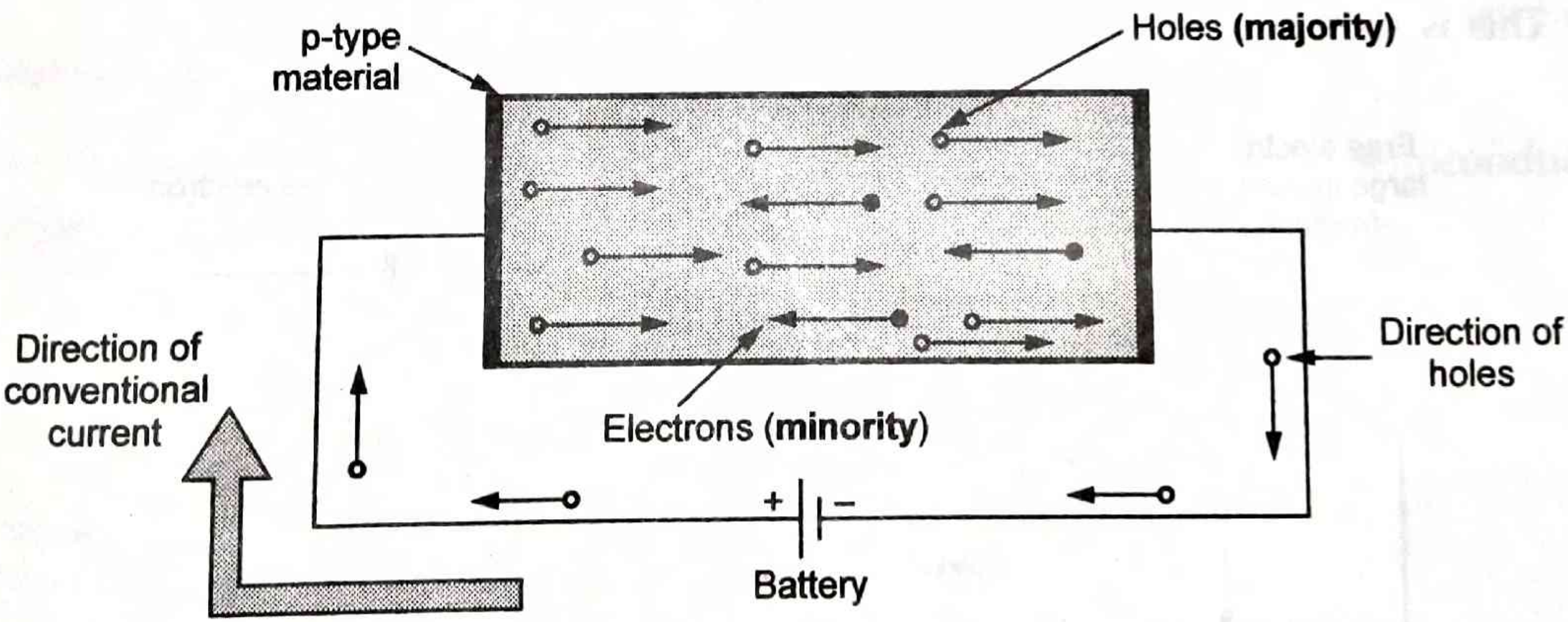


Fig. 1.5.4 Conduction in p-type material