SEMICONDUCTOR

Introduction

Classification of solids on the basis of their electrical properties. On the basis of their relative values of electrical conductivity (σ) or resistivity ($\rho = 1/\sigma$), we can broadly classify solids into *three* categories :

A. Metals. They have very low resistivity or high conductivity.

$$\rho \approx 10^{-2} - 10^{-8} \, \Omega m$$
$$\sigma \approx 10^{2} - 10^{8} \, Sm^{-1}$$

B. Insulators. They have high resistivity or low conductivity.

$$\rho \approx 10^{8} \, \Omega m$$
$$\sigma \approx 10^{-8} \, Sm^{-1}$$

C. Semiconductors. They possess resistivity or conductivity intermediate to metals and insulators.

$$\rho \approx 10^{5} - 10^{0} \, \Omega m$$
$$\sigma \approx 10^{-5} - 10^{0} \, Sm^{-1}$$

In this chapter we are mainly concerned with semiconductors. Some of their distinguishing features are as follows :

1. Semiconductors have a much higher resistivity than metals.

2. Semiconductors have a *temperature coefficient of resistivity* (α) that is both *negative* and *high*. That is the resistivity of *semiconductors decreases* rapidly with temperature

3. Semiconductors have a considerable lower number density n of charge carriers (charge carriers per unit volume) than **metals**.

Classification of semiconductors on the basis of their chemical composition. This scheme divides semiconductors broadly into elemental and compound semiconductors.

A. Elemental semiconductors : Si and Ge.

B. Compound semiconductors : Examples are :

(i) *Inorganic* : CdS, GaAs, CdSe, InP, etc.

(ii) *Organic polymers* : Polypyrrole, polyaniline, polythiophene, etc.

Types of Semiconductor

A. Intrinsic semiconductors. *The pure semiconductors (impurity less than 1 part in 10^{10}) are called intrinsic semiconductors.* The presence of the mobile charge carriers (electrons and holes) is an *intrinsic* property of the material and these charges are obtained as a result of thermal excitation.
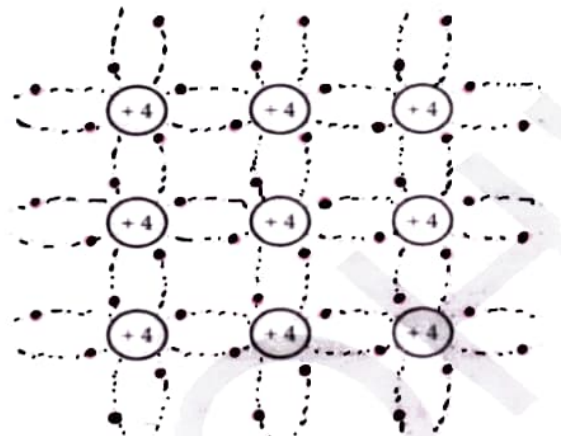
B. Extrinsic semiconductors. *The semiconductors obtained by adding or doping the pure semiconductor with small amounts of certain specific impurity atoms having valency different from that of the host atoms are called extrinsic semiconductors.* Doping drastically changes the number density of mobile electrons and holes. The electrical conductivity of such semiconductors is essentially due to the foreign atoms *i.e., extrinsic* in nature.

Conductivity in Intrinsic Semiconductor

Consider the crystal of semiconductor Ge or Si. Each Ge atom has four valence electrons which it shares with the four nearest neighbouring atoms to form four covalent bonds. Thus each Ge atom is bonded to four neighbouring Ge atoms

As the temperature increases, the thermal energy of the valence electrons increases. an electron may break away from the covalent bond and becomes *free* to conduct electricity. This electron leaves behind a vacancy in the covalent bond (at site 1). This vacancy of an electron with an effective *positive electronic charge is called a **hole**.*
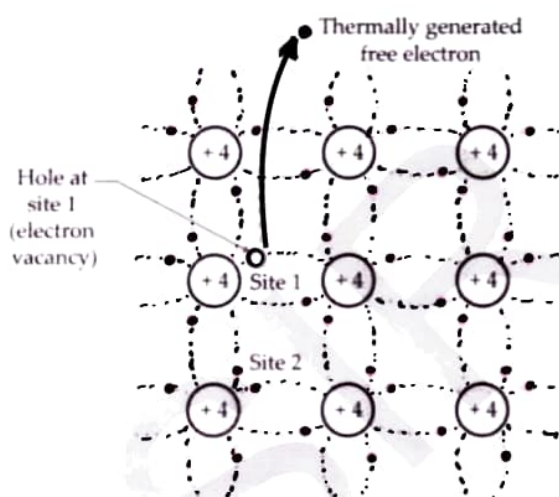
Fig. 14.2 Generation of a hole at site 1 and liberation of a free electron due to thermal energy at moderate temperature.

As each free electron creates one hole, so in an intrinsic semiconductor, the number density of free electrons (n_e) is equal to the number density of holes (n_h) and each is equal to the *intrinsic charge carrier concentration* (n_i).

$$n_e = n_h = n_i$$

The total current is

$$I = \text{Electron current} + \text{hole current} = I_e + I_h.$$

limitations of Intrinsic Semiconductor

Limitations of intrinsic semiconductors. When intrinsic semiconductors are used for developing semiconductor devices, they have many limitations as discussed below :

1. Intrinsic semiconductors have low intrinsic charge carrier concentration (of hole and electrons) $\approx 10^6 \, m^{-3}$. So they have low electrical conductivity.
2. As intrinsic charge carriers are always thermally generated, so flexibility is not available to control their number.

Doping

*The process of deliberate addition of a desirable impurity to a pure semiconductor so as to increase its conductivity is called doping. The impurity atoms added are called **dopants** and the semiconductors doped with the impurity atoms are called **extrinsic** or **doped semiconductors**.*

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

(i) *Pentavalent dopants.* They **have** 5 valence electrons. For example, arsenic (As), antimony (Sb) and phosphorous (P).

(ii) *Trivalent dopants.* They have 3 valence electrons. For example, indium (In), boron (B) and aluminium (Al).

On doping Si or Ge with pentavalent and trivalent impurity atoms, we get two entirely different types of semiconductors, called **n-type** and **p-type** semiconductors respectively.

Extrinsic Semiconductor

Extrinsic semiconductors. *A semiconductor doped with some suitable impurity atoms so as to increase its number of charge carriers is called an extrinsic semiconductor.*

Extrinsic semiconductors are of *two* types :

1. *n*-type semiconductors.
2. *p*-type semiconductors.

1. *n*-type semiconductor. This semiconductor is obtained by doping the tetravalent semiconductor Si (or Ge) with pentavalent impurities such as As, P or Sb of group V of the periodic table.

when a pentavalent impurity atom substitutes the tetravalent Si atom, it uses four of its five valence
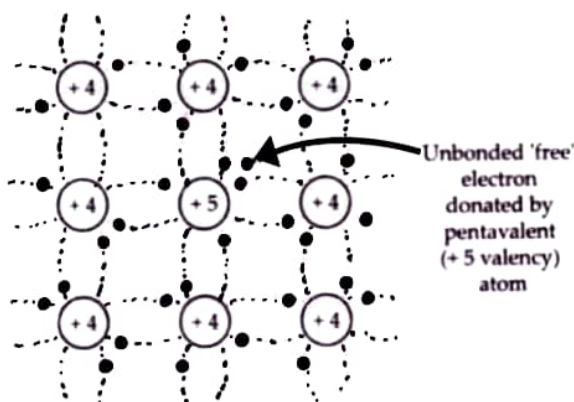

Fig. 14.4 Formation of *n*-type semiconductor by doping tetravelent Si with pentavalent impurity.

electrons in forming four covalent bonds with neighbouring Si atoms while the fifth electron is loosely bound to the impurity atom. A very small amount of ionisation energy (≈ 0.01 eV for Ge and 0.05 eV for Si) is required to detach this electron. At room temperature, the thermal energy is enough to set free this electron.

As each pentavalent impurity atom donates one extra electron for conduction, it is called a **donor**. These semiconductors have free electrons contributed by donors and generated by the thermal process while the holes are only due to thermal generation. Hence, the **electrons are the majority charge carriers** and **holes** are the **minority charge carriers**. As most of the current is carried by the negatively charged electrons, so the semiconductors doped with donor type impurities are known as *n-type* semiconductors.

For such semiconductors,

$$n_e \gg n_h \quad \text{or} \quad n \gg p$$

2. p-type semiconductor. Such a semiconductor is obtained by doping the tetravalent semiconductor Si (or Ge) with trivalent impurities such as In, B, Al or Ga. the impurity atom uses its three valence electrons in forming covalent bonds with three neighbouring Si atoms and one covalent bond with a
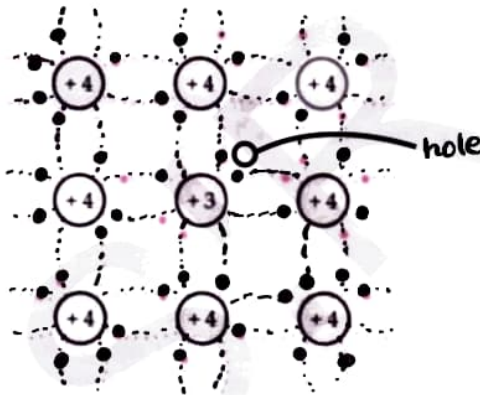

Fig. 14.6 Formation of **p-type** semiconductor by doping tetravelent Si with trivalent impurity.

neighbouring Si atom is left incomplete due to the deficiency of one electron. An electron from the neighbouring Si-Si covalent bond can slide into this vacant bond, creating a vacancy or hole in that bond. This hole is now available for conduction.

The *trivalent impurity atom is called an acceptor* because it creates a hole which can accept an electron from the neighbouring bond. Obviously, there are holes created by the acceptor atoms in addition to the thermally generated holes while the free electrons are only due to thermal generation. Hence, holes are the *majority charge carriers* and electrons are the *minority charge carriers*. The semiconductors doped with acceptor type impurities are called *p-type semiconductors*, because most of the current in these semiconductors is carried by holes which have effective positive charge. For such semiconductors,

$$n_h \gg n_e \quad \text{or} \quad p \gg n$$

Band theory

Valence Band

The electrons in the outermost shell are known as valence electrons. These valence electrons contain a series of energy levels and form an energy band known as the valence band. The valence band has the highest occupied energy.

Conduction Band

The valence electrons are not tightly held to the nucleus due to which a few of these valence electrons leave the outermost orbit even at room temperature and become free electrons. The free electrons conduct current in conductors and are therefore known as conduction electrons. The conduction band is one that contains conduction electrons and has the lowest occupied energy levels.

Forbidden Energy Gap

The gap between the valence band and the conduction band is referred to as the forbidden gap. As the name suggests, the forbidden gap doesn't have any energy and no electrons stay in this band. If the forbidden energy gap is greater, then the valence band electrons are tightly bound or firmly attached to the nucleus. We require some amount of external energy that is equal to the forbidden energy gap.
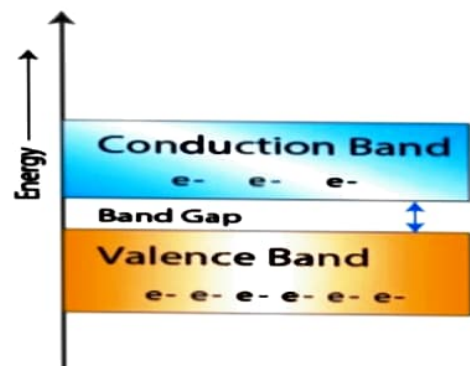
1. Metals. Here the last occupied band, called conduction band is partially filled with electrons. Two types of band structures are found in metals :

(i) Either there is energy gap between the completely filled valence band and the partially filled conduction band. As shown in Fig. 14.10[a(i)], this band structure is met in alkali metals (Li, Na, K, etc), noble metals (Cu, Ag, Au) and third group elements like Al, Ga, In and Tl.
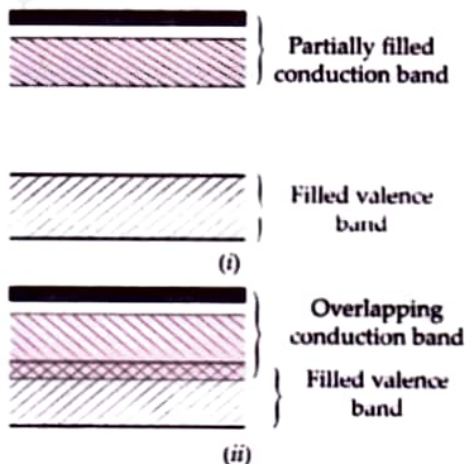

(i)

(ii)

Fig. 14.10 (a) **Energy band diagram for a metal.**

(ii) Or the conduction and valence bands partly overlap. As shown in Fig. 14.10[a(ii)], this band structure is seen in metals like Be $(Z = 4 : 1s^2 2s^2)$, Mg$(Z = 12 :$

2. Insulators. In insulators, the valence band is completely filled while the conduction band is empty. As shown in Fig. 14.10(b), there is a large energy gap $(E_g > 3 \text{ eV})$ between the valence and conduction bands. For example, in case of diamond, $E_g = 6$ eV. Even an electric field cannot give this much energy to an electron to make it jump from the valence band into the conduction band. Hence due to the lack of free electrons in the conduction band, the insulators are poor conductors of electricity.
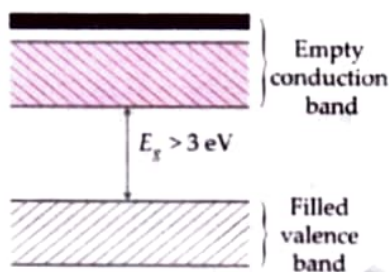

Fig. 14.10 (b) **Energy band diagram for an insulator.**

3. Semiconductors. At 0 K, the conduction band is empty and the valence band is filled. So the material is essentially insulator at low temperatures. However, the energy gap between conduction and valence bands is small $(E_g < 3 \text{ eV})$. For example, $E_g = 1.17$ eV for Si and $E_g = 0.74$ eV for Ge. At room temperature, some valence electrons acquire enough thermal energy and jump to the conduction band where they are free to conduct electricity (according to Boltzmann law, number of thermally excited electrons $n \propto e^{-E_g/kT}$). Thus the semiconductor acquires a small conductivity at room temperature.
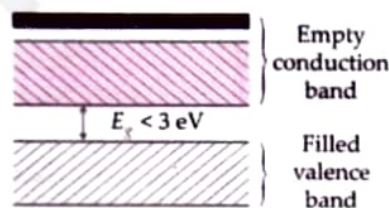

Fig. 14.10 (c) **Energy band diagram for a semiconductor.**

Fermi Level

The highest energy level in the conduction band filled up with electrons at absolute zero is called Fermi level and the energy corresponding to the Fermi level is called **Fermi Energy**.

Energy band of Semiconductors

Energy band diagram of *n*-type semiconductor. In *n*-type semiconductors, the extra (fifth) electron is very weakly attracted by the donor impurity. A very small energy (≈ 0.01 eV) is required to free this electron When freed, this electron will occupy the lowest possible energy level in the conduction band i.e., the energy of the donor electron is slightly less than E_c. Thus the donor energy level E_D lies just below the bottom of the conduction band as shown in Fig. 14.11(b). At room temperature this small energy gap is easily covered by the thermally excited electrons. The conduction band has more
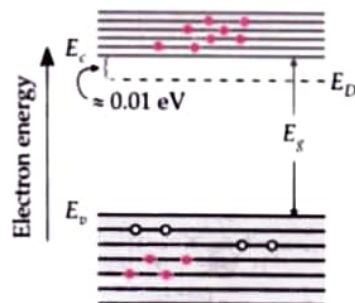

Fig. 14.11 (b) **Energy band diagram of *n*-type semiconductor at $T > 0$ K**

electrons (than holes in valence band) as they have been contributed both by thermal excitation and donor impurities.

Energy band diagram of p-type semiconductors. In p-type semiconductors, each acceptor impurity creates a hole which can be easily filled by an electron of Si-Si covalent bond i.e., a very small energy ($\approx 0.01 - 0.05$ eV) is required by an electron of the valence band to move into this hole. Hence the acceptor energy level E_A lies slightly above the top of the valence band, as shown in Fig. 14.11(c). At room temperature, many electrons of the valence band get excited to these acceptor energy levels, leaving behind equal number of holes in the valence band. These holes can conduct current. Thus the valence band has more holes than electrons in the conduction band.
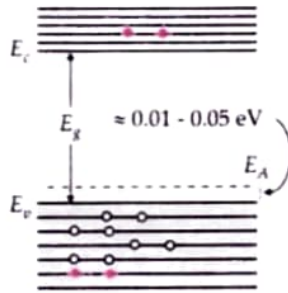

Fig. 14.11 (c) Energy band diagram of p-type semiconductor at $T > 0$ K.

Energy band diagram of intrinsic semiconductors. At $T = 0$ K, the valence band of a semiconductor is completely filled with electrons while the conduction band is empty, as shown in Fig. 14.11[a(i)]. Hence an intrinsic semiconductor behaves like an insulator at $T = 0$ K. At higher temperatures ($T > 0$ K), some electrons of the valence band gain sufficient thermal

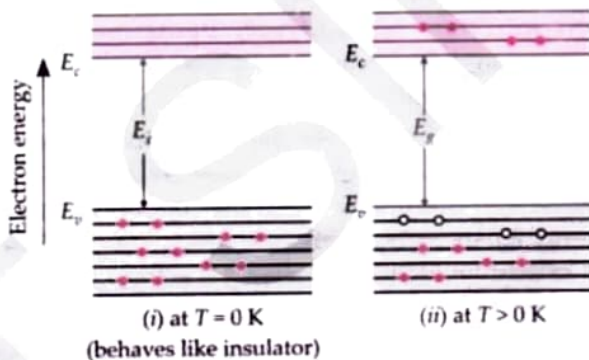(i) at $T = 0$ K
(behaves like insulator)
(ii) at $T > 0$ K

Fig. 14.11 (a) Energy band diagrams of intrinsic semiconductor

energy and jump to the conduction band, creating an equal number of holes in the valence band. These thermally excited electrons occupy the lowest possible energy levels in the conduction band. Therefore, the energy band diagram of an intrinsic semiconductor at $T > 0$ K is of the type shown in Fig. 14.11[a(ii)]. Clearly, the number of electrons in conduction band is equal to the number of holes in valence band.

Difference

	Intrinsic Semiconductors	Extrinsic Semiconductors
1.	These are pure semi-conducting tetravalent crystals.	These are semi-conducting tetravalent crystals doped with impurity atoms of group III or V.
2.	Their electrical conductivity is low.	Their electrical conductivity is high.
3.	There is no permitted energy state between valence and conduction bands.	There is permitted energy state of the impurity atom between valence and conduction bands.
4.	The number of free electrons in the conduction band is equal to the number of holes in valence band.	The electrons are majority charge carriers in n-type semiconductors while holes are majority charge carries in p-type semiconductors.
5.	Their electrical conductivity depends on temperature.	Their electrical conductivity depends on temperature as well as on dopant concentration.

	n-type semiconductors	p-type semiconductors
1.	These are extrinsic semiconductors obtained by doping impurity atoms of group V to Ge or Si crystal.	These are extrinsic semiconductors obtained by doping impurity atoms of group III to Ge or Si crystal.
2.	The impurity atoms added provide free electrons and are called donors.	The impurity atoms added create vacancies of electrons (or holes) and are called acceptors
3.	The donor impurity level lies just below the conduction band.	The acceptor impurity level lies just above the valence band.
4.	The electrons are majority charge carriers while holes are minority charge carriers.	The holes are majority charge carriers while electrons are minority charge carriers.
5.	The free electron density is much greater than hole density, i.e., $n_e \gg n_h$.	The hole density is much greater than free electron density, i.e., $n_h \gg n_e$.

Hole

Holes. *The vacancy or absence of an electron in the bond of a covalently bonded crystal is called a hole.* In terms of band theory, whenever an electron is removed from the completely filled valence band of a semiconductor, a vacancy is left behind in the valence band. This vacancy serves as a positive charge carrier and is called a hole.

Characteristics of holes :

1. A hole is just a vacancy created by the removal of an electron from a covalent bond of semiconductor.
2. It has the same mass as the (removed) electron.
3. It is associated with a positive charge of magnitude e.

Mobility

Electrical mobility. *The drift velocity acquired by a charge carrier in a unit electric field is called its electrical mobility and is denoted by μ.* In a semiconductor,

| Drift velocity of | $\propto$ | Applied |
| a charge carrier | | electric field |

or $\quad v \propto E \quad$ or $\quad v = \mu E \quad \therefore \quad \boxed{\mu = \dfrac{v}{E}}$

Hence, *the electrical mobility μ is the drift velocity per unit electric field.*

The mobility of an electron in the conduction band of a semiconductor is greater than the mobility of a hole in the valence band. The electrons in the conduction band are almost free. They get easily accelerated by an electric field. But the electrons in the valence band are bound between the atoms of a semiconductor. They are less accelerated by an electric field and so acquire drift velocity smaller than that of electrons in the conduction band. The mobility of electrons in the valence band is less than the mobility of electrons in the conduction band. As the motion of an electron in the valence band is equivalent to the motion of a hole in the opposite direction, hence the mobility of hole in the valence band is smaller than the mobility of an electron in conduction band.

Conductivity and Resistivity

Electrical conductivity of a semiconductor. Consider a block of semiconductor of length l, area of cross-section A, and having free electron density n_e
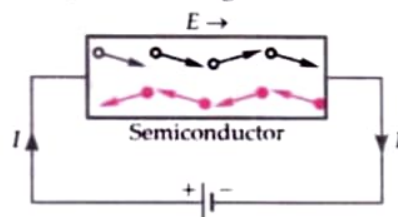

Fig. 14.12 Drifting of electrons and holes in a semiconductor on application of voltage V.

and hole density n_h. Suppose a potential difference V is applied across its ends. The electric field set up inside it will be

$$E = \frac{V}{l} \qquad \text{...(1)}$$

Electrons begin to drift with velocity v_e in the opposite direction of E while the holes drift in the direction of E with velocity v_h

∴ Total current = Electron current + Hole current

or $\qquad I = I_e + I_h \qquad \text{...(2)}$

As electrons in the conduction band and holes in the valence band move randomly like free electrons in metals, therefore we can write

$$I_e = e n_e A v_e \text{ and } I_h = e n_h A v_h$$

$$\therefore \quad I = e n_e A v_e + e n_h A v_h$$

$$= e A (n_e v_e + n_h v_h) \qquad \text{...(3)}$$

If R is the resistance of the semiconductor block and ρ its resistivity, then

$$R = \rho \frac{l}{A} \qquad \text{...(4)}$$

If the applied electric field E is low, the semiconductors obey Ohm's law so that

$$I = \frac{V}{R} = \frac{El}{\rho l / A} \qquad \text{[By using (1) and (4)]}$$

or $\qquad I = \dfrac{EA}{\rho} \qquad \text{...(5)}$

From equations (3) and (5), we get

$$I = \frac{EA}{\rho} = e A (n_e v_e + n_h v_h) \qquad \text{...(6)}$$

or $\qquad \dfrac{E}{\rho} = e(n_e v_e + n_h v_h)$

As mobility μ is defined as drift velocity per unit electric field, therefore

Electron mobility,

$$\mu_e = \frac{v_e}{E} \quad \text{or} \quad v_e = \mu_e E$$

Hole mobility,

$$\mu_h = \frac{v_h}{E} \quad \text{or} \quad v_h = \mu_h E$$

Hence

$$\frac{E}{\rho} = e(n_e \mu_e E + n_h \mu_h E)$$

or

$$\frac{1}{\rho} = e(n_e \mu_e + n_h \mu_h)$$

The conductivity, which is reciprocal of resistivity, is given by

$$\sigma = \frac{1}{\rho} = e(n_e \mu_e + n_h \mu_h) \qquad ...(7)$$

Also, the resistivity of the semiconductor is given by

$$\rho = \frac{1}{e(n_e \mu_e + n_h \mu_h)} \qquad ...(8)$$

Effect of Temperature

Variation of conductivity of a semiconductor with temperature. The conductivity of a semiconductor is given by

$$\sigma = e(n_e \mu_e + n_h \mu_h)$$

As the temperature increases, the mobilities μ_e and μ_h of electrons and holes decrease due to the increase in their collision frequency. But due to the small energy gap of semiconductors, more and more electrons $[n \propto e^{-E_g/kT}]$ from the valence band cross over to the conduction band. The increase in carrier concentrations, n_e and n_h is so large that the decrease in the values of μ_e and μ_h has no influence. The overall effect is that the conductivity increases or the resistivity decreases with the increase of temperature.

P-N Junction

p-n junction. It is a single crystal of Ge or Si doped in such a manner that one half portion of it acts as p-type semiconductor and the other half as n-type semiconductor.
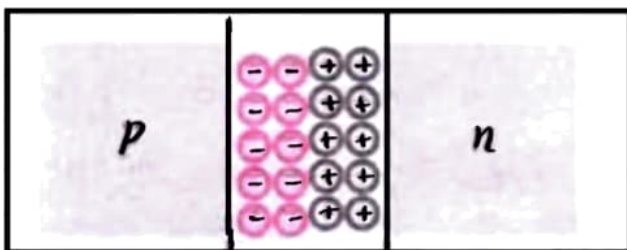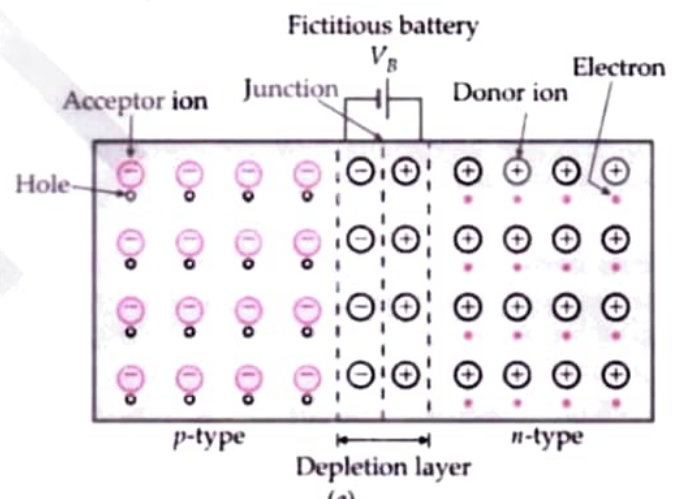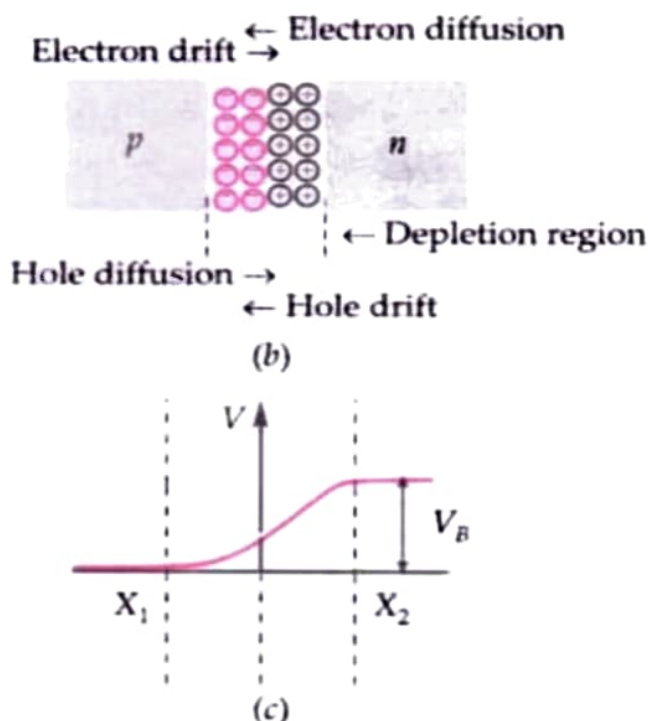

|←Junction→|

Unbiased p-n junction : Depletion region and potential barrier in a p-n junction. Two important processes involved during the formation of p-n junction are *diffusion* and *drift*. When a p-n junction is formed, the p-side of the junction has a higher concentration of holes while the n-side has a higher concentration of electrons. Due to the concentration gradient at the junction, holes begin to diffuse from p-side to n-side ($p \to n$) and electrons begin to diffuse from n-side to p-side ($n \to p$). As holes diffuse from $p \to n$ side, they leave behind −ve acceptor ions which set up a layer of negative charge or negative *space-charge region* on the p-side of the junction. Similarly, as the electrons diffuse from $n \to p$ side, they leave behind +ve donor ions which set up a layer of positive charge or *positive space-charge region* on the n-side of the junction. This sets up an electric field near the junction from $n \to p$ side.

The small region in the vicinity of the junction which is depleted of free charge carriers and has only immobile ions is called **depletion region.**

The accumulation of negative charges in the p-region and positive charges in the n-region sets up a potential difference across the junction. This acts as a barrier and is called **barrier potential** V_B which opposes the further diffusion of electrons and holes across the junction.

This diffusion of majority charge carriers across the junction gives rise to an electric current from $p \to n$ side and is called **diffusion current.**

p-type   Depletion layer   n-type
(a)

Electron drift → ← Electron diffusion

p n

← Depletion region

Hole diffusion →

← Hole drift

(b)

V

V_B

X_1 X_2

(c)

In the depletion region, electron-hole pairs are continuously produced due to thermal or electric field conditions. The electric field $\vec{E}_B$ immediately pushes the electrons towards the n-side and holes towards the p-side. *This current set up by the barrier field from $n \rightarrow p$ side is called* **drift current**.
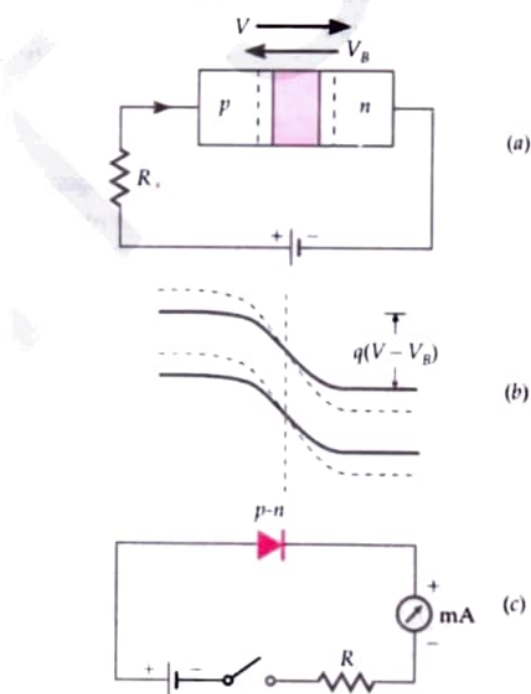

p-n

Anode   Cathode
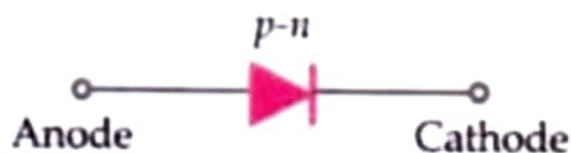
Fig. 14.14 Symbol for a p-n junction diode.

1. Forward biasing. *If the positive terminal of a battery is connected to the p-side and the negative terminal to the n-side, then the p-n junction is said to be forward biased.*

As shown in Fig.   the applied voltage V opposes the barrier voltage V_B. As a result of this

(i) the effective barrier potential decreases to $(V_B - V)$ and hence the energy barrier across the junction decreases

(ii) the majority charge carries *i.e.*, holes from p-side and electrons from n-side begin to flow towards the junction,

(iii) the diffusion of electrons and holes into the depletion layer decreases its width, and

(iv) the effective resistance across the p-n junction decreases.

Fig. 14.15 (a) Reduced depletion layer, (b) Reduced energy barrier, (c) Symbolic representation, for a forward biased p-n junction.

When V exceeds V_B, the majority charge carriers start flowing easily across the junction and set up a large current ($\approx$ mA), called forward *current*, in the circuit. The current increases with the increase in applied voltage.

2. Reverse biasing. *If the positive terminal of a battery is connected to the n-side and negative terminal to the p-side, then the p-n junction is said to be reverse biased.*

As shown in Fig. 14.16(a), the applied voltage V and the barrier potential V_B are in the same direction.
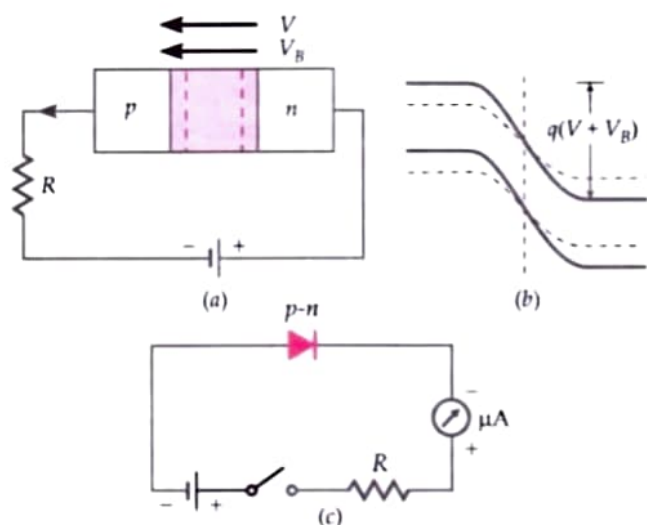
Fig. 14.16 (a) Increased depletion layer, (b) Increased energy barrier, (c) Symbolic representation for a reverse biased p-n junction.

As a result of this

(i) the barrier potential increases to $(V_B + V)$ and hence the energy barrier across the junction increases,

(ii) the majority charge carriers move away from the junction, increasing the width of the depletion layer,

(iii) the resistance of the p-n junction becomes very large, and

(iv) no current flows across the junction due to majority charge carriers.

However, at room temperature there are always present some minority charge carriers like holes in n-region and electrons in p-region. The reverse biasing pushes them towards junction, setting a current, called reverse or leakage current, in the external circuit in the opposite direction. As the minority charge carriers are much less in number than the majority charge carriers, hence the reverse current is small ($\approx \mu A$).

V-I Characteristics of P-N Diode

V-I characteristics of a p-n junction diode. A graph showing the variation of current flowing through a p-n junction with the voltage applied across it (both when it is forward and reverse biased) is called the voltage-current or V-I characteristic of a p-n junction
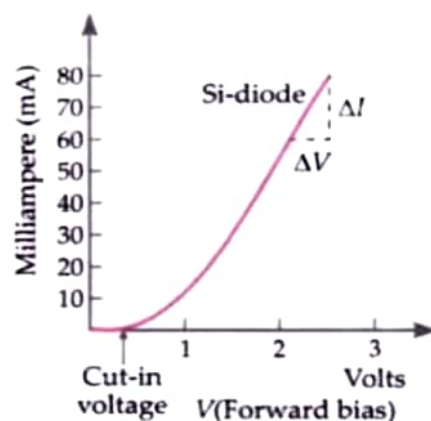
Forward Biasing :-

i. 14.18 Forward characteristic of a junction diode.

Important features of the graph. (i) The V-I graph is not a straight line i.e., a junction diode does not obey Ohm's law.

(ii) Initially, the current increases very slowly almost negligibly, till the voltage across the diode crosses a certain value, called the threshold-voltage or cut-in voltage. The value of the cut-in voltage is about 0.2 V for a Ge diode and 0.7 V for a Si diode.

(iii) After the cut-in voltage, the diode current increases rapidly (exponentially), even for a very small increase in the diode bias voltage. Here the majority charge carriers feel negligible resistance at the junction i.e., the resistance across the junction is quite low.
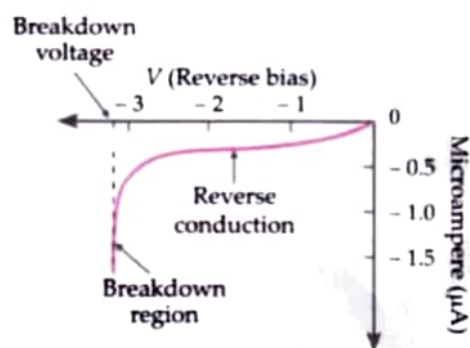
Reverse Biasing

Fig. 14.20 Reverse characteristic of a junction diode.

Important features of the graph. (i) When the diode is reverse biased, the reverse bias voltage produces a very small current, about a few microamperes which almost remains constant with bias. This small current is called reverse saturation current. It is due to the drift of minority charge carriers (a few holes in n-region and a few electrons in p-region) across the junction.

(ii) When the reverse **voltage** across the *p-n* junction reaches a sufficiently **high** value, the reverse current suddenly increases to a large value. This voltage at which breakdown of the junction diode occurs is called **Zener breakdown voltage** or **peak-inverse voltage** of the diode. It ranges from as low as 1 to 2 V to several hundred volts, depending on the dopant density and the depletion layer.
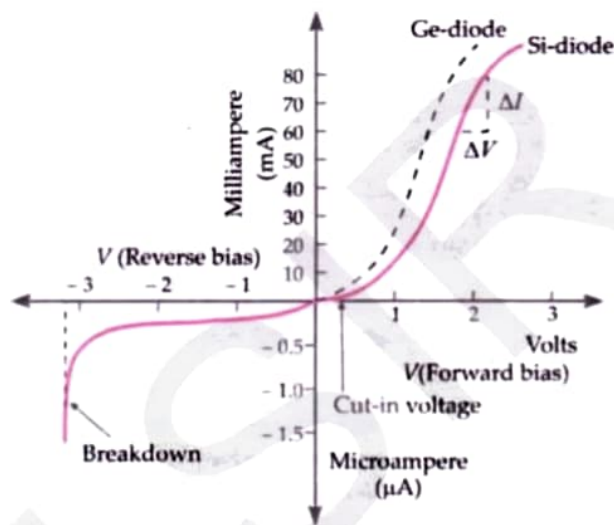

Fig. 14.21 Complete **V-I** characteristic of a junction diode.

Rectifier

Rectifier. *The process of converting alternating current into direct current is called* **rectification** *and the device used for this process is called* **rectifier.**

Principle of a rectifier. When a *p-n* junction diode is forward biased, it offers less resistance and a current flows through it ; but when it is reverse biased, it offers high resistance and almost no current flows through it. This unidirectional property of a diode enables it to be used as a rectifier. When *a.c.* signal is fed to a diode, the diode is forward biased during the positive half cycle and a current flows through it. During the negative half cycle, the diode is reverse biased and it does not conduct. Thus the signal is rectified.

The *p-n* junctions can be used as

(i) a *half-wave rectifier*, and

(ii) a *full-wave rectifier*.

Half wave Rectifier

Junction diode as a half-wave rectifier. A half-wave rectifier consists of a transformer, a junction diode *D* and a load resistance R_L. The primary coil of the transformer is connected to the a.c. mains and the secondary coil is connected in series with the junction diode *D* and load resistance R_L.
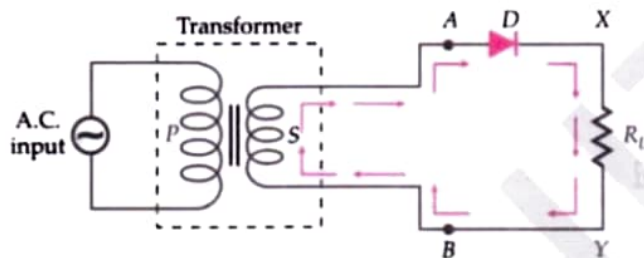

Fig. 14.22 **Half-wave rectifier circuit.**

Working. When a.c. is supplied to the primary, the secondary of the transformer supplies desired alternating voltage across *A* and *B*. During the positive half cycle of a.c., the end *A* is positive and the end *B* is negative. The diode *D* is forward biased and a current *I* flows through R_L.

Output voltage across R_L is of same waveform as the **positive half wave** of the input. During the negative
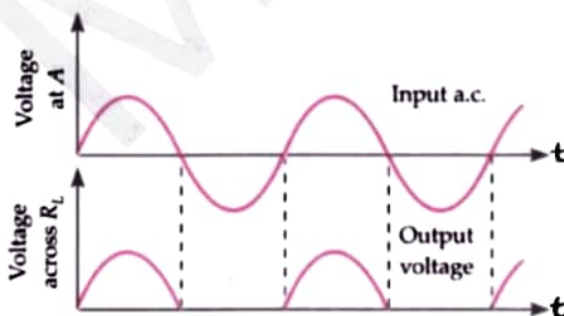

Fig. 14.23 **Waveforms of input a.c. and output voltage obtained from a half-wave rectifier.**

half cycle, the end *A* becomes negative and *B* positive. The diode is reverse biased and no current flows. No voltage appears across R_L. In the next positive half cycle, again we get output voltage.

Since the voltage across the load appears only during the positive half cycle of the input *a.c.*, this process is called *half-wave rectification* and the arrangement used is called a *half-wave rectifier*.

Full wave Rectifier

Junction diode as a full wave rectifier. A full wave rectifier consists of a transformer, two junction diodes D_1 and D_2 and a load resistance R_L. The input a.c. signal is fed to the primary coil P of the transformer. The two ends A and B of the secondary S are connected to the p-ends of diodes D_1 and D_2.
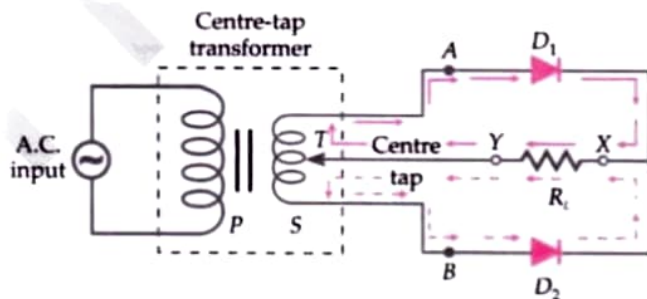
Full wave rectifier circuit.

Working → . Suppose during the positive half cycle of a.c. input, the end A is positive and the end B is negative with respect to the centre tap T. Then the diode D_1 gets forward biased and conducts current along the path $AD_1 XYTA$, as indicated by the solid arrows. The diode D_2 is reverse biased and does not conduct. During the negative half cycle, the end A becomes negative and the end B becomes positive with respect to the centre tap T. The diode D_1 gets reverse biased and does not conduct. The diode D_2 conducts current along the path $BD_2 XYTB$, as indicated by broken arrows. As during both half cycles of input a.c. the current through load R_L flows in the same direction $(X \rightarrow Y)$, so we get a pulsating d.c.
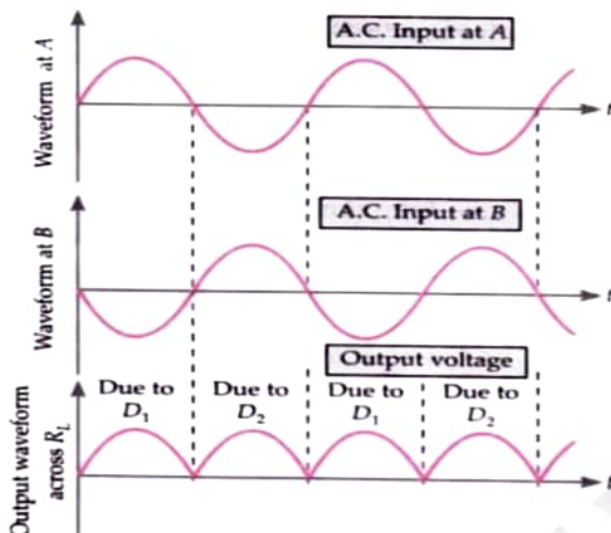

Fig. 14.25 **Waveforms of input a.c. and output voltage obtained from a full wave rectifier.**

voltage across R_L, as shown in Fig. 14.25. Since output voltage across the load resistance R_L is obtained for both half cycles of input a.c., this process is called **full wave rectification** and the arrangement used is called **full-wave rectifier.**

Filter Circuits

**Filter circuits.** The output obtained from a junction diode rectifier is unidirectional but pulsating.

We can obtain d.c. voltage by filtering out the a.c. components. We describe here two simplest filter circuits.

1. **Series inductor filter.** Figure 14.26 shows the circuit of a full wave rectifier with an inductor of inductance L connected in series with its load resistance R_L.
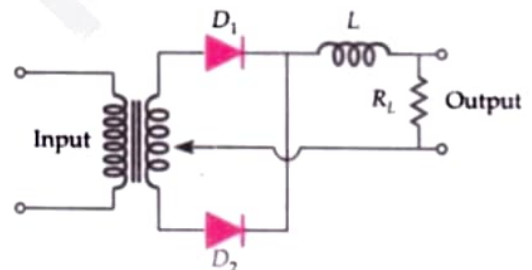
The inductance L offers a reactance $X_L = 2\pi f L$ to the flow of current through it. Clearly, it blocks high frequency a.c. component and allows low frequency d.c. component to pass through it. A smooth d.c. voltage appears across the load resistance.

2. **Shunt capacitor filter.** Figure 14.27 shows the circuit of a full wave rectifier with a capacitor of capacitance C connected in parallel with its load resistance R_L.
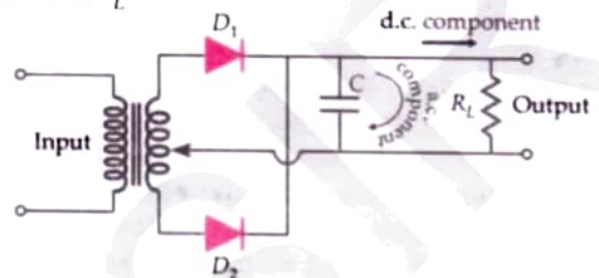
Full wave rectifier with shunt capacitor filter.

The capacitor has a reactance of $X_C = 1/2\pi f C$. A high capacitance C offers a low impedance path to high frequency a.c. component but high, almost infinite, impedance to low frequency d.c. component. Hence the a.c. component is bypassed through C or filtered. A smooth d.c. voltage appears at the load resistance.