CHAPTER / 18

Solids and Semiconductor

Topics Covered

Solids and Energy Bands
- Solids
- Classification of Conductors, Semiconductors and Insulators
- Energy Band
- Semiconductors

p-n Junction
- *p-n* Junction Diode
- *V-I* Characteristics of *p-n* Junction Diode
- *p-n* Junction Diode as a Rectifier
- Special purpose *p-n* Junction Diode

TOPIC ~01 Solids and Energy Bands

In nature, matter exists in three states, i.e. solid, liquid and gas. The fourth state of matter is plasma which exists under special conditions.

Solids

A solid substance has the tendency to maintain a definite shape and volume because of strong intermolecular forces.

Structure of Solids

Structure of solids can be divided into two main groups:

(i) **Crystalline solids** In crystalline solids, atoms are arranged in a regular periodic geometrical pattern. This arrangement is repeated throughout the three dimensions of the crystal. They have definite sharp melting point and are anisotropic (their physical properties like thermal conductivity, refractive index, etc., are different in different directions) in nature. e.g. sodium chloride, sugar, mica, quartz, etc.

(ii) **Amorphous solids** In amorphous solids, atoms are not arranged in a regular periodic geometrical pattern. They have no sharp melting points and are isotropic in nature. e.g. glass, wax, rubber, etc.

Binding in Solids

The atoms or molecules in solids are held together by electrostatic force of attraction between oppositely charged particles, known as **cohesive force**. This force is visualised as link formed between oppositely charged particles to form a stable solid, called bond.

The common types of bonds are:

(i) **Ionic or heteropolar bond** The bond formed by transfer of one or more electrons from one atom to another is called ionic bond.
e.g. NaCl, $CuSO_4$, KOH, etc.

(ii) **Covalent bond** The bond formed by mutual sharing of electrons between neighbouring atoms is called covalent bond.
e.g. H_2, Cl_2, H_2O, NH_3, carbon, silicon, etc.

(iii) **Metallic bond** The bond formed due to electrostatic attraction between electrons and ions of different atoms is called metallic bond.
e.g. Li, Na, K, etc.

(iv) **van der Waals' bond or molecular bond** The bond formed due to very weak attractive force between molecules of inert gas crystals and in molecular crystals is called van der Waals' bond.
e.g. neon, paraffin, benzene, etc.

Classification of Conductors, Semiconductors and Insulators

Solids are classified on the basis of their conductivity as conductors ($\sigma \sim 10^2$ to $10^8\ \mu\,m^{-1}$), semiconductors ($\sigma \sim 10^5$ to $10^{-6}\ \mu\,m^{-1}$) and insulators ($\sigma \sim 10^{-11}$ to $10^{-19}\ \mu\,m^{-1}$).

Mechanism of conduction in solids can be best understood quantitatively, on the basis of band theory of solids.

Energy Band

In a crystal, due to interatomic interaction, valence electrons of one atom are shared by more than one atom. Now, splitting of energy level takes place.

The collection of these closely spaced energy levels is called an energy band.

(i) **Valence Band** Valence band is the energy band which includes the energy levels of the valence electrons. This band may be partially or completely filled with electrons. This band is never empty.

(ii) **Conduction Band** Conduction band is the energy band above the valence band. At room temperature, this band is either empty or partially filled with electrons. Electrons can gain energy from external electric field and contribute to the electric current.

(iii) **Energy Band Gap** The minimum energy required for shifting electrons from valence band to conduction band is called energy band gap (E_g).

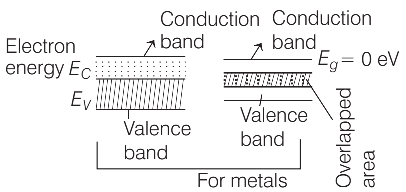
(iv) **Fermi Energy** It is the maximum possible energy possessed by free electrons of a material at absolute zero temperature (i.e. 0 K). The value of Fermi energy is different for different materials.

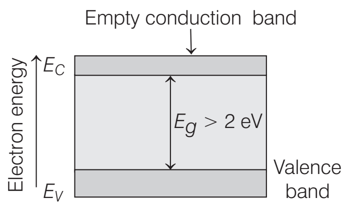
Classification of Solids on the Basis of Band Theory

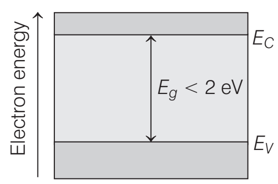
On the basis of width of forbidden energy gap (E_g) of band theory, solids can be classified into three categories : conductors ($E_g = 0$ eV), insulators ($E_g > 2$ eV) and semiconductors ($E_g < 2$ eV).

Difference between Conductor, Insulator and Semiconductor on the Basis of Energy Bands

Conductor (metal)	Insulator	Semiconductor
In conductor, either there is no energy gap between the conduction band which is partially filled with electrons and valence band or the conduction band and valence band overlap each other.	In insulator, the valence band is completely filled, the conduction band is completely empty and energy gap is quite large that small energy from any other source cannot overcome it.	In semiconductor also, like insulator, the valence band is totally filled and the conduction band is empty but the energy gap between conduction band and valence band, unlike insulator is very small.
Thus, many electrons from below the Fermi level can shift to higher energy levels above the Fermi level in the conduction band and behave as free electrons by acquiring a little more energy from any other sources.	Thus, electrons are bound to valence band and are not free to move and hence electric conduction is not possible in this type of material.	Thus, at room temperature, some electrons in the valence band acquire thermal energy greater than energy band gap and jump over to the conduction band where they are free to move under the influence of even a small electric field and acquire small conductivity.







Semiconductors

Semiconductors are the materials whose conductivity lies between metals and insulators. They are characterised by narrow energy gap (~1 eV) between the valence band and conduction band.

Electrons and Holes in Semiconductors

At room temperature, however some of the valence electrons acquire thermal energy greater than E_g and move into conduction band. A vacancy is created in the valence band at each place, where an electron was present before moving into conduction band. This vacancy is called **hole**, it is a seat of positive charge of magnitude equal to the charge of an electron.

Thus, free electrons in the conduction band and the holes created in the valence band, can move even under a small applied field.

With further increase in temperature, more and more electrons jump from valence band to conduction band, thereby increasing the conductivity of semiconductors.

Types of Semiconductors

On the basis of purity, semiconductors are of two types:

Intrinsic Semiconductors

It is a pure semiconductor without any significant dopant species present.

$$n_e = n_h = n_i$$

where, n_e and n_h are number densities of electrons and holes respectively and n_i is called intrinsic carrier concentration. An intrinsic semiconductor is also called an undoped semiconductor or ***i*-type semiconductor.**

The total current I is the sum of the electron current I_e and hole current I_h.

$$I = I_e + I_h$$

where, $I_e =$ electron current and $I_h =$ hole current

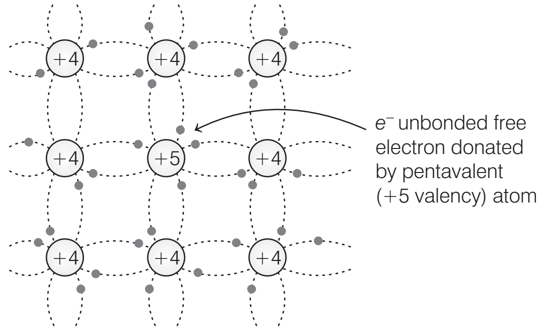
Extrinsic Semiconductors

A pure semiconductor when doped with the impurity, it is known as extrinsic semiconductor. Extrinsic semiconductors are basically of two types:

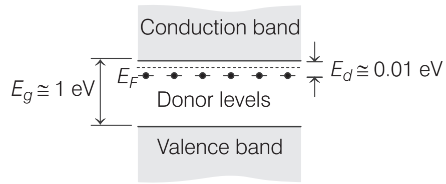
(i) ***n*-type Semiconductor** In this type of extrinsic semiconductor, majority charge carriers are electrons and minority charge carriers are holes, i.e. $n_e > n_h$.

Here, we dope a tetravalent element like Si or Ge with a pentavalent element, such as As, P or Sb of group V, then four of its electrons bond with the four silicon neighbours, while fifth remains very weakly bound to its parent atom.

Formation of n-type semiconductor is shown below:



Donor energy level lies just below the conduction band

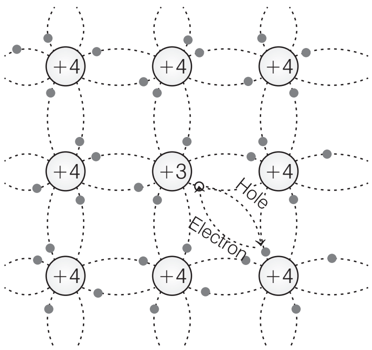


n-type

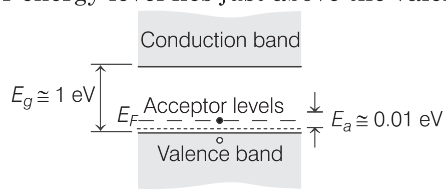
(ii) ***p*-type Semiconductor** In this semiconductor, majority charge carriers are holes and minority charge carriers are electrons i.e. $n_h > n_e$.

In a p-type semiconductor, doping of tetravalent atoms is done with trivalent impurity atoms such as Al, P, i.e. those atoms which have three valence electrons in their valence shell.

Formation of p-type semiconductor is shown below:



Acceptor energy level lies just above the valence band



p-type

Effect of Temperature on Extrinsic Semiconductors

With increase in temperature of extrinsic semiconductors, minority charge carriers increase because of bond breakage and minority carriers may become almost equal with majority carriers. Thus, extrinsic semiconductor behaves almost as an intrinsic semiconductor with increase in temperature.

Electrical Conductivity in Semiconductors

Electrical conductivity in semiconductors is given by

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

where, n_e is free electron density and n_h is free hole density and μ_e and μ_h are mobilities of electrons and holes, respectively.

In intrinsic semiconductor, $n_e = n_h = n$ (say)

$\therefore \quad \sigma_{\text{int}} = en\,(\mu_e + \mu_h)$

In n-type semiconductor, $n_e >> n_h$

$\therefore \quad \sigma_{n\text{-type}} \approx en_e\,\mu_e$

In p-type semiconductor, $n_h >> n_e$

$\therefore \quad \sigma_{p\text{-type}} \approx en_h\,\mu_h$

PRACTICE QUESTIONS

Exam', Textbook's & Other Imp. Questions

1 MARK *Questions*

Exams' Questions

Q.1 In a solid, the valence band is almost filled, the conduction band is almost empty and the band gap is small. Is the solid an insulator? (Answer in 'Yes' or 'No') **[2014]**

Sol No, the solid is a semiconductor. **(1)**

Q.2 Name the charge carrier in p-type semiconductor. **[2014, 2009]**

Sol Hole **(1)**

Q.3 An n-type semiconductor is obtained by doping germanium with a ……element.
(Fill in the blank) **[2013 Instant, Textbook]**

Sol A pentavalent element can donate one electron to change pure semiconductor to n-type. **(1)**

Q.4 The material for which the resistivity is maximum, is **[2013 Cancelled]**

(a) a conductor
(b) an insulator
(c) a semiconductor
(d) an alloy

Sol (*b*) an insulator **(1)**

Q.5 …… is the charge carrier in a germanium crystal doped with boron. (Fill in the blank using hole/electron) **[2012]**

Sol Hole, since boron is a trivalent inpurity atom. **(1)**

Q.6 The solid in which the conduction band and the valence band overlap on each other is called **[2011 Instant, Textbook]**

(a) semiconductor (b) insulator
(c) conductor (d) dielectric

Sol (*c*) Conductor **(1)**

Q.7 A p-type semiconductor is obtained by doping germanium crystal with which of the following elements? **[2010, Textbook]**

(a) Silver (b) Arsenic (c) Gold (d) Indium

Or

Which of the following elements makes germanium, a p-type semiconductor on doping? **[2008]**

(a) Sodium (b) Copper
(c) Arsenic (d) Indium

Sol (*d*) Indium **(1)**

Q.8 An …… semiconductor is obtained by doping germanium with arsenic. (Fill in the blank) **[2010 Instant, Textbook]**

Or

What type of semiconductor is obtained when arsenic is added to germanium? **[2006]**

Sol n-type **(1)**

Q.9 When does a pure semiconductor behave as an insulator? **[2007, Textbook]**

Sol At low temperature or zero kelvin. **(1)**

Q.10 What are current carriers in semiconductors? **[2007 Instant, Textbook]**

Sol In case of pure semiconductors, electrons (in conduction band) and holes (in valence band) are current carriers. In n-type semiconductors, electrons are majority charge carriers and in p-type semiconductors, holes are majority charge carriers. **(1)**

Q.11 Does the n-type semiconductor contain a net charge? **[2006 Instant, Textbook]**

Sol No, it is electrically neutral. **(1)**

Q.12 What is doping in semiconductors? **[2005, Textbook]**

Sol The process of adding impurity to an intrinsic semiconductor in a controlled manner is called doping. **(1)**

Q.13 Under what situation, silicon can be an insulator? Is it realisable? **[2001, Textbook]**

Sol At low temperature or zero kelvin. It is not realisable. **(1/2 + 1/2)**

Important Questions

Q.14 In case of a semiconductor, which of the following statement is wrong? **[Textbook]**

(a) At 0 K, it behaves like a conductor.
(b) Number of free electrons increases with increase in temperature.
(c) Number of free electrons is less than that in a conductor.
(d) Temperature coefficient of resistivity is negative.

Sol (*a*) At 0 K, it behaves like a conductor. **(1)**

Q.15 The energy gap is of the order of 0.07 eV of

(a) an insulator (b) a semiconductor
(c) an alloy (d) a conductor

Sol (*d*) a conductor **(1)**

Q.16 In a semiconductor, electric conduction takes place due to **[Textbook]**

(a) holes only
(b) electrons only
(c) Both holes and electrons
(d) Neither electrons nor holes

Sol (*c*) Both holes and electrons **(1)**

Q.17 If n_e and n_h are the number of electrons and number of holes respectively, in an intrinsic semiconductor, then **[Textbook]**

(a) $n_h < n_e$ (b) $n_h = n_e$
(c) $n_h > n_e$ (d) $n_h \neq n_e$

Sol (*b*) $n_h = n_e$ **(1)**

Q.18 The range of energies possessed by an electron in a solid is called …… . (Fill in the blank) **[Textbook]**

Sol energy band **(1)**

Q.19 Conductivity of a semiconductor increases by …… process. (Fill in the blank)

Sol doping **(1)**

Q.20 The majority charge carriers in n-type semiconductor are ……. (Fill in the blank) **[Textbook]**

Sol electrons **(1)**

Q.21 With rise in temperature, conductivity of conductors ……. (Fill in the blank) **[Textbook]**

Sol decreases **(1)**

Q.22 H_2 is formed due to covalent bonding. (Correct the sentence, if necessary) **[Textbook]**

Sol Sentence is correct. **(1)**

Q.23 The forbidden energy gap for a conductor is very large. (Correct the sentence, if necessary) **[Textbook]**

Sol The forbidden energy gap for a conductor is zero. **(1)**

Q.24 What is an energy band? **[Textbook]**

Sol The collection of closely spaced energy levels is called an energy band. **(1)**

Q.25 Give one essential requirement to carry out doping process.

Sol For doping process, semiconductor should be of very high purity, i.e. 99.9% or more. **(1)**

Q.26 The type of bonding in a germanium crystal is **[Textbook]**

(a) ionic (b) metallic
(c) covalent (d) van der Waals'

Sol (*c*) The germanium crystal by covalent bonded solids. In covalent bond, an atom shares one valence electron with each of its nearest atoms. **(1)**

Q.27 In an intrinsic semiconductor, the forbidden energy gap between valence band and a conduction band is of the order of **[Textbook]**

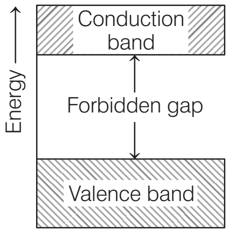
(*a*) 1 eV (b) 4 eV (c) 1 keV (d) 1 MeV

Sol (*a*) In an intrinsic semiconductor, the forbidden energy gap between valence band and a conduction band is of the order of 1 eV. **(1)**

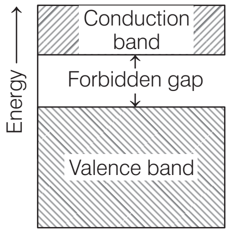
Q.28 The forbidden energy gap in conductors, semiconductors and insulators are Δ_1, Δ_2 and Δ_3, respectively. The relations among them is **[Textbook]**

(a) $\Delta_1 = \Delta_2 = \Delta_3$ (b) $\Delta_1 > \Delta_2 > \Delta_3$
(c) $\Delta_1 < \Delta_2 > \Delta_3$ (d) $\Delta_1 < \Delta_2 < \Delta_3$

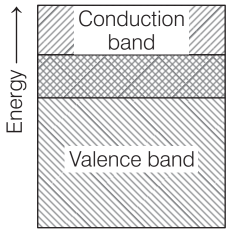
Sol (*d*)



(a) Insulator
Forbidden gap$\rightarrow \Delta_3$



(b) Semiconductor
Forbidden gap$\rightarrow \Delta_2$



(c) Conductor
Forbidden gap$\rightarrow \Delta_1$

$\therefore \quad \Delta_1 < \Delta_2 < \Delta_3$ **(1)**

Q.29 The level formed due to impurity atom, in the forbidden energy gap, very near to conduction band in n-type semiconductor is called **[Textbook]**

(a) acceptor level (b) donor level
(c) conduction level (d) forbidden level

Sol (*b*) The level formed due to impurity atom, in the forbidden energy gap, very near to conduction band in n-type semiconductor is called donor level. **(1)**

Q.30 Acceptor level in a p-type semiconductor is **[Textbook]**

(a) nearer to valence band
(b) nearer to conduction band
(c) at the middle of the gap between conduction and valence bands
(d) None of the above

Sol (*a*) In a p-type semiconductor, holes are the majority carriers and electrons are the minority carriers. Acceptor level in a p-type semiconductor is lies closer to the valence band than the conduction band. **(1)**

Q.31 The impurity atoms with which pure germanium may be doped with it to form a p-type semiconductor are those of **[Textbook]**

(a) boron (b) aluminium (c) gallium (d) All of these

Sol (*d*) Pure germanium can be doped with boron, aluminium and gallium to form a p-type semiconductor. **(1)**

Q.32 A semiconductor is doped with an acceptor impurity. **[Textbook]**

(a) The hole concentration increases
(b) The electron concentration decreases
(c) Both of the above are correct
(d) None of the above are correct

Sol (*c*) A semiconductor is doped with an acceptor impurity called p-type semiconductor. Hence, hole concentration increases while electron concentration decreases. **(1)**

Q.33 When pure silicon is doped with trivalent impurity like boron, the conduction is due to **[Textbook]**

(a) electrons (b) holes (c) protons (d) positrons

Sol (*b*) When pure silicon is doped with trivalent atom boron, then a p-type semiconductor forms. In p-type semiconductor, majority charge carriers are holes, i.e. the conduction is due to holes. **(1)**

Q.34 If silicon atom is doped with a donor impurity, then the donor atoms should be **[Textbook]**

(a) trivalent (b) pentavalent
(c) tetravalent (d) None of these

Sol (*b*) A donor impurity is pentavalent element that has 5 electrons and when doped, it will leave an extra electron.

Therefore, if silicon atom is doped with a donor impurity, then the donor atoms should be pentavalent. **(1)**

Q.35 Majority charge carriers in extrinsic semiconductors are **[Textbook]**

(a) holes in n-type and electrons in p-type
(b) both holes in n-type and p-type
(c) electrons in n-type and holes in p-type
(d) both electrons in n-type and p-type

Sol (*c*) The semiconductors in which impurity atoms are embedded are known as extrinsic semiconductors. Extrinsic semiconductors are of two types:
(i) n-type semiconductor
(ii) p-type semiconductor

In n-type semiconductors, majority charge carriers are electrons and in p-type semiconductors, majority charge carriers are holes. **(1)**

2 MARKS *Questions*

Exams' Questions

Q.36 State the difference between p-type and n-type semiconductors. **[2017, Textbook]**

Sol

p-type Semiconductor	n-type Semiconductor
The majority charge carriers are holes and minority charge carriers are electrons.	The majority charge carriers are electrons and minority charge carriers are holes. **(1)**
These are obtained by doping of impure atoms from group 13 into group 14.	These are obtained by doping of impure atoms from group 15 into group 14. **(1)**

Q.37 Compare a conductor with a semiconductor discussing their energy bands. **[2016, Textbook]**

Sol **Table** Refer to text on page 297. **(2)**

Q.38 According to band theory, compare a semiconductor with an insulator. **[2013, Textbook]**

Sol **Table** Refer to text on page 297. **(2)**

Q.39 Write two differences between covalent bond and ionic bond. **[2007, 2003, Textbook]**

Sol

Covalent bond	Ionic bond
Bond formed by mutual sharing of electrons between neighbouring atoms is called covalent bond. e.g. H_2, Cl_2, NH_3, etc.	Bond formed by transfer of one or more electrons from one atom to another is called ionic bond. e.g. NaCl, KOH, etc. **(1)**
Crystals having covalent bond have low melting point as well as high boiling point.	Crystals having ionic bond have high melting and boiling points. **(1)**

Q.40 Distinguish between intrinsic and extrinsic semiconductors. **[2002, Textbook]**

Sol

Intrinsic semiconductor	Extrinsic semiconductor
An intrinsic semiconductor is a pure semiconductor, which becomes a conductor by virtue of rise in temperature.	An extrinsic semiconductor is a doped semiconductor, which becomes a conductor by doping or adding some impurity atoms. **(1)**
The number of excited electrons is equal to the number of holes, i.e. $n_e = n_h$	In n-type extrinsic semiconductors ($n_e >> n_h$) and in p-type extrinsic semiconductors ($n_e << n_h$). **(1)**

Important Questions

Q.41 What is the order of energy of forbbiden band?

(i) Diamond (ii) Silicon **[Textbook]**

(iii) Germanium (iv) Aluminium

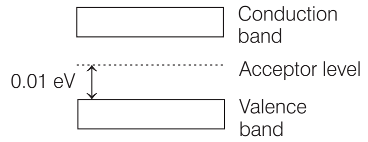
Sol The order of energy of forbbiden band is

diamond (5 eV) > silicon (1eV) > germanium (0.7 eV) > aluminium (0). **(2)**

Q.42 What is energy band gap of a semiconductor? How does the energy gap in an intrinsic semiconductor vary, when doped with a trivalent impurity? **[Textbook]**

Sol The minimum energy required for shifting electrons from valence band to conduction band is called energy band gap (E_g). **(1/2)**

In intrinsic semiconductor, at room temperature, the valence band is full. The energy gap for Ge is 0.72eV and for Si is 1.17eV and the conduction band is totally empty. When a trivalent impurity like Al or B is added to a tetravalent material like Ge or Si, a p-type semiconductor is formed. In p-type semiconductor, an acceptor level corresponding to the deficit valence electron is formed in forbidden energy gap of Si or Ge, as shown below.



In case of trivalent impurity, energy gap is slightly reduced by holes. **(1½)**

Q.43 Name two donor impurities and two acceptor impurities. **[Textbook]**

Sol Donor – Phosphorous, Indium **(1)**

Acceptor – Aluminium, Boron **(1)**

Q.44 What is the effect of temperature on extrinsic semiconductors?

Sol With increase in temperature of extrinsic semiconductors, minority charge carriers increase because of bond breakage and minority charge carriers may become almost equal with majority charge carriers. Thus, extrinsic semiconductor behaves almost as an intrinsic semiconductor with increase in temperature.

Therefore, extrinsic semiconductor has positive temperature coefficient of resistance (α), whereas intrinsic semiconductor has negative α. **(2)**

Q.45 A doped semiconductor has impurity levels 0.01 eV above the valence band.

(i) Is the material n-type or p-type?

(ii) Find maximum wavelength of light which can create a hole in the valence band. **[Textbook]**

Sol (i) As impurity level exists just above valance band, it is a p-type semiconductor. **(1)**

(ii) Also, $E_g = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E_g} = \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{0.01 \times 1.6 \times 10^{-19}}$

$= 1.24 \times 10^{-6}$ m **(1)**

Q.46 In a p-n junction, the depletion region is $2\mu m$ wide and an electric field of 1.0×10^5 V/m exists in it. (i) Find the height of the potential barrier (ii) What should be the minimum kinetic energy of conduction electron which can diffuse from n-side to p-side? **[Textbook]**

Sol Given, $d = 2\ \mu m = 2 \times 10^{-6}$ m,

$E = 1 \times 10^5$ V/m

(i) Potential barrier, $V = Ed$

$= 1 \times 10^5 \times 2 \times 10^{-6} = 0.2$ V **(1)**

(ii) Kinetic energy $= 0.2$ eV **(1)**

Q.47 Pure silicon at 300 K has equal electron and hole concentration of $1.5\times 10^{16}\,m^{-3}$. Doping by indium increases the hole concentration to $4.5\times 10^{22}\,m^{-3}$. Calculate the new electron concentration in the doped silicon. **[Textbook]**

Sol Thermally generated holes $= 1.5\times10^{16}\,m^{-3}$

Number of holes due to indium atoms $= 4.5\times10^{22}\,m^{-3}$

Total number of holes $= 1.5\times10^{16} + 4.5\times10^{22} \cong 4.5\times10^{22}$

Now, $n_i^2 = n_e n_h \Rightarrow n_e = \dfrac{n_i^2}{n_h} = \dfrac{(1.5\times10^{16})^2}{4.5\times10^{22}} = 0.5\times10^{10}$ **(2)**

Q.48 What is van der Waals' bond? Write its two properties?

Sol **van der Waals' bond** Refer to text on page 297. **(1)**

Properties of molecular crystals

(i) They have very low melting and boiling points because of very weak bonding.

(ii) They are bad conductors of heat and electricity. **(1)**

3 MARKS *Questions*

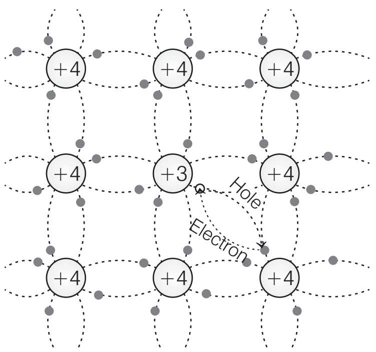
Important Questions

Q.49 On the basis of band theory, distinguish among insulator, semiconductor and conductor of electricity.

Sol **Table** Refer to text on page 297. **(3)**

Q.50 How do holes act as positive charge carriers? Draw the covalent bonding diagram for a p-type semiconductor.

Sol A hole is created when the electron come from silicon-silicon covalent bond to complete the covalent bond between indium and silicon. Now, an electron will move from any one of the covalent bond to fill the empty hole. This will result in a new hole formation. So, in p-type semiconductor, the hole movement results in the formation of the current. Holes are positively charged. Hence, these conductors are known as p-type semiconductors or acceptor type semiconductors. **(1)**



(1)

When these conductors are placed at room temperature, then the covalent bond breakage will take place. In this type of semiconductors, the electrons are very less as compared to the holes, i.e. $n_h >> n_e$. So, in p-type semiconductors, holes are the majority carriers and electrons are the minority carriers. **(1)**

Q.51 What is the concentration of holes in Si crystals having donor concentration of $1.6\times 10^{24}/m^3$. When the intrinsic carrier concentration is $1.6\times 10^{18}/m^3$? Calculate the ratio of electron hole concentration.

Sol Given, intrinsic carrier concentration, $n_i = 1.6\times10^{18}\,/m^3$

Donor concentration, $n_D = 1.6\times10^{24}\,/m^3$

Concentration of electrons, $n_e \approx n_D = 1.6\times10^{24}\,/m^3$ **(1)**

$\therefore$ Concentration of holes, $n_h = \dfrac{n_i^2}{n_e} = \dfrac{(1.6\times10^{18})^2}{1.6\times10^{24}}$

$= 1.6\times10^{12}\,/m^3$ **(1)**

Hence, ratio of electron to hole concentration is

$$\frac{n_e}{n_h} = \frac{1.6\times10^{24}}{1.6\times10^{12}} = 10^{12}$$ **(1)**

Q.52 Explain energy band diagram of an n-type semiconductor.

Sol ***n*-type semiconductor** Refer to text on page 298. **(3)**

Q.53 The potential barrier of 0.25 V exists across an unbiased p-n junction. What minimum kinetic energy, a hole should have to diffuse from p-side to n-side, if (i) the junction is unbiased, (ii) the junction is forward biased at 0.15 V and (iii) the junction is reverse biased at 0.15 V? **[Textbook]**

Sol (i) In unbiased junction,

$$\text{KE} = eV = 0.25\,\text{eV}$$ **(1)**

(ii) In case of forward biased,

$$\Delta V = 0.25 - 0.15 = 0.10$$

$\therefore$ KE required $= e\Delta V = 0.10\,\text{eV}$ **(1)**

(iii) In case of reverse biased,

$$\Delta V = 0.25 - (-0.15) = 0.40$$

$\therefore$ KE required $= 0.40$ eV **(1)**

7 MARKS *Questions*

Exams' Questions

Q.54 Explain the energy bands in solids. Distinguish among insulators, semiconductors and conductors in terms of these. **[2013 Cancelled]**

Sol **Energy band and table** Refer to text on page 297. **(7)**

Q.55 What are characteristic features of a semiconductor? Explain clearly how its conductivity depends upon the temperature and doping. **[2007 Instant]**

Sol **Characteristics of semiconductor** Refer to text on page 298. **(1)**

Effect of temperature on conductivity of semiconductors Refer to text on page 299. **(2)**

Effect of doping on conductivity of semiconductors Under the action of an electric field E on intrinsic semiconductor, electrons and holes move in opposite directions but currents due to them are in same direction. Hence, total current in semiconductor is

$$I = I_e + I_h$$

where, I_e = electron current

and I_h = hole current. **(2)**

Also, $I_e = n_e Aev_e$ and $I_h = n_h \, Aev_h$

where, n_e is free electron density, n_h is free hole density, v_e is drift speed of electron and v_h is drift speed of hole.

$$\therefore \quad I = Ae\,(n_e \, v_e + n_h \, v_h)$$

Since, current density is defined as current per unit cross-sectional area, i.e.

$$J = \frac{I}{A} = \sigma E = e\,(n_e v_e + n_h v_h)$$

where, σ is conductivity.

$$\Rightarrow \quad \sigma = e\left(n_e \frac{v_e}{E} + n_h \frac{v_h}{E}\right)$$

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

where, μ_e and μ_h are mobilities of electrons and holes, respectively.

So, $\sigma = \sigma_e + \sigma_h$

In intrinsic semiconductor, $n_e = n_h = n$ (say)

$$\therefore \quad \sigma_{\text{int}} = en\,(\mu_e + \mu_h)$$

In n-type semiconductor, $n_e >> n_h$

$$\therefore \quad \sigma_{n\text{-type}} \approx en_e \mu_e$$

In p-type semiconductor, $n_h >> n_e$

$$\therefore \quad \sigma_{p\text{-type}} \approx en_h \, \mu_h$$ **(2)**

Important Questions

Q.56 What are extrinsic semiconductors? Explain the formations of n-type semiconductors.

Sol Those semiconductors in which some impurity atoms are embedded are known as extrinsic semiconductors. **(1)**

Formation of *n*-type semiconductor When we dope Si or Ge with a pentavalent element, then four of its electrons bond with the four silicon neighbours while fifth remains very weakly bound to its parent atom and hence ionisation energy required to set this electron free is very small. 0.01 eV for Ge and 0.05 eV for Si are energy required to make the electron free from the nuclear forces. **(2)**

These electrons are almost free to move. In other words, we can say that these electrons are donated by the impurity atoms. So, these are also known as donor atoms. So, the conduction inside the semiconductor will take place with the help of the negatively charged electrons. Due to this negative charge, these semiconductors are known as n-type semiconductors. **(2)**

When the semiconductors are placed at room temperature, then the covalent bond breakage will take place. So, more free electrons will be generated. As a result, same number of holes generation will take place. But, as compared to the free electrons, the number of holes are comparatively less due to the presence of donated electrons, i.e. $n_e >> n_h$. So, in n-type semiconductors, electrons are majority charge carriers and holes are minority charge carriers.

***n*-type semiconductor figure** see on page 298. **(2)**

Q.57 What are extrinsic semiconductors? Explain the formation of p-type semiconductor.

Sol **Extrinsic semiconductors** See solution 56. **(2)**

Formation of *p*-type semiconductor In a p-type semiconductor, doping is done with trivalent impurity atoms such as aluminium, boron, etc. The three valence electrons of the doped impure atoms will form the covalent bonds with silicon atoms. But silicon atoms have four electrons in its valence shell. So, one covalent bond will be improper. **(1)**

So, one more electron is needed for the proper covalent bonding. This need of one electron is fulfilled from any of the bond between two silicon atoms. So, the bond between the silicon and impurity atoms will be completed. After bond formation, the indium will get ionised. As we know that, ions are negatively charged. So, indium will also get negative charge.

A hole is created when the electron come from silicon-silicon bond to complete the bond between indium and silicon. Now, an electron will move from anyone of the covalent bond to fill the empty hole. This will result in a new hole formation.

So, in p-type semiconductor, the hole movement results in the formation of the current. Holes are positively charged. Hence, these conductors are known as p-type semiconductors or acceptor type semiconductors. **(2)**

When these conductors are placed at room temperature, then the covalent bond breakage will take place. In this type of semiconductors, the electrons are very less as compared to the holes, i.e. $n_h >> n_e$. So, in p-type semiconductors, holes are the majority charge carriers and electrons are the minority charge carriers.

***p*-type semiconductor figure** see on page 298. **(2)**

TOPIC TEST 1

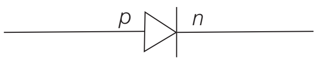
1. Which of the following is a crystalline solid?
   (a) Wax (b) Glass (c) Sugar (d) Rubber [**Ans.** (c)]
2. ....is an unoccupied band above the valence band. (Fill in the blank) [**Ans.** Conduction band] **[Textbook]**
3. Impurity atom making p-type semiconductor is trivalent. (Correct the sentence, if necessary)
   [**Ans.** Statement is correct]
4. Name one trivalent impurity. What type of extrinsic semiconductor is formed when Ge is doped with trivalent impurity? **[Textbook]**
5. State the type of bonding in
   (i) $CuSO_4$ and (ii) Carbon
   Give two properties of each type of bonding. [**Ans.** (i) Ionic (ii) Covalent]

TOPIC ~02 *p-n* Junction

A *p-n* junction is an arrangement made by a close contact of *n*-type semiconductor and *p*-type semiconductor.

p-n Junction Diode

A *p-n* junction diode is basically a *p-n* junction with metallic contacts provided at the ends for the application of an external voltage. It is a two terminal device. A *p-n* junction diode is represented by the symbol



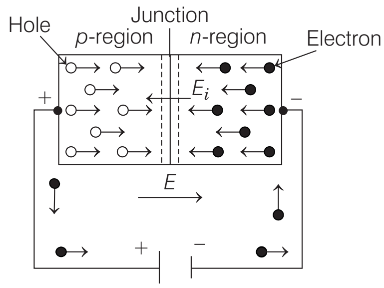
The direction of arrow indicates the conventional direction of current.

The junction diode can be connected to an external battery in two ways, called forward biasing and reverse biasing of the junction.

Forward biasing

A junction is said to be forward biased when the positive terminal of the external battery is connected to the *p*-side and negative terminal to the *n*-side of the diode.

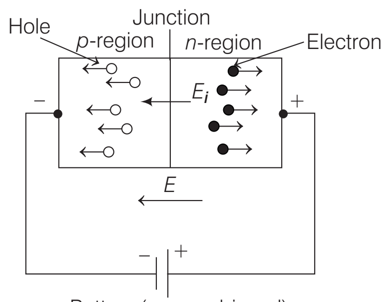
In this situation, the forward voltage opposes the potential barrier, due to which the potential barrier decreases and depletion layer decreases. Under the effect of external electric field, holes in the *p*-region and electrons in *n*-region, both move towards the junction and combine. A current called forward current, is constituted by the motion of majority charge carriers across the junction. In forward bias, the junction diode offers low resistance.



Battery (forward biased)

Reverse Biasing

A junction diode is said to be reverse biased when the positive terminal of the external battery is connected to the *n*-side and negative terminal to the *p*-side of the diode. In this situation, the reverse voltage supports the potential barrier, due to which the potential barrier increases and depletion layer increases.



Battery (reverse biased)

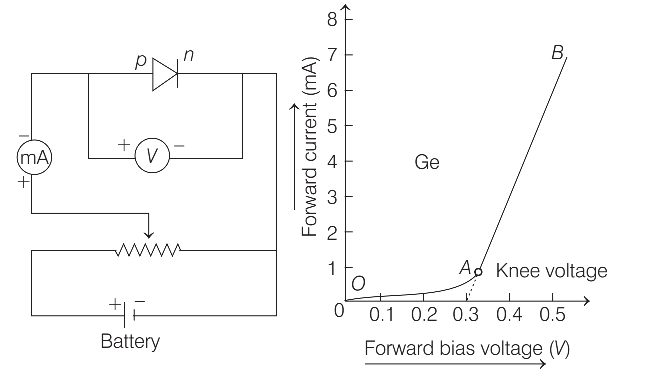
Under the effect of external electric field, holes in the p-region and electrons in the n-region are pushed away from the junction, i.e. they cannot be combined at the junction. So, there is almost no flow of current due to majority charge carriers. However, a very small current due to minority charge carriers flows across the junction. This current is called reverse current.

V-I (Voltage-Current) Characteristics of *p-n* Junction Diode

The graphical relations between voltage applied across p-n junction and current flowing through the junction are called V-I characteristics of junction diode.

Forward Biased characteristics

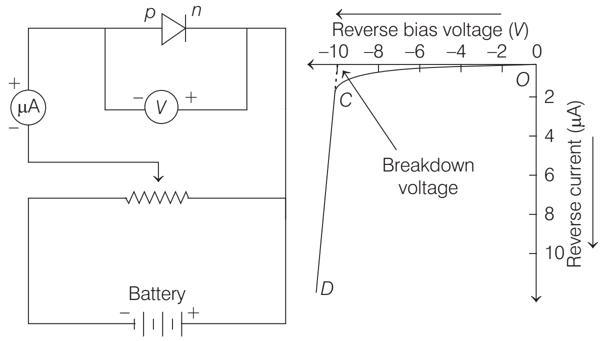
At the start when applied voltage is low, the current through the diode is almost zero. As the applied voltage exceeds the potential barrier, the current increases very slowly with increase in applied voltage (OA portion of the graph). With further increase in applied voltage, the current increases very rapidly (AB portion of the graph). The forward voltage beyond which the current through the junction starts increasing rapidly with voltage is called knee voltage.



(a) Circuit for forward bias (b) Forward biased characteristics

Reverse Biased Characteristics

In reverse biased, the applied voltage supports the flow of minority charge carriers across the junction. So, a very small current flows across the junction due to minority charge carriers.



(a) Circuit for reverse bias (b) Reverse biased characteristics

The small reverse current remains almost constant over a sufficiently long range of reverse bias, increasing very little with increasing voltage (OC portion of the graph). This reverse current is voltage independent up to certain voltage known as **breakdown voltage** and this voltage independent current is called **reverse saturation current**.

Avalanche Breakdown

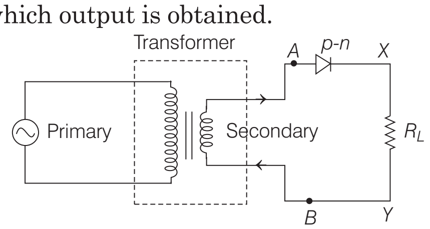
If the reverse bias voltage is equal to the breakdown voltage, then the reverse current through the junction increases very rapidly (CD portion of the graph), this situation is called avalanche breakdown and the junction may get damaged due to excessive heating, if this current exceeds the rated value of p-n junction.

p-n Junction Diode as a Rectifier

The process of converting alternating voltage/current into direct voltage/current is called rectification. Diode is used as a rectifier for converting alternating current/voltage into direct current/voltage. There are two ways of using a diode as rectifier, i.e.

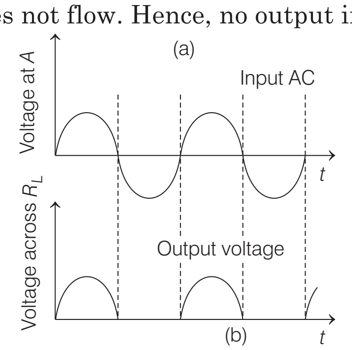
1. Diode as a Half-Wave Rectifier

In this, AC voltage to be rectified is connected to the primary coil of a step-down transformer. Secondary coil is connected to the diode through resistor R_L, across which output is obtained.



Working

During positive half cycle of the input AC, the p-n junction is forward biased. Thus, the resistance in p-n junction becomes low and current flows. Hence, we get output in the load. Similarly, during negative half cycle, the p-n junction is reverse biased. Thus, the resistance of p-n junction is high and current does not flow. Hence, no output in the load.



Disadvantages of Half-Wave Rectifier

(i) An elaborate filter circuit is required to smoothen pulsating DC.

(ii) Output is low as it is obtained only during half of the input AC cycle.

Efficiency (η) of Half-Wave Rectifier

It is defined as the ratio between DC output power to the AC input power, i.e. $\eta = \dfrac{P_{DC}}{P_{AC}} = \dfrac{4}{\pi^2} \cdot \dfrac{1}{\left(\dfrac{r_f}{R_L} + 1\right)}$

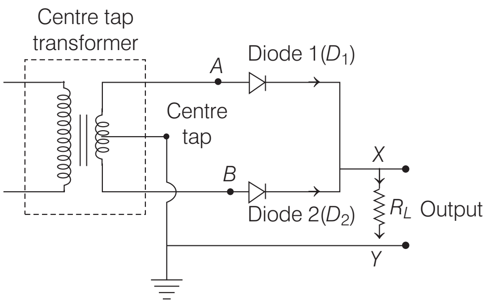
[where, r_f = forward biased resistance]

η is maximum, if $R_L >> r_f$.

$\therefore \eta_{max} \approx 40.6\%$ for half-wave rectifier.

2. Diode as a Full Wave Rectifier

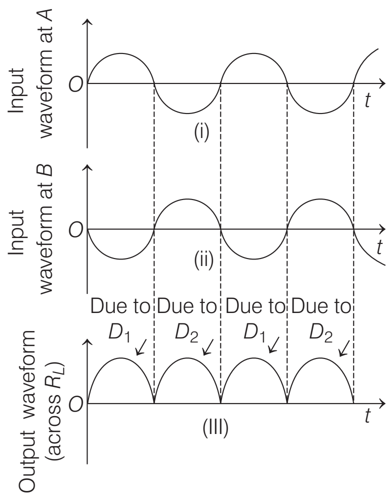
In the full wave rectifier, two p-n junction diodes, D_1 and D_2 are used. This arrangement is shown in the diagram as below:



Working

During the positive half cycle of the input AC, the diode D_1 is forward biased and the diode D_2 is reverse biased. The forward current flows through diode D_1.

During the negative half cycle, the diode D_1 is reverse biased and diode D_2 is forward biased. Thus, current flows through diode D_2. Thus, we find that during both the halves, current flows in the same direction.



Efficiency (η) of Full Wave Rectifier

$\therefore$ Rectification efficiency, $\eta = \dfrac{P_{DC}}{P_{AC}} = \dfrac{8}{\pi^2} \cdot \dfrac{1}{\left(\dfrac{r_f}{R_L} + 1\right)}$

η is maximum, if $r_f <<< R_L$.

$\therefore \eta_{max} \approx 81.2\%$ for full wave rectifier.

Ripple factor (r)

It is defined as the ratio of rms value of AC component to DC component in the rectifier output,

i.e. $r = \dfrac{I_{AC}}{I_{DC}}$

For half-wave rectification, $r = 1.21$

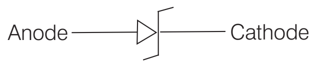
For full wave rectification, $r = 0.48$

Special Purpose p-n Junction Diode

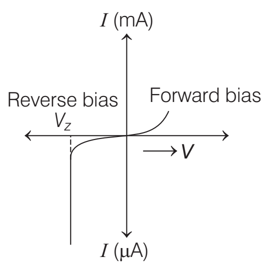
Zener Diode

It is a reverse biased heavily doped p-n junction diode. It is operated in breakdown region. Zener diode is designed to operate in the reverse breakdown voltage continuously without being damaged.

Its symbol is given by

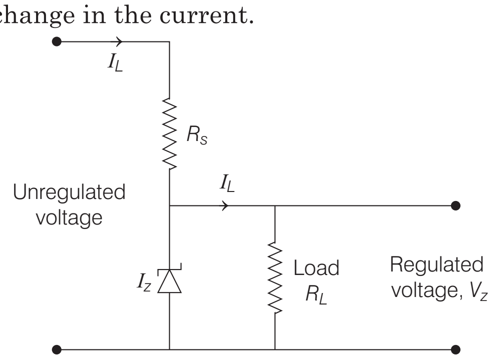


V-I characteristics of Zener diode are shown as below:



Zener Diode as a Voltage Regulator

When the applied reverse voltage (V) reaches the breakdown voltage (V_z) of the Zener diode, there is a large change in the current.

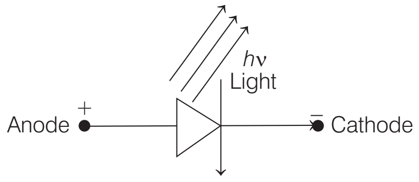


So, after the breakdown voltage V_z, a large change in the current can be produced by almost insignificant change in the reverse bias voltage, i.e. Zener voltage remains constant even though the current through the Zener diode varies over a wide range. The circuital arrangement is shown here. This breakdown in a diode due to the band to band tunneling is called **Zener breakdown.**

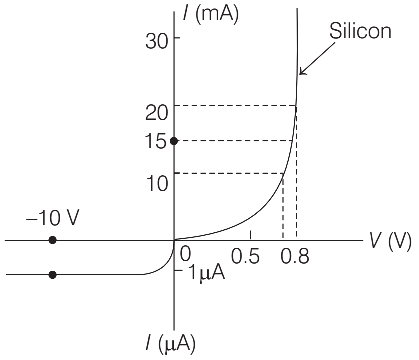
Light Emitting Diode (LED)

It is a heavily doped *p-n* junction diode which converts electrical energy into light energy.

Its symbol is given by



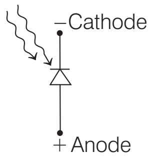
V-I characteristics of LED are as shown below:



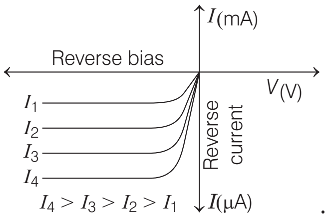
Photodiode

A photodiode is a special type of junction diode used for detecting optical signals. It is a reverse biased *p-n* junction made from a photosensitive material.

Its symbol is given by



V-I characteristics of photodiode are as shown below:

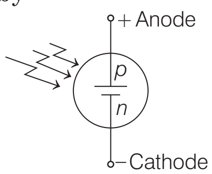


We observe that current in photodiode changes with change in light intensity (I), when reverse bias is applied.

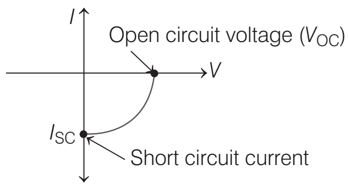
Solar Cell

It is a *p-n* junction diode which converts solar energy into electrical energy. It is based on photovoltaic effect. It is used in toys, watches, calculators, electric fans, remote lighting systems, water pumping, water treatment, emergency power, portable power supplies and satellite.

Its symbol is given by



V-I characteristics of solar cell are as shown below:



PRACTICE QUESTIONS

Exam', Textbook's & Other Imp. Questions

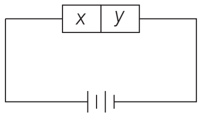
1 MARK Questions

Exams' Questions

Q.1 LED emits light when connected in ……… . (Fill in the blank using 'forward bias' or 'reversed bias') **[2019]**

Sol LED emits light when connected in **forward biasing**. It is heavily doped *p-n* junction diode which converts electrical energy into light energy. The diode is covered with a transparent cover, so that the emitted light may come out. **(1)**

Q.2 In the given circuit diagram, a junction diode x and y has been connected to a source of emf. The semiconductors x and y have been made by doping the germanium crystal with arsenic and indium, respectively. Then, which of the following statements regarding the diode is correct? **[2017, Textbook]**



(a) x is p-type and y is n-type semiconductor and the diode is reverse biased
(b) x is n-type and y is p-type semiconductor and the diode is reverse biased
(c) x is p-type and y is n-type semiconductor and the diode is forward biased
(d) x is n-type and y is p-type semiconductor and the diode is forward biased

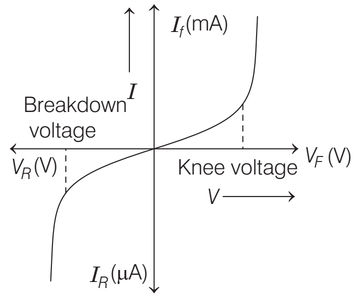
Sol (*b*) Arsenic is a pentavalent impurity and indium is a trivalent impurity. So, x is n-type and y is p-type. As, x is connected to positive terminal of battery and y is connected to negative terminal, the diode is reverse biased. **(1)**

Q.3 What is the ratio of the efficiency of a half-wave rectifier to that of a full wave rectifier? **[2017]**

Sol The efficiency of full wave rectifier is double that of half-wave rectifier. So, the ratio = 1 : 2. **(1)**

Q.4 Show the knee voltage and breakdown voltage by drawing the characteristic curves for a junction diode. **[2015]**

Sol

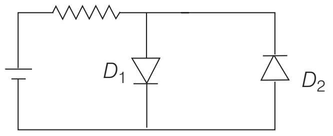


(1)

Q.5 Method of connecting p-side of a junction diode to negative pole of the battery and the n-side to the positive pole is called …… connection. (Fill in the blank) **[2013]**

Sol reverse biased **(1)**

Q.6 The correct statement for the given circuit **[2013 Instant]**



(a) D_1 and D_2 both are forward biased
(b) D_1 is forward biased and D_2 is reverse biased
(c) D_1 and D_2 both are reverse biased
(d) D_2 is forward biased and D_1 is reverse biased

Sol (*b*) D_1 is forward biased and D_2 is reverse biased.

[Since, the p-side of diode D_1 is connected to positive pole of battery and n-side to negative pole, whereas the p-side of D_2 is connected to negative pole of battery and n-side to positive pole.] **(1)**

Q.7 …… is used to make a half-wave rectifier. (Fill in the blank using *p-n* junction/triode) **[2013 Instant]**

Sol *p-n* junction **(1)**

Q.8 A junction diode, when forward biased, behaves as a device of **[2011]**

(a) no resistance
(b) infinite resistance
(c) high resistance
(d) low resistance

Sol (*d*) Low resistance **(1)**

Q.9 What does a rectifier circuit perform? **[2007]**

Sol A rectifier converts AC into DC. **(1)**

Important Questions

Q.10 A diode is commonly used as **[Textbook]**

(a) an amplifier (b) an oscillator
(c) a modulator (d) a rectifier

Sol (*d*) A diode is commonly used as a rectifier, due to its unidirectional behaviour of current. **(1)**

Q.11 In a full wave rectifier, the minimum number of diodes required is **[Textbook]**

(a) 1 (b) 2 (c) 3 (d) 4

Sol (*b*) A centre tap rectifier uses two diodes for full wave rectification, which is minimum number of diodes in any full wave rectifier. **(1)**

Q.12 In a full wave rectifier, input frequency is 50 Hz. The frequency of the ripples in the output is **[Textbook]**

(a) 50 Hz (b) 100 Hz (c) 25 Hz (d) 2500 Hz

Sol (*b*) In a full wave rectifier, the frequency of the ripples in output is 100 Hz, i.e. double of input frequency. **(1)**

Q.13 Which has a greater resistance: a forward biased *p-n* junction or a reverse biased *p-n* junction? **[Textbook]**

Sol Reverse biased has greater resistance. **(1)**

Q.14 What is a rectifier? **[Textbook]**

Sol A device that converts AC to DC is known as rectifier. **(1)**

Q.15 Compare the forward and reverse current characteristics of a semiconductor diode. **[Textbook]**

Sol (i) Forward current is high (mA), whereas reverse current is less (μA). **(1/2)**

(ii) There is no breakdown voltage in forward biased characteristics. **(1/2)**

Q.16 What do you mean by a *p-n* junction? **[Textbook]**

Sol It is an arrangement made by a close contact of *n*-type semiconductor and *p*-type semiconductor. **(1)**

Q.17 Why should we not physically join one slab of *p*-type semiconductor to another *n* -type semiconductor to get *p-n* junction?

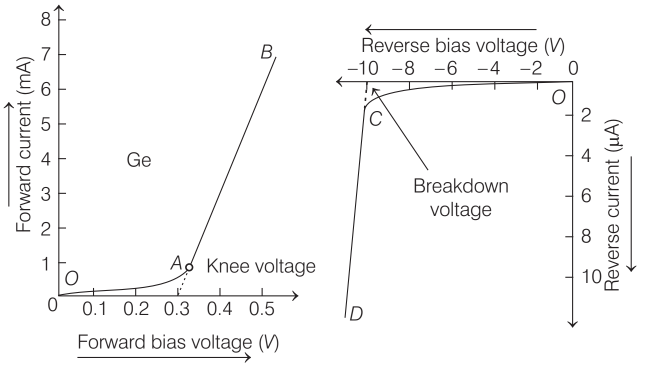
Sol Because continuous contact cannot be produced at atomic level and junction will behave as discontinuous for flowing charge carriers. **(1)**

2 MARKS *Questions*

Exams' Questions

Q.18 Draw the volt-ampere (*V-I*) characteristic curves of a *p-n* junction diode. **[2019, 2008, Textbook]**

Sol The volt-ampere (*V-I*) characteristic curves of a *p-n* junction diode.



(a) Forward biased characteristics (b) Reverse biased characteristics

(1 + 1)

Q.19 Draw the circuit diagram of a half-wave rectifier made up of junction diode. **[2013, 2007 Instant, Textbook]**

Sol **Circuit diagram of half-wave rectifier** Refer to diagram on page 306. **(2)**

Q.20 Draw the circuit diagram to study the *V-I* characteristic of a junction diode in forward biasing. **[2008]**

Sol **Forward biased characteristics** Refer to text on page 306. **(2)**

Important Questions

Q.21 What is meant by depletion region in a *p-n* junction diode? How it is affected by biasing? **[Textbook]**

Sol The region on either side of the junction which becomes depleted (free) from the mobile charge carriers is called depletion region. By biasing, the width of depletion region is affected, width increases in reverse bias and decreases in forward biasing. **(2)**

Q.22 Can the potential barrier across a *p-n* junction be measured by simply connecting a voltmeter across the junction? **[Textbook]**

Sol We cannot measure the potential barrier across a *p-n* junction by a voltmeter because there is no actual flow of current due to potential barrier when the voltmeter is connected across the junction. **(1 + 1)**

3 MARKS *Questions*

Exams' Question

Q.23 Draw a neat circuit diagram of a half-wave rectifier using *p-n* junction diode. Draw the curves for input and output voltage.

Sol **Diode as a half-wave rectifier** Refer to diagram on page 306. **(3)**

Important Questions

Q.24 (i) Draw a circuit diagram of a full wave rectifier using junction diode. **[Textbook]**

(ii) What are chief merits of junction diode over vacuum diode? **[Textbook]**

Sol (i) **Diode as a full wave rectifier** Refer to diagram on page 307. **(1½)**

(ii) Semiconductor diode has smaller interelectrode capacitances which operate at lower voltage than vacuum tubes. **(1½)**

Q.25 (i) Draw the circuit diagram of a full wave rectifier made up of junction diode. **[Textbook]**

(ii) Draw input and output curves of full wave rectifier. **[Textbook]**

Sol **Diode as a full wave rectifier** Refer to text on page 307. **(1½ + 1½)**

7 MARKS *Questions*

Exams' Questions

Q.26 With a neat circuit diagram, explain how *p-n* junction diode can be used as full wave rectifier. **[2018]**

Sol **Diode as a full wave rectifier** Refer to text on page 307. **(3 + 4)**

Q.27 With a neat circuit diagram, explain the working of a full wave rectifier made of junction diodes. Discuss the nature of the output current and voltage. **[2016]**

Sol Refer to text on page 307. **(2 + 4 + 1)**

Q.28 With a neat circuit diagram, explain the working of a full wave rectifier. Write an expression for its efficiency. **[2014]**

Sol **Diode as a full wave rectifier** Refer to text on page 307. **(2 + 4 + 1)**

Q.29 Draw circuit diagrams of forward biased and reverse biased *p-n* junctions. Describe the use of *p-n* junction diode as a half-wave rectifier. **[2014]**

Sol **Forward biasing** Refer to circuit diagram on page 306. **(1)**

Reverse biasing Refer to circuit diagram on page 306. **(1)**

Diode as a half-wave rectifier Refer to text on page 306. **(5)**

Q.30 With a neat circuit diagram, explain the working of a full wave rectifier made up of junction diodes. Discuss its efficiency. **[2012]**

Or Describe with neat circuit diagram, the working of junction diode as a full wave rectifier. Show that for an ideal full wave rectifier, the efficiency is 81.2%. **[2010]**

Or With a neat circuit diagram, explain the principle and working of a full wave rectifier using *p-n* junction diode. Discuss its efficiency. **[2010 Instant]**

Or Mention what is rectifier. With a neat circuit diagram, explain the working of a full wave rectifier made of junction diodes. Comment on its efficiency. **[2008]**

Or Give a neat diagram of a full wave rectifier circuit and describe its working with the aid of input and output curves. **[2008 Instant]**

Sol **Diode as a full wave rectifier** Refer to text on page 307. **(7)**

Q.31 With neat circuit diagrams, discuss the forward and reverse biasing of a *p-n* junction diode. Draw their characteristic curves. **[2007]**

Sol **Forward biased characteristics**
Refer to text on page 306. **(3½)**
Reverse biased characteristics
Refer to text on page 306. **(3½)**

Q.32 Explain what is meant by forward bias of a *p-n* junction diode. Describe the working of a *p-n* junction diode as a full wave rectifier with a neat circuit diagram. **[2006 Instant]**

Sol **Forward biasing** Refer to text on page 305 **(3½)**

Diode as a full wave rectifier Refer to text on page 307. **(3½)**

Q.33 What is a *p-n* junction? With a neat circuit diagram, explain how a *p-n* junction diode is used as a half-wave rectifier. **[2002]**

Sol ***p-n* junction** Refer to text on page 305. **(1)**

Diode as a half-wave rectifier Refer to text on page 306. **(6)**

Important Questions

Q.34 The input voltage applied to a half-wave rectifier is $220 \sin 100\pi t$ volt. The load resistance is $900\,\Omega$ and forward resistance is $100\,\Omega$. Calculate (i) maximum value of load current, (ii) DC load current, (iii) rms value of current, (iv) rectification efficiency, (v) frequency of the rectified DC. **[Textbook]**

Sol Here, $V_{max} = 220$ V,

$$R_1 = 900\,\Omega, R_f = 100\,\Omega$$

(i) $I_{max} = \dfrac{V_{max}}{R_{total}} = \dfrac{220}{900+100} = 0.22$ A

(ii) $I_{DC} = \dfrac{V_{rms}}{2R} = \dfrac{220/\sqrt{2}}{2\,(900+100)} = 0.07$ A

(iii) $I_{rms} = I_{max}/\sqrt{2} = \dfrac{0.22}{\sqrt{2}} = 0.11$A

(iv) $\eta = \dfrac{P_{out}}{P_{in}} \times 100 = 36.54\%$

(v) Output frequency = Input frequency

$$= 100\,\pi\,\frac{\text{radian}}{\text{second}}$$

$$= \frac{100\,\pi}{2\pi}\,\text{Hz} = 50\,\text{Hz}$$ **(7)**

Q.35 The input voltage to a full wave rectifier is $220 \sin 100\pi t$ volt. If the load resistance is 1100 Ω and forward resistance is negligible, then find the (i) peak value of load current, (ii) DC load current, (iii) rms value of current, (iv) rectification efficiency and (v) frequency of rectified output voltage. **[Textbook]**

Sol Here, $V_{max} = 220$ V,

$$R_1 = 1100\,\Omega$$

(i) $I_{max} = \dfrac{V_{max}}{R} = 0.2$A

(ii) $I_{DC} = \dfrac{V_{DC}}{R} = 0.127$ A

(iii) $I_{rms} = \dfrac{I_{max}}{\sqrt{2}} = 0.14$ A

(iv) $\eta = \dfrac{P_{out}}{P_{in}} \times 100 = 81.2\%$ *Or* $\eta = \dfrac{81.2}{1+\left(\dfrac{r_f}{R_L}\right)}$

$\therefore$ For $r_f << R_L$, $n = 81.2\%$

(v) Output frequency $= 2 \times$ Input frequency

$$= 2 \times 100\,\pi\,\frac{\text{radian}}{\text{second}} = 100\,\text{Hz}$$ **(7)**

TOPIC TEST 2

1. The depletion layer in a *p-n* junction is caused by **[Textbook]**
(a) drift of holes
(b) diffusion of charge carriers
(c) migration of impurity atoms
(d) drift of electrons [**Ans.** (b)]

2. In the depletion region of an unbiased *p-n* junction diode, there are **[Textbook]**
(a) only electrons
(b) only holes
(c) Both electrons and holes
(d) only fixed ions [**Ans.** (d)]

3. In a semiconductor diode, *p*-side is earthed and *n*-side is applied a potential of –3V, then the diode is **[Textbook]**
(a) forward biased
(b) reverse biased
(c) unbiased
(d) depletion region widens [**Ans.** (a)]

4. In reverse bias, the width of depletion layer
(a) increases
(b) decreases
(c) first increases then decreases
(d) Neither increases nor decreases [**Ans.** (a)]

5. In comparison to a half-wave rectifier, a full wave rectifier gives lower .... (Fill in the blank) [**Ans.** ripple in output]

6. Discuss working of a *p-n* junction. Draw circuit diagram to draw *V-I* characteristic of a junction diode and discuss its different regions. Which regions are useful for voltage regulation and rectification? **[Textbook]**

7. What is a rectifier? Explain with a neat circuit diagram how a *p-n* junction diode acts as a rectifier. **[Textbook]**

8. In a *p-n* junction, the depletion region is 0.5 μm wide and an electric field of 1.8×10^6 V/m exists in it. Calculate the height of potential barrier. What should be the minimum kinetic energy of a conduction electron which can diffuse from *n*-side to *p*-side? [**Ans.** 0.9 V, 0.9 eV]

9. How many junction diodes shall be used for affecting half-wave rectification?

10. What do you mean by avalanche breakdown?

11. Discuss the concept of photodiode.

12. How does Light Emitting Diode (LED) work?

Chapter Test

1 MARK *Questions*

1 In case of semiconductor, conduction band and valence band
(a) overlap
(b) have small energy gap
(c) have large energy gap
(d) are absent

2 In a *p-n* junction, the formation of depletion region is due to
(a) drift of holes
(b) drift of electrons
(c) diffusion of charge carriers
(d) migration of impurity atoms

3 What is the order of energy gap in a semiconductor? **[Textbook]**

4 At what temperature would an intrinsic semiconductor behave like a perfect insulator? **[Textbook]**

5 State the basic principle of a solar cell.

6 What is the approximate value of the potential barrier of a germanium *p-n* junction?

7 What do you mean by efficiency of a rectifier?

2 MARKS *Questions*

8 Draw a diagram of *p-n* junction under reverse biasing. **[Textbook]**

9 Calculate the intrinsic resistivity of germanium, if intrinsic carrier density is 2.4×10^{19} per m^3 and hole and electron mobilities are 0.2 and 0.4 $m^2 V^{-1} s^{-1}$, respectively.

10 If electrical conductivity of germanium at 27°C is 2.5 μ/m, calculate the current density, if the electric field intensity is 2000 V/m.

11 When reverse biased, the junction diode acts as a high resistance device. Why is it so? **[Textbook]**

3 MARKS *Questions*

12 Explain the working of a junction diode when it is reverse biased.

7 MARKS *Questions*

13 What do you mean by a semiconductor? Discuss how can you improve its conductivity on the basis of band theory. **[Textbook]**

HINTS and ANSWERS

1. (b)
2. (c)
3. 10^{-19}
4. 0 kelvin
6. 0.3 V
9. **Hint** $\sigma = e(n_e \mu_e + n_h \mu_h)$ [**Ans.** 0.43 Ω-m]
10. **Hint** $J = \sigma E$ [**Ans.** 5×10^3 Am^{-2}]