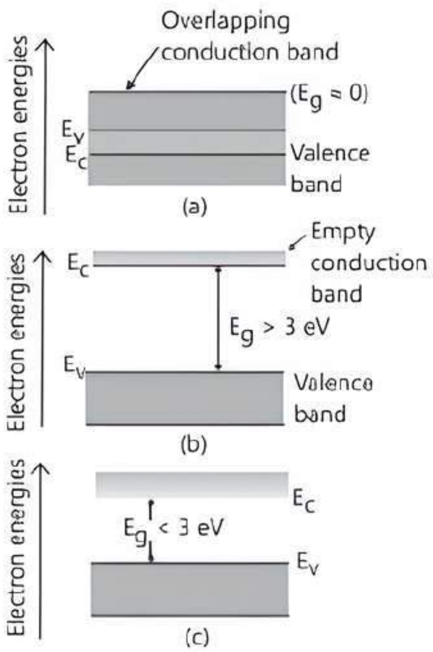
# 14 Semiconductor Electronics : Materials, Devices and Simple Circuits

## Fastrack Revision

- **Metal or Conductors:** The materials which possess very low resistivity ($10^{-2}$ to $10^{-8}$ Ωm) or high conductivity ($10^2$ to $10^8$ $Sm^{-1}$) are called conductors.
- **Insulators:** The materials which possess high resistivity ($10^{11}$ to $10^{19}$ Ωm) or low conductivity ($10^{-11}$ to $10^{-19}$ $Sm^{-1}$) are called insulators.
- **Semiconductors:** The materials which have resistivity ($10^{-5}$ to $10^6$ Ωm) or conductivity ($10^5$ to $10^{-6}$ $Sm^{-1}$) intermediate to conductors and insulators. The conductivity of semiconductors lie between conductors and insulator.
- **Energy Bands in Solids:** The energy levels of electrons with continuous energy variation form what are called energy bands.
  - **Valence Band:** The energy band which includes the energy levels of the valence electrons is called the valence band. This band may be partially or completely filled with electrons but is never empty.
  - **Conduction Band:** The energy band above the valence band is called conduction band. Normally, the conduction band is empty but when it overlaps on the valence band electrons can move freely into it.
  - **Energy Band Gap:** The gap between the top of the valence band and bottom of the conduction band is called energy band gap. It is denoted by $E_g$.
- **Energy Bands in Conductors, Semiconductors and Insulators:** Energy band diagrams for conductor, Semiconductor and insulator are shown in figure given below:




- **Energy Band in Conductor:** In conductor, valence band and conduction band overlap each other or there is no energy gap between the conduction band and valence band.
- **Energy Band in Insulator:** In case of insulator, a large band gap exists *i.e.,* $E_g$ > 3eV [See fig. (b)]. There are no electrons in the conduction band and therefore no electrical conduction is possible. Electrons cannot be excited from the valence band to the conduction band by thermal excitation.
- **Energy Band in Semiconductor:** In case of semiconductors, a finite but small band gap ($E_g$ < 3eV) exists [See fig. (c)]. Because of the small band gap, at room temperature, some electrons from valence band acquire enough energy to cross the energy gap and enter the conduction band.
- **Types of Semiconductors:** Semiconductors are mainly classified into two categories—Intrinsic and Extrinsic.
  - **Intrinsic Semiconductor:** An intrinsic semiconductor material is chemically very pure and possesses poor conductivity. It has equal number of negative charge carriers (electrons) and positive charge carriers (holes).
  - **Extrinsic Semiconductor:** An extrinsic semiconductor is an improved intrinsic semiconductor with a small amount of impurities added by a process, known as doping, which alters the electrical properties of the semiconductor and improves its conductivity.
    The impurity atoms are called dopants.
    - Introducing impurities into the semiconductor materials (doping process) can control their conductivity.
    - Silicon and Germanium are the most common elemental semiconductors.
    - Compound semiconductors includes InSb, InAs, GaP, GaSb, GaAs, SiC, GaN.
    - Si and Ge both have a crystalline structure called the diamond lattice. That is, each atom has its four nearest neighbours at the corners of a regular tetrahedron with the atom itself being at the centre.
- **Types of Extrinsic Semiconductor:** There are two types of extrinsic semiconductor:
  - ***n*-type Semiconductor:** In *n*-type semiconductor, electrons are majority charge carriers and holes are minority charge carriers ($n_e >> n_h$) carriers. *n*-type semiconducting Si or Ge is obtained by doping with pentavalent atoms such as As, Sb, P etc.

- **$p$-type Semiconductor:** In $p$-type semiconductor, electrons are minority and holes are majority charge carriers ($n_h >> n_e$). $p$-type semiconducting Si or Ge is obtained by doping with trivalent atoms such B, Al , In etc.

- **Doping of Semiconductors:** The addition of a small percentage of foreign atoms in the regular crystal lattice of Silicon or Germanium produces dramatic changes in their electrical properties, producing $n$-type and $p$-type semiconductors.

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

  - **Pentavalent Impurities:** Pentavalent impurities (5 valence electrons) produce $n$-type semiconductors by contributing extra electrons. The addition of pentavalent impurities such as Antimony (Sb), Arsenic (As) or Phosphorous (P) etc., contributes free electrons, greatly increasing the conductivity of the intrinsic semiconductor. Pentavalent impurities are also known as donor impurities.
  - **Trivalent Impurities:** Trivalent impurities (3 valence electrons) produce $p$-type semiconductors by producing a 'hole' or electron deficiency.

    The addition of trivalent impurities such as Boron (B), Aluminium (Al) or Gallium (Ga), etc. to an intrinsic semiconductor creates deficiencies of valence electrons called holes. Trivalent impurities are also known as acceptor impurities:

- **Electron and Hole Concentration:** The electron and hole concentration in a semiconductor in thermal equilibrium is given by

$$n_e n_h = n_i^2$$

- **Electrical Mobility:** Electrical mobility is the ability of charged particles (such as electrons or holes) to move through a medium in response to an electric field that is pulling them. It is denoted by $\mu$.

  Electrical mobility, $$\mu = \frac{v_d}{E}$$

  where,

  $v_d$ = drift velocity (in $ms^{-1}$)

  $E$ = magnitude of the applied electric field (in $Vm^{-1}$).

  SI unit of mobility is $m^2 V^{-1} s^{-1}$.

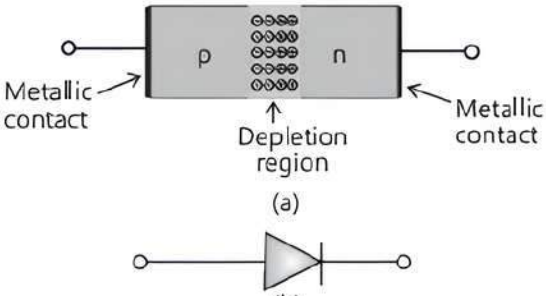
- **Electrical Conductivity of Semiconductor**

$$\sigma = e[n_e \mu_e + n_h \mu_h]$$

- **$p$-$n$ Junction:** When a $p$-type semiconductor crystal is brought in contact with an $n$-type semiconductor crystal, the resulting arrangement is called a $p$-$n$ junction.

  The region on either side of junction which become depleted free from the mobile charge carriers is called depletion region. The potential difference developed across the depletion region is called the potential barrier.

- **Semiconductor Diode:** A semiconductor diode or $p$-$n$ 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 diode.



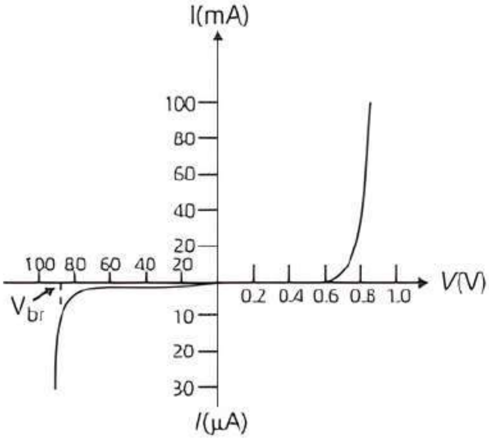

(a) Semiconductor diode

(b) Symbol of p-n junction diode

- **Forward Biased $p$-$n$ Junction (Diode):** When we connect $p$-type region of a junction with the positive terminal of a voltage source and $n$-type region with the negative terminal of the voltage source, then the junction is said to be forward biased.

- **Reverse Biased $p$-$n$ Junction (Diode):** When we connect $n$-type region of a junction with the positive terminal of a voltage source and $p$-type region with the negative terminal of the voltage source, then the junction is said to be reverse biased.

- **$V$-$I$ Characteristics of Semiconductor Diode:** The $V$-$I$ characteristics of semiconductor diode is shown below:




The current first increases very slowly, almost negligibly, till the voltage across the diode crosses a certain value. After the characteristic voltage, the diode current increases significantly (exponentially), even for a very small increase in the diode bias voltage. This voltage is called the **threshold voltage** or **cut-in-voltage** (~0.2V for germanium diode and ~ 0.7V for silicon diode).

For the diode in reverse bias, the current is very small (~μA) and almost remains constant with change in bias, It is called **reverse saturation current**. However, for special cases, at very high reverse bias (breakdown voltage), the current suddenly increase.

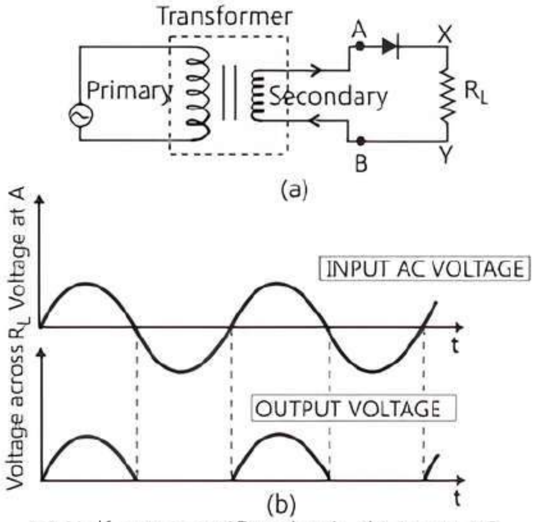
For diodes, we define a quantity called **dynamic resistance** ($r_d$) as the ratio of small change in voltage ($\Delta V$) to a small change in current ($\Delta I$).

$$r_d = \frac{\Delta V}{\Delta I}$$

- **Diode as a Rectifier:** The most popular application of diode is a rectifier. Rectifier is a diode which converts an Alternating Current (AC) into Direct Current (DC) by using $p$-$n$ junction diode.

  There are mainly two types of rectifiers:

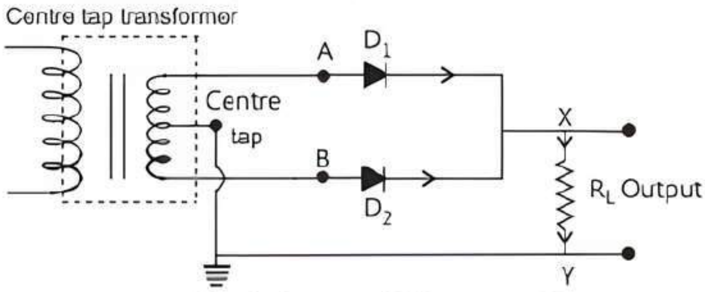
  - **Half Wave Rectifier:** If an AC voltage is applied across a diode in series with a load, a pulsating voltage will appear across the load only during half cycles of the AC input during which the diode is forward biased. Such a circuit is called half wave rectifier. Only one diode is used in half wave rectifier.



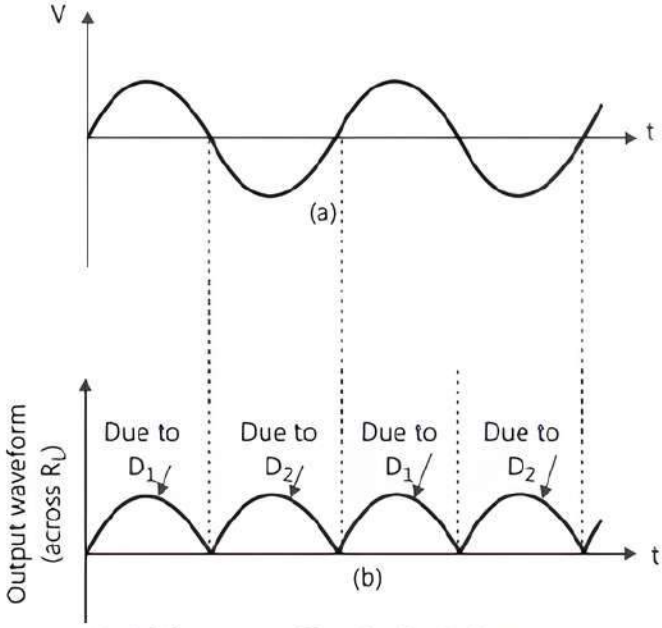

(a) Half-wave rectifier circuit, (b) Input AC voltage and output voltage waveforms of rectifier circuit.

When the voltage at *A* is positive, the diode is forward biased and it conducts. When *A* is negative, the diode is reversed-biased and it does not conduct. Thus, in the positive half cycle of AC, there is a current through the load resistor $R_L$ and we get an output voltage, whereas there is no current in the negative half cycle.

**(ii) Full Wave Diode Rectifier:** In full wave rectifier, two diodes and one centre-tap transformer is used. This rectifier circuit gives output rectified voltage corresponding to both the positive as well as negative half of the AC cycle. If two diodes $D_1$ and $D_2$ are connected in such a way that one diode conducts during one half cycle of the input voltage and the other one conducts during the next half cycle of the input voltage in a unidirectional current flow through the load during the full cycle of the input voltage.




**Circuit diagram of full wave rectifier**




(a) A full-wave rectifier circuit, (b) Output wave form across the load $R_L$ connected in the full-wave rectifier circuit.

# Practice Exercise

## Multiple Choice Questions

**Q 1. In conductor, semiconductor and insulator, the forbidden energy gap are $E_1$, $E_2$ and $E_3$ respectively. Which one is correct?**

a. $E_1 < E_2 < E_3$ b. $E_1 > E_2 = E_3$
c. $E_1 = E_2 < E_3$ d. $E_1 > E_2 > E_3$

**Q 2. Carbon, silicon and germanium have four valence electrons each. These are characterised by valence and conduction bands separated by energy band gap respectively equal to $(E_g)_C$, $(E_g)_{Si}$ and $(E_g)_{Ge}$. Which of the following statements is true?**

a. $(E_g)_{Si} < (E_g)_{Ge} < (E_g)_C$
b. $(E_g)_C < (E_g)_{Ge} < (E_g)_{Si}$
c. $(E_g)_C > (E_g)_{Si} > (E_g)_{Ge}$
d. $(E_g)_C = (E_g)_{Si} = (E_g)_{Ge}$

**Q 3. The electrical conductivity of a semiconductor increases when electromagnetic radiation of wavelength shorter than 2480 nm is incident on it. The band gap (in eV) for semiconductor is:**

a. 0.9 b. 0.7 c. 0.5 d. 1.1

**Q 4. The intrinsic semiconductor becomes an insulator at:**

a. 0°C b. –100°C c. 300 K d. 0 K

**Q 5. At 0 K, the resistivity of an intrinsic semiconductor is:** *(CBSE 2023)*

a. same as that at 0°C b. same as that at 300 K
c. zero d. infinite

**Q 6. A semiconductor has an electron concentration of $6 \times 10^{22}$ per $m^3$ and hole concentration of $8.5 \times 10^9$ per $m^3$. Then it is:**

a. *n*-type semiconductor
b. *p*-type semiconductor
c. intrinsic semiconductor
d. conductor

**Q 7. In an *n*-type semiconductor, which of the following statements is true?**

a. Electrons are majority carriers and trivalent atoms are the dopants.
b. Electrons are minority carriers and pentavalent atoms are the dopants.
c. Holes are minority carriers and pentavalent atoms are the dopants.
d. Holes are majority carriers and trivalent atoms are the dopants.

**Q 8. The energy required by an electron to jump the forbidden band in silicon at room temperature is about:** *(CBSE 2023)*

a. 0.01 eV b. 0.05 eV c. 0.7 eV d. 1.1 eV

**Q 9. In an unbiased *p-n* junction, holes diffuse from the *p*-region to *n*-region because:**

a. free electrons in the *n*-region attract them

b. they move across the junction by the potential difference

c. hole concentration in *p*-region is more as compared to *n*-region

d. All of the above

**Q 10. When a forward bias is applied to a *p-n* junction, it:**

a. raises the potential barrier

b. reduces the majority carrier current to zero

c. lowers the potential barrier

d. None of the above

**Q 11. In the forward bias arrangement of a *p-n* junction diode:**

a. the *n*-end is connected to the positive terminal of the battery.

b. the *p*-end is connected to the positive terminal of the battery.

c. the direction of current is from *n*-end to *p*-end in the diode.

d. the p-end is connected to the negative terminal of the battery.

**Q 12. Potential barrier developed in a junction diode opposes the flow of:**

a. minority carrier in both regions

b. majority carriers only

c. electrons in *p*-region

d. holes in *p*-region

**Q 13. Which of the following statement is incorrect for the depletion region of a diode?**

a. There the mobile charges exist.

b. Equal number of holes and electrons exist, making the region neutral.

c. Recombination of holes and electrons has taken place.

d. None of the above

**Q 14. If a *p-n* junction diode is reverse biased:** *(CBSE 2023)*

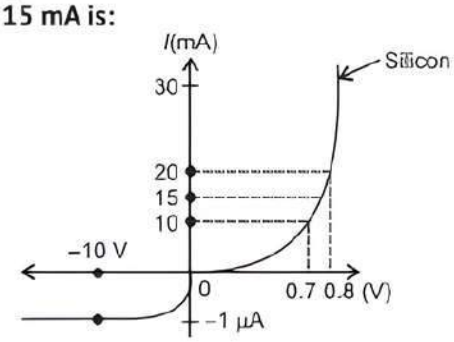
a. the potential barrier is lowered

b. the potential barrier remains unaffected

c. the potential barrier is raised

d. the current is mainly due to majority carriers

**Q 15. The *V-I* characteristic of a silicon diode is shown in figure. The forward resistance of the diode at $I_D = 15$ mA is:**




a. 5 Ω b. 10 Ω c. 2 Ω d. 20 Ω

**Q 16. The SI unit of mobility of charge carriers is:** *(CBSE 2023)*

a. $\Omega\, s^{-1}$ b. $m^2V^{-1}s^{-1}$ c. $ms^{-1}V^{-1}$ d. $\Omega\, m$

**Q 17. Rectifier is used to:**

a. convert AC voltage to DC voltage

b. convert DC voltage to AC voltage

c. convert high voltage to low voltage

d. All of the above

**Q 18. The equivalent DC output voltage of a full wave rectifier is ............. the equivalent DC output voltage of a half wave rectifier.**

a. equal b. half c. double d. two times

**Q 19. How many diodes does the full wave rectifier consists of?**

a. One b. Two c. Three d. Four

**Q 20. In a half wave rectifier circuit operating from 50Hz mains frequency, the fundamental frequency in the ripple would be:**

a. 25 Hz b. 50 Hz c. 70.7 Hz d. 100 Hz

## Assertion & Reason Type Questions

**Directions (Q.Nos. 21-30):** *In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:*

a. Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

b. Both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).

c. Assertion (A) is true but Reason (R) is false.

d. Both Assertion (A) and Reason (R) are false.

**Q 21. Assertion (A): Electron has higher mobility than hole in a semiconductor.**
**Reason (R): Mass of electron is less than the mass of hole.**

**Q 22. Assertion (A): Silicon is preferred over germanium for making semiconductor devices.**
**Reason (R): The energy gap for germanium is more than the energy gap of silicon.**

**Q 23. Assertion (A): At 0 K, germanium is a super-conductor.**
**Reason (R): At 0K, germanium offers zero resistance.**

**Q 24. Assertion (A): The resistivity of a semiconductor increases with temperature.**
**Reason (R): The atoms of a semiconductor vibrate with larger amplitude at higher temperature thereby increasing its resistivity.**

**Q 25. Assertion (A): The resistance of an intrinsic semiconductor decreases with increase in its temperature.**
**Reason (R): The number of conduction electrons as well as hole increase in an intrinsic semiconductor with rise in its temperature.** *(CBSE 2023)*

Q 26. Assertion (A): An $n$-type semiconductor has a large number of electrons but still it is electrically neutral.
Reason (R): An $n$-type semiconductor is obtained by doping an intrinsic semiconductor with a pentavalent impurity.

Q 27. Assertion (A): Putting $p$-type semiconductor slab directly in physical contact with $n$-type semiconductor slab cannot form the $pn$-junction.
Reason (R): The roughness at contact will be much more than interatomic crystal spacing and continuous flow of charge carriers is not possible.
*(CBSE SQP 2023-24)*

Q 28. Assertion (A): The depletion layer in the $p$-$n$ junction is free from mobile charge carriers.
Reason (R): There is no electric field across the junction barrier.

Q 29. Assertion (A): The dominant mechanism for motion of charge carriers in forward and reverse biased silicon $p$-$n$ junction are drift in both forward and reverse bias.
Reason (R): In reverse biasing, no current flow through the junction.

Q 30. Assertion (A): The half wave rectifier work only for positive half cycle of AC.
Reason (R): In half wave rectifier, only one diode is used.

## Fill in the Blanks Type Questions

Q 31. Metals have ............... conductivity and ............... resistivity.

Q 32. Mobility of hole is ............... than that of electrons.

Q 33. Hole density is ............... as compare to electron density in a $p$-type semiconductor.

Q 34. A pure semiconductor which is free of every impurity is called ............... semiconductor.

Q 35. The resistance of $p$-$n$ junction is ............... when reverse biased.

Q 36. In $p$-$n$ junction diode there is a ............... of majority carriers across the junction in forward bias.

Q 37. In half wave rectification, if the input frequency is 50 Hz, then the output frequency of the signal will be ............... Hz.

Q 38. In full wave rectification, if the input frequency is 50 Hz, then the output frequency of the signal will be ............... Hz.

## Answers

1. (a) $E_1 < E_2 < E_3$
2. (c) $(E_g)_C > (E_g)_{Si} > (E_g)_{Ge}$
3. (c) 0.5

Energy gap, $E_g = \dfrac{hc}{\lambda} = \dfrac{6.63\times10^{-34}\times3\times10^8}{1.6\times10^{-19}\times2480}$

$= \dfrac{1243\text{ eV nm}}{2480\text{ nm}} = 0.5\text{ eV}$

4. (d) 0 K
At 0 K temperature, semiconductor behaves as an insulator, because at very low temperature, electrons cannot jump from the valence band to conduction band.
5. (d) infinite
6. (a) $n$-type semiconductor
7. (c) Holes are minority carriers and pentavalent atoms are the dopants.
8. (d) 1.1 eV
9. (c) hole concentration in $p$-region is more as compared to $n$-region
10. (c) lowers the potential barrier
11. (b) the $p$-end is connected to the positive terminal of the battery.
12. (b) majority carriers only
13. (a) There the mobile charges exist.
14. (c) The potential barrier is raised.
15. (b) 10 Ω
In figure, at $I = 20$ mA, V = 0.8 V
At $I = 10$ mA, V = 0.7 V
Forward resistance,
$$r_{fb} = \frac{\Delta V}{\Delta I} = \frac{(0.8-0.7)\text{ V}}{(20-10)\text{ mA}} = \frac{0.1\text{ V}}{10\text{ mA}} = 10\ \Omega$$
16. (b) $m^2 V^{-1} s^{-1}$.
17. (a) Convert AC voltage to DC voltage
18. (c) double
19. (b) Two
20. (b) 50 Hz
As the output voltage obtained in a half wave rectifier circuit has a single variation in one cycle of AC voltage. Hence, the fundamental frequency in the ripple of output voltage would be 50 Hz.
21. (a) The ratio of the velocity to the applied field is called the mobility. Since, electron is lighter than holes, they move faster in applied field than holes.
22. (c) The energy gap for germanium is less (0.72 eV) than the energy gap of silicon (1.1 eV) and silicon is preferred over germanium for making semiconductor devices.
23. (d) At 0 K, germanium offers infinite resistance and it behaves as an insulator.
24. (d) Resistivity of semiconductors decreases with temperature. The atoms of a semiconductor vibrate with larger amplitudes at higher temperatures thereby increasing it's conductivity not resistivity.
25. (b) Both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).

26. (b)

| Intrinsic semiconductor (Neutral) | + | Pentavalent impurity (Neutral) | = | $n$-type semiconductor (Neutral) |
|---|---|---|---|---|

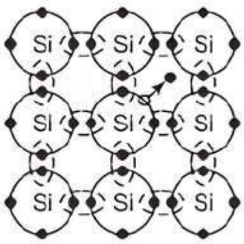
27. (a) Both Assertion (A) and Reason (R) are true but Reason (R) is the correct explanation of Assertion (A).
28. (c) Due to diffusion of holes from the $p$-region to the $n$-region and of electrons from the $n$-region to the $p$-region, an electric field is set up across the junction barrier. Once the depletion layer is formed, it is in equilibrium and becomes free of mobile charge carriers.
29. (d) In $p$-$n$ junction, the diffusion of majority carriers takes place when junction is forward biased and drifting of minority carriers takes place across the junction, when reverse biased. The reverse bias opposes the majority carriers but makes the minority carriers to cross the $p$-$n$ junction. Thus, the small current (in $\mu$A) flows during reverse bias.
30. (a) In half wave rectifier, only one diode is used. Diode is biased only when AC is in positive half cycle. For negative half AC cycle, the diode is reversed biased and there is no output corresponding to that. Since for only one-half cycle, we get a voltage output, because of which it is called half wave rectifier.

31. high, low
32. less
33. greater
34. intrinsic
35. high
36. diffusion
37. 50
38. 100

## Case Study Based Questions

### Case Study 1

Consider a thin $p$-type silicon ($p$-Si) semiconductor wafer. By adding precisely a small quantity of pentavalent impurity, part of the $p$-Si wafer can be converted into $n$-Si. There are several processes by which a semiconductor can be formed. The wafer now contains $p$-region and $n$-region and a metallurgical junction between $p$ and $n$-regions. Two important processes occur during the formation of a $p$-$n$ junction: diffusion and drift. We know that in an $n$-type semiconductor, the concentration of electrons is more compared to the concentration of holes. Similarly, in a $p$-type semiconductor, the concentration of holes is more than the concentration of electrons. During the formation of $p$-$n$ junction and due to the concentration gradient across $p$ and $n$-sides, holes diffuse from $p$-side to $n$-side ($p \rightarrow n$) and electrons diffuse from $n$-side to $p$-side ($n \rightarrow p$). This motion of charge carriers gives rise to diffusion current across the junction.




*Read the given passage carefully and give the answer of the following questions:*

**Q 1. How can a $p$-type semiconductor be converted into $n$-type semiconductor?**
a. By adding pentavalent impurity
b. By adding trivalent impurity
c. By not possible
d. By heavy doping

**Q 2. Which of the following is true about $n$-type semiconductor?**
a. Concentration of electrons is less than that of holes.
b. Concentration of electrons is more than that of holes.
c. Concentration of electrons is equal to that of holes.
d. None of the above

**Q 3. Which of the following is true about $p$-type semiconductor?**
a. Concentration of electrons is less than that of holes.
b. Concentration of electrons is more than that of holes.
c. Concentration of electrons is equal to that of holes.
d. None of the above

**Q 4. Which of the following is the reason about diffusion current?**
a. Diffusion of holes from $p$ to $n$
b. Diffusion of electrons from $n$ to $p$
c. Both a. and b.
d. None of the above

#### Answers

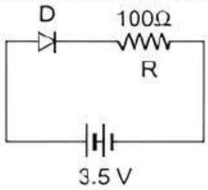
1. (a) By adding pentavalent impurity
2. (b) Concentration of electrons is more than that of holes.
3. (a) Concentration of electrons is less than that of holes.
4. (c) Both a. and b.

### Case Study 2

A semiconductor diode is basically a $pn$-junction with metallic contacts provided at the ends for the application of an external voltage. It is a two terminal device. When an external voltage is applied across a semiconductor diode such that $p$-side is connected to the positive terminal of the battery and $n$-side to the negative terminal, it is said to be forward biased. When an external voltage is applied across the diode such that $n$-side is positive and $p$-side is negative, it is said to be reverse biased. An ideal diode is one whose resistance in forward biasing is zero and the resistance is infinite in reverse biasing. When the diode is forward biased, it is found that beyond forward voltage called knee voltage, the conductivity is very high. When the biasing voltage is more than the knee voltage, the potential barrier is overcome and the current increases rapidly with increase in forward voltage. 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 reverse saturation current.

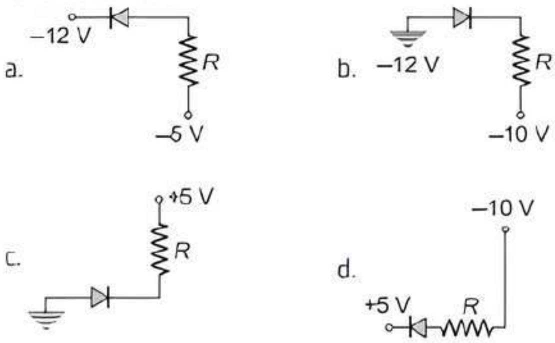
***Read the given passage carefully and give the answer of the following questions:***

**Q 1. In the given figure, a diode *D* is connected to an external resistance $R = 100\ \Omega$ and an emf of 3.5 V. If the barrier potential developed across the diode is 0.5 V, the current in the circuit will be:**




a. 40 mA
b. 20 mA
c. 35 mA
d. 30 mA

**Q 2. In which of the following figures, the pn diode is reverse biased?**

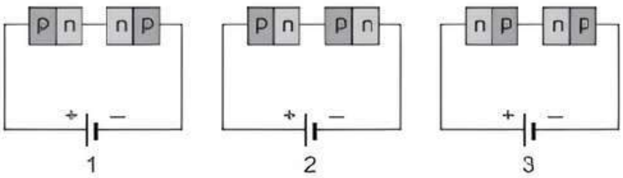



**Q 3. Based on the *V-I* characteristics of the diode, we can classify diode as:**

a. bilateral device
b. ohmic device
c. non-ohmic device
d. passive element

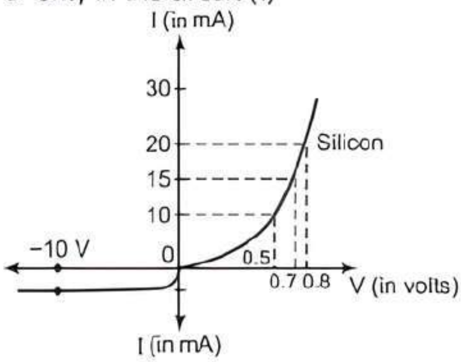
*OR*

**Two identical *pn*-junctions can be connected in series by three different methods as shown in the figure. If the potential difference in the junctions is the same, then the correct connections will be**




a. in the circuits (1) and (2)
b. in the circuits (2) and (3)
c. in the circuits (1) and (3)
d. only in the circuit (1)

**Q 4.**




**The V-I characteristic of a diode is shown in the figure. The ratio of the resistance of the diode at $I = 15$ mA to the resistance at $V = -10$ V is:**

*(CBSE SQP 2023-24)*

a. 100
b. $10^6$
c. 10
d. $10^{-6}$

## Answers

**1.** (d) The potential difference across the resistance *R* is

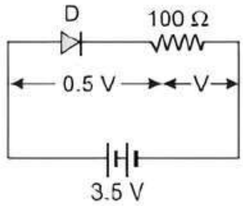
$V = 3.5\ \text{V} - 0.5\ \text{V} = 3\ \text{V}$

By ohm's law,

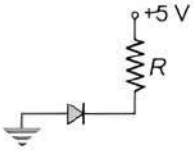
The current in the circuit,

$$I = \frac{V}{R} = \frac{3\text{V}}{100\ \Omega} = 3 \times 10^{-2}\ \text{A}$$

$$= 30 \times 10^{-3}\ \text{A} = 30\ \text{mA}$$




**2.** (c)




**3.** (c) non-ohmic device OR (b) in the circuits (2) and (3)

**4.** (d) From the given curve, we have

$V = 0.8$ V for current $I = 20$ mA

and $V = 0.7$ V for current $I = 10$ mA

Resistance at $I = 15$ mA

$\therefore \quad \Delta I = (20 - 10)\ \text{mA} = 10 \times 10^{-3}$ A

and $\Delta V = (0.8 - 0.7) = 0.1$ V

Thus $R = \dfrac{\Delta V}{\Delta I} = \dfrac{0.1}{10 \times 10^{-3}} = 10\ \Omega$

**Resistance at V = – 10 V:**

$I = -1\ \mu\text{A} = -1 \times 10^{-6}$ A

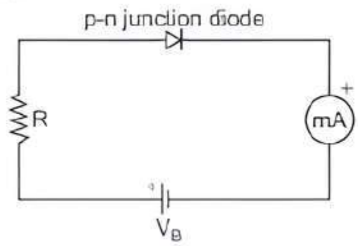
$$R = \frac{-10}{-1 \times 10^{-6}} = 1.0 \times 10^{7}\ \Omega$$

$$\therefore \text{Ratio of resistance} = \frac{10}{1.0 \times 10^{7}} = 10^{-6}$$

## Case Study 3

A silicon *p-n* junction diode is connected to a resistor *R* and a battery of voltage $V_B$ through milliampere (mA) as shown in figure. The knee voltage for this junction diode is $V_N = 0.7$ V. The *p-n* junction diode requires a minimum current of 1 mA to attain a value higher than the knee point on the *V-I* characteristics of this junction diode. Assuming that the voltage *V* across the junction is independent of the current above the knee point.

A *p-n* junction is the basic building block of many semiconductor, devices like diodes. Important process occurring during the formation of a *p-n* junction are diffusion and drift. In an *n*-type semiconductor concentration of electrons is more as compared to holes. In a *p*-type semiconductor, concentration of holes is more as compared to electrons.



*Read the given passage carefully and give the answer of the following questions:*

**Q 1. If $V_B = 5$ V, then what will be the maximum value of $R$ so that the voltage $V$ is above the knee point voltage?**

**Q 2. If $V_B = 5$ V, then what will be the value of $R$ in order to establish a current to 6 mA in the circuit?**

**Q 3. When the diode is reverse biased with a voltage of 6 V and $V_{bl} = 0.63$ V, calculate the total potential.**

**Q 4. If $V_B = 6$ V, then calculate the power dissipated in the resistor $R$, when a current of 6 mA flows in the circuit.**

## Answers

1. Voltage drop across $R$,
$$V_R = V_B - V_N = 5 - 0.7 = 4.3 \text{ V}$$
Given, $I_{min} = 1 \times 10^{-3}$ A
Maximum value of resistance,
$$R_{max} = \frac{V_R}{I_{min}} = \frac{4.3}{1 \times 10^{-3}}$$
$$= 4.3 \times 10^3 \ \Omega = 4.3 \text{ k}\Omega$$

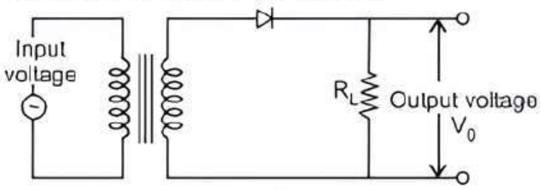
2. Given, $I = 6$ mA $= 6 \times 10^{-3}$ A;
$$V_R = V_B - V_N = 5 - 0.7 = 4.3 \text{ V}$$
$$R = \frac{V_R}{I} = \frac{4.3}{6 \times 10^{-3}} = 717 \ \Omega$$

3. Total potential, $V_t = V_{bi} + V_R = 0.63 + 6 = 6.63$ V

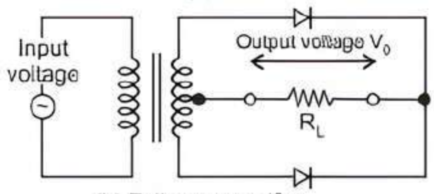
4. Given, $V_B = 6$V; $V_N = 0.7$V, $V_R = 6 - 0.7 = 5.3$ V
Power dissipated, $P = I \times V_R = (6 \times 10^{-3}) \times 5.3$
$= 31.8 \times 10^{-3}$ W $= 31.8$ mW

## Case Study 4

Rectifier is a device which is used for converting alternating current or voltage into direct current or voltage. Its working is based on the fact that the resistance of *p-n* junction becomes low when forward biased and becomes high when reverse biased. A half wave rectifier uses only a single diode while a full wave rectifier uses two diodes as shown in figures (a) and (b).




(a) Half wave rectifier



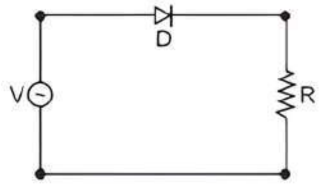

(b) Full wave rectifier

*Read the given passage carefully and give the answer of the following questions:*

**Q 1. If the rms value of sinusoidal input to a full wave rectifier is $\frac{V_0}{\sqrt{2}}$, then what is the rms value of the rectifier's output?**

**Q 2. When an input of frequency 200 Hz is fed at input, what will be the ratio of output frequencies of half wave rectifier and full wave rectifier?**

**Q 3. A *p-n* junction diode is shown in figure can act as a rectifier. An alternating voltage source (*V*) is connected in the circuit. Show the waveform of current (*I*) in the resistor (*R*).**



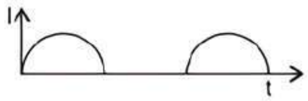

**Q 4. What will be the fundamental ripple frequency in a half wave rectifier circuit operating from 50 Hz mains frequency?**

## Answers

1. The rms value of the output voltage at the load resistance.
$$V_{rms} = \frac{V_0}{\sqrt{2}}$$
In full wave rectifier, the whole cycle is rectified so the value of input voltage will be same as output.

2. Output frequency of full wave rectifier is twice the output frequency of half wave rectifier.
Hence,
$$\frac{\text{Frequency of half wave rectifier}}{\text{Frequency of full wave rectifier}} = \frac{1}{2} = 1:2$$

3. The given circuit works as a half wave rectifier. In this circuit, we will get current through $R$ when *p-n* junction diode is forward biased and no current flow when *p-n* junction diode is reverse biased. Thus, the current (*I*) through resistor (*R*) will be shown in the waveform.




4. As the output voltage obtained in a half wave rectifier, circuit has a single variation in one cycle of AC voltage, hence the fundamental frequency in the ripple of output voltage would be 50 Hz.

## Very Short Answer Type Questions

**Q 1. Why a pure semiconductor behaves like an insulator at 0 K?**

**Ans.** A semiconductor acts like an ideal insulator at absolute zero temperature (0 K). It is because the free electrons in the valence band of semiconductors will not carry enough thermal energy to overcome the forbidden energy gap at absolute zero.

**Q 2. What are the two types of semiconductors on the basis of purity?**

**Ans.** On the basis of purity, semiconductor can be classified as:
(i) intrinsic semiconductors
(ii) extrinsic semiconductors

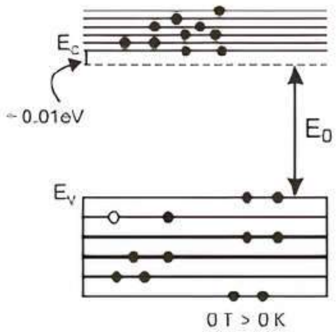
**Q 3. By which charge carriers, an intrinsic semiconductor will have conduction?**

**Ans.** Electrons and holes.

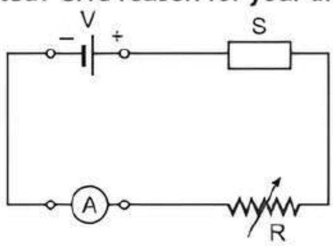
**Q 4. How does the resistance of a semiconductor change when heated?**

**Ans.** With increase in temperature, a greater number of bonds inside the semiconductor are broken.

Hence, a large number of electrons come out from those bonds. As a result, the number of charge carriers increases and consequently the resistance decreases.




**Q 5. In the following diagrams 'S' is a semiconductor. Would you increase or decrease the value of *R* to keep the reading of the ammeter *A* constant when *S* is heated? Give reason for your answer.**




**Ans.** *R* would be increased; because resistance of semiconductor '*S*' decreases on heating.

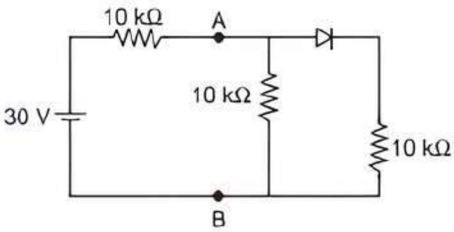
**Q 6. How does an increase in doping concentration affect the width of depletion layer of a *p-n* junction diode?** *(CBSE 2020)*

**Ans.** The width of depletion layer of a *p-n* junction diode decreases on an increase in doping concentration.

**TiP**

*Doping decreases width of depletion layer.*

**Q 7. In the given circuit, what is the potential difference between *A* and *B*?**




**Sol.** In the given circuit, *p-n* junction diode is forward biased. If *p-n* junction diode is ideal, its resistance is zero. The effective resistance across *A* and *B*

$$= \frac{10 \times 10}{10 + 10} = \frac{100}{20} = 5 k\Omega$$

Current in the circuit,

$$I = \frac{V}{R} = \frac{30}{(10 + 5) \times 10^3}$$

$$= \frac{30}{15} \times 10^{-3} = 2 \times 10^{-3} A$$

$\therefore \quad I = 2$ mA

Since, 10 kΩ and 10 kΩ resistances are connected in parallel, current in each 10 kΩ resistance is equal to

$$\frac{I}{2} = \frac{2 mA}{2} = 1 mA$$

$\therefore$ Potential difference across *A* and *B*

$$= 1 \text{ mA} \times 10 \text{ k}\Omega$$

$$= 1 \times 10^{-3} \times 10 \times 10^3$$

$$= 10 \text{ V}$$

**Q 8. In half wave rectification, what is the output frequency if input frequency is 25 Hz?**

**Sol.** Output frequency = 25 Hz

In half wave rectification, input frequency = output frequency.

**Q 9. In full wave rectification, what is the output frequency if input frequency is 50 Hz?**

**Sol.** If input frequency is 50 Hz, then output frequency = 2 × 50 = 100 Hz.

## Short Answer Type-I Questions

**Q 1. C, Si and Ge have same lattice structure. Why is C insulator, while Si and Ge intrinsic semiconductors?** *(NCERT SOLVED EXAMPLE)*

**Ans.** The 4 bonding electrons of C, Si or Ge lie, respectively, in the second, third and fourth orbits. Hence, energy required to take out an electron from these atoms (*i.e.,* ionisation energy $E_g$) will be least for Ge, followed by Si and highest for C. Hence, number of free electrons for conduction in Ge and Si are significant but negligibly small for C.

**Q 2. Suppose a pure Si crystal has $5 \times 10^{28}$ atoms $m^{-3}$. It is doped by 1 ppm concentration of pentavalent As. Calculate the number of electrons and holes. Given that $n_i = 1.5 \times 10^{16}$ $m^{-3}$.** *(NCERT SOLVED EXAMPLE)*

**Sol.** Note that thermally generated electrons ($n_i \sim 10^{16}$ $m^{-3}$) are negligibly small as compared to those produced by doping.

Therefore, $\quad n_e \approx N_D$

Since $\quad n_e n_h = n_i^2$.

$\therefore$ Number of holes, $n_h = (2.25 \times 10^{32})/(5 \times 10^{22})$

$$\approx 4.5 \times 10^9 \text{ m}^{-3}$$

**Q 3. Write two points of difference between intrinsic and extrinsic semiconductors.** *(CBSE 2017, 15)*

**Ans.**

| S.No. | Basis of Difference | Intrinsic semiconductor | Extrinsic semiconductor |
|---|---|---|---|
| 1. | Formation | The addition of impurity with a pure semiconductor does not take place. | It is formed by the doping of impurity in a pure semiconductor. |
| 2. | No. of free electrons and holes | The number of free electrons present in the conduction band is equal to the number of holes in the valence band. | The number of electrons and holes are not equal. |

**Q 4. Write two points of difference between *n*-type and *p*-type semiconductors.** *(CBSE 2017)*

**Ans.** Difference between *n*-type and *p*-type semiconductors are as follows:

| S. No. | Basis of Difference | *n*-type Semiconductor | *p*-type Semiconductor |
|---|---|---|---|
| 1. | Formation | It is formed by doping pentavalent impurities with tetravalent atoms. | It is formed by doping trivalent impurities with tetravalent atoms. |
| 2. | Electrons and holes | The electrons are majority carriers and holes are minority carriers. ($n_e >> n_h$) | The holes are majority carriers and electrons are minority carriers. ($n_h >> n_e$) |

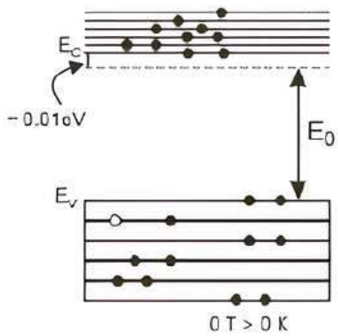
**COMMON ERROR**

*Students often write opposite.*

**Q 5. In a pure semiconductor crystal of Si, if antimony is added, then what type of extrinsic semiconductor is obtained? Draw the energy band diagram of this extrinsic semiconductor so formed.** *(CBSE SQP 2022 Term-2)*

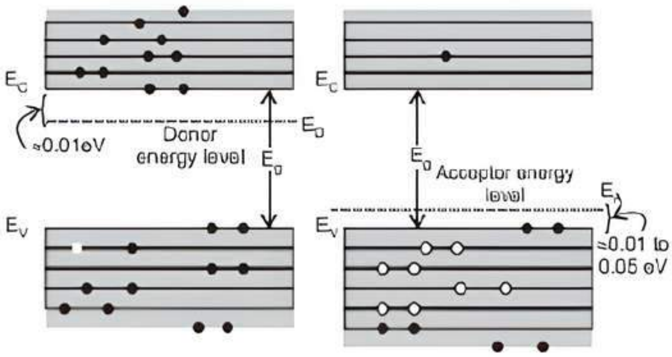
**Ans.** Since, antimony is a pentavalent impurity, hence when it is added to a pure semiconductor crystal of silicon (Si), then *n*-type semiconductor is obtained.

Energy level diagram of *n*-type semiconductor is given below:




**Q 6. Draw energy band diagrams of *n*-type and *p*-type semiconductors at temperature $T > 0$ K. Mark the donor and acceptor energy levels with their energies.**

**Ans.** Energy band diagram of *n*-type and *p*-type semiconductors at $T > 0$ K are as follows:




**TiP**

*Understand the difference between the band diagrams of p-type and n-type semiconductors.*

**Q 7. How is forward biasing different from reverse biasing in a *p-n* junction diode?**

**Ans.** Difference between forward and reverse biasing are given below:

| S.No. | Basis of Difference | Forward Biasing | Reverse Biasing |
|---|---|---|---|
| 1. | Connection | In forward biasing, positive terminal of battery is connected to *p*-type and negative terminal to *n*-type semiconductor. | In reverse biasing, positive terminal of battery is connected to *n*-type and negative terminal to *p*-type semiconductor. |
| 2. | Resistance | *p-n* junction diode offers very low resistance. | *p-n* junction diode offers very high resistance. |
| 3. | Size of depletion layer | Depletion layer is very thin. | Depletion layer is thick. |
| 4. | Resistance of an ideal diode | An ideal diode have zero resistance in forward bias. | An ideal diode have infinite resistance in reverse bias. |

**Q 8. Explain the terms 'depletion layer' and 'potential barrier' in a *p-n* junction diode. How are the (i) width of depletion layer and (ii) value of potential barrier affected when the *p-n* junction is forward biased?** *(CBSE 2020)*

**Ans. Depletion layer:** The small region in the vicinity of the junction which is depleted of free charge carrier and has only immobile ions is called depletion layer.

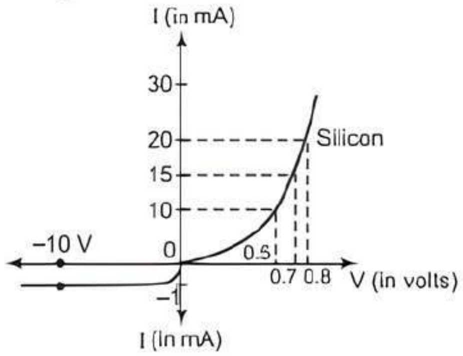
**Potential barrier:** The accumulation of negative charges in *p*-region and positive charges in *n*-region set up a potential difference across the junction, which acts as a barrier is called potential barrier.

In forward biased *p-n* junction.

(i) width of depletion layer decreases.

(ii) value of potential barrier decreases.

**Q 9. The *V-I* characteristics of a silicon diode is as shown in the figure.**




**Calculate the resistance of the diode at:**

**(i) $I = 15$ mA and**

**(ii) $V = -10$ V.** *(CBSE 2015)*

**Sol.** (i) From the given curve, we have

Voltage, $V = 0.7$ V and current, $I = 15$ mA.

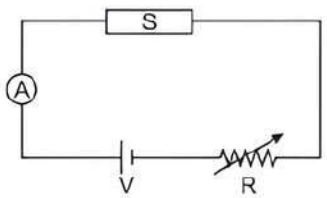
$$\therefore \text{ Resistance, } R = \frac{V}{I} = \frac{0.7}{15 \times 10^{-3}} = 47\Omega$$

(ii) For $V = -10$ V, we have

$$I = -1\ \mu A = -1 \times 10^{-6}\ A$$

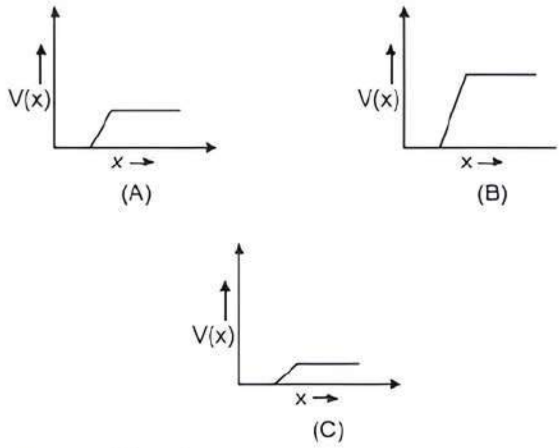
$$\Rightarrow \quad R = \frac{-10}{-1 \times 10^{-6}} = 1.0 \times 10^{7}\ \Omega$$

**Q 10. The figure shows a piece of pure semiconductor *S* in series with a variable resistor *R* and a source of constant voltage *V*. Should the value of *R* be increased or decreased to keep the reading of the ammeter constant, when semiconductor *S* is heated?** *(CBSE SQP 2022-23)*




**Ans.** To keep the reading of ammeter constant when semiconductor *S* is heated, value of *R* should be increased as with the increase in temperature of a semiconductor, its resistance decreases and current tends to increase.

**Q 11. The graph of potential barrier *versus* width of depletion region for an unbiased diode is shown in graph *A*. In comparison to *A*, graphs *B* and *C* are obtained after biasing the diode in different ways. Identify the type of biasing in *B* and *C* and justify your answer.** *(CBSE SQP 2022-23)*




**Ans.** *B*—reverse biased

In the case of reverse biased diode, the potential barrier becomes higher as the battery further raises the potential of the *n* side.

*C*—forward biased

Due to forward biased connection, the potential of *p* side is raised and hence the height of the potential barrier decreases.

**Q 12. How is the width of depletion layer of a *p-n* junction diode affected when it is (i) forward biased and (ii) reverse biased? Justify your answers.** *(CBSE 2023)*

**Ans.** (i) The width of a p-n junction decreases when the junction is forward biased.

(ii) The width of a *p-n* junction increases when the junction is reverse biased.

**Q 13. Explain the property of a *p-n* junction which makes it suitable for rectifying alternating voltages. Differentiate between a half wave and a full wave rectifier.** *(CBSE 2023)*

**Ans.** If an alternating voltage is applied across a junction diode, then the current will only in the part where it is forward biased. This property of *p-n* junction diode can be used to rectify alternating current. The circuit used for this purpose is a rectifier.

Difference between half wave and full wave rectifier:

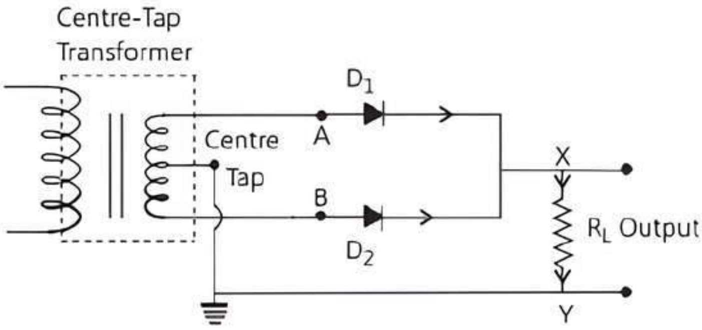
| S. No. | Basis of Difference | Half wave Rectifier | Full wave Rectifier |
|---|---|---|---|
| 1. | Definition | The half wave rectifier is used to convert the one-half cycle of AC input to DC output. | It is used to convert both the half cycles of AC input to DC output. |
| 2. | Number of diodes used | 1 | 2 or 4 |
| 3. | Form factor | 1.57 | 1.11 |

**Q 14. (i) Name the device which utilizes unilateral action of a *pn* diode to convert AC into DC.** *(CBSE 2020)*

**(ii) Draw the circuit diagram of full wave rectifier.**

**Ans. (i)** Rectifier

**(ii)** Circuit diagram of full wave rectifier is shown in figure:

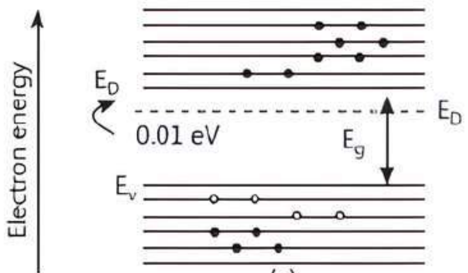



## Short Answer Type-II Questions

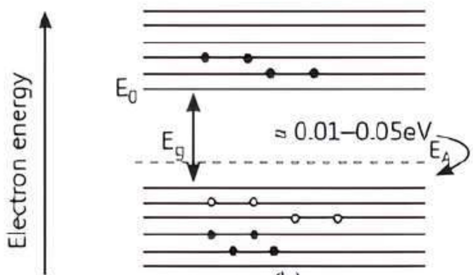
**Q 1. (i) Distinguish between *n*-type and *p*-type semiconductors on the basis of energy band diagram.**

**(ii) Compare their conductivities at absolute zero temperature and at room temperature.**

**Ans.** (i)

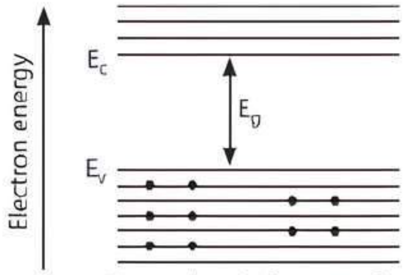



(a)
Energy band diagram of *n*-type semiconductor at T > 0 K




(b)
Energy band diagram of *p*-type semiconductor at T > 0 K

In *n*-type extrinsic semiconductors, the number of free electrons in conduction band is much more than number of holes in valence band. The donor energy level lies just below the conduction band. In *p*-type extrinsic semiconductor, the number of holes in valence band is much more than number of free electrons in conduction band. The acceptor energy level lies just above the valence band.



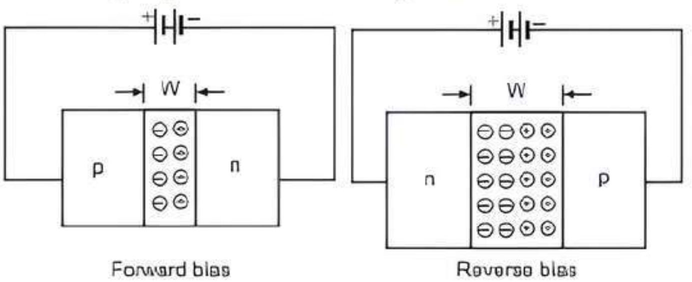

Energy band diagram of semiconductor at $T = 0$ K

(ii) At absolute zero temperature (0 K), conduction band of semiconductor is completely empty. *i.e.*, $\sigma = 0$.

Hence, the semiconductor behaves as an insulator. At room temperature, some valence electrons acquire enough thermal energy and jump to the conduction band where they are free to conduct electricity. Thus, the semiconductor acquires a small conductivity at room temperature.

**Q 2. Explain briefly with the help of necessary diagrams, the forward and the reverse biasing of a *p-n* junction diode. Also, draw their characteristic curves in the two cases.** *(CBSE 2017)*

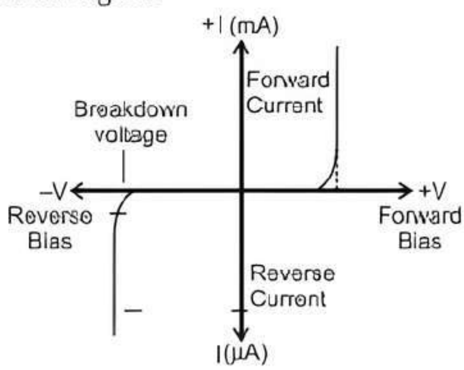
**Ans.** In forward bias, *p*-side of the junction is connected to +ve terminal of battery and *n*-side of the junction with –ve terminal, so that electric current flow due to majority carrier constituting forward current.




Small increase in forward bias voltage show large increase in forward current, so resistance is low. Depletion layer width decreases and barrier height is reduced.

In reverse bias, *p*-side of junction is connected to –ve terminal of the battery and *n*-side with +ve terminal. This cause effective barrier voltage enhancement $V_B + V$. Resistance of *p-n* junction in reverse bias is high.

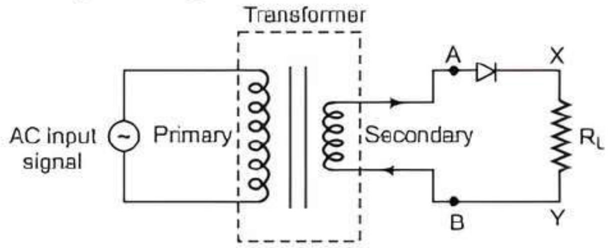
Their characteristics curves in the two cases are shown in figure.

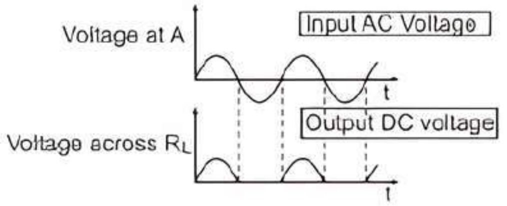


**Q 3. Explain with the help of a circuit diagram, the working of *p-n* junction diode as half wave rectifier.** *(CBSE 2014)*

**Ans. Working of *p-n* Junction Diode as Half wave rectifier:**

During the positive half cycle of AC input signal, the diode is forward biased and it conducts. Hence, there is current in the load resistance $R_L$ and we get an output voltage.



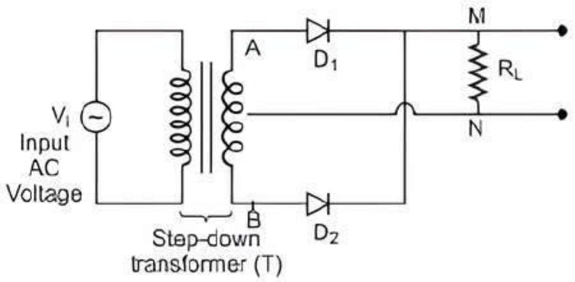




During the negative half cycle of AC input signal, diode is reverse biased and it does not conduct. Hence, there is no current in the load resistance and there is no output.

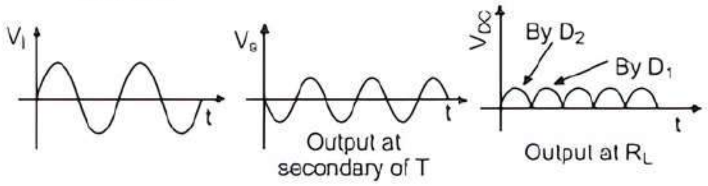
Thus, we get the output only for half cycle of AC input signal.

**Q 4. Draw the circuit diagram of a full wave rectifier using two *p-n* junction diodes. Explain its working and show input and output voltage variations.** *(CBSE 2020, 19)*

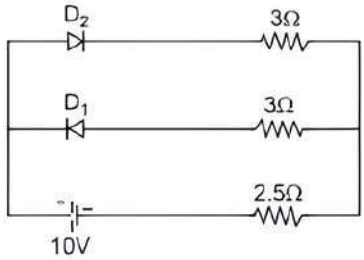
**Ans.** Circuit diagram of full wave rectifier using two *p-n* junction diodes:



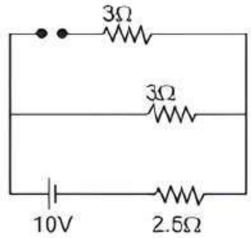

For the +ve half cycle of AC input, terminal A of transformer $T$ will be at low voltage and B at high voltage. So, $D_1$ will be reverse biased and $D_2$ will be forward biased. Diode $D_2$ conducts to give an output across $R_L$ through M. For –ve half cycle of input AC, A will be at high voltage and B will be at low voltage to make $D_1$ forward biased and $D_2$ reverse biased. $D_1$ conducts to give an output across $R_L$ with same polarity.




**Q 5. Assuming that the two diodes $D_1$ and $D_2$ used in the electric circuit shown in the figure are ideal. Find out the value of the current flowing through 2.5 Ω resistor.**

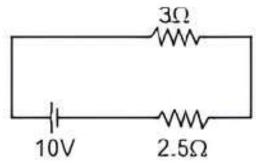



**Sol.** In the circuit, if $D_1$ is open and $D_2$ is short, then equivalent circuit will be:




∵ $D_2$ is reverse biased and $D_1$ conducts.

Hence, equivalent circuit will be:

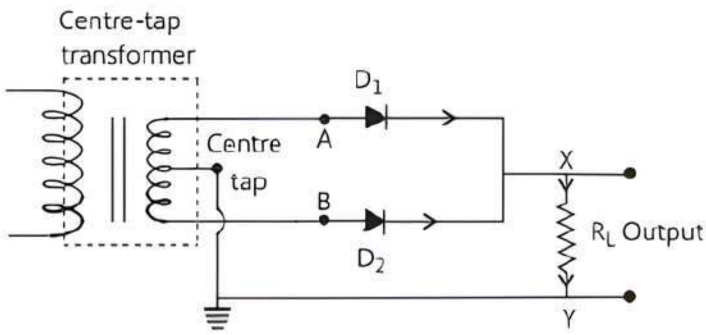


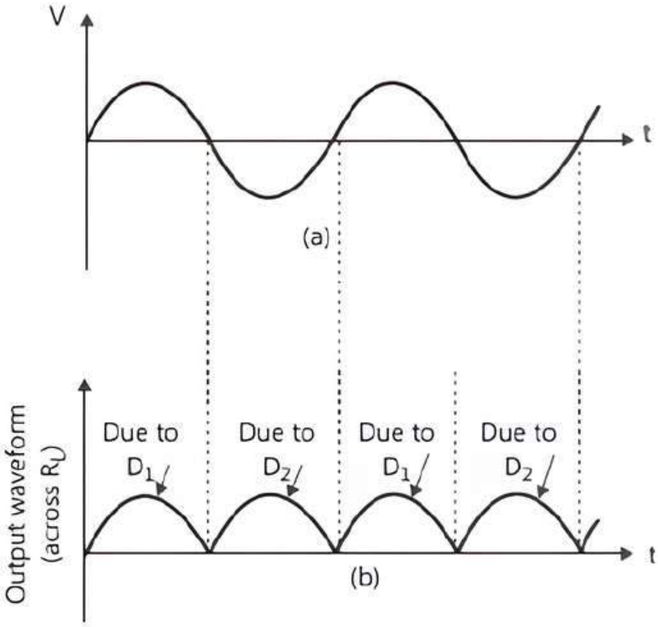

∴ Current, $I = \frac{10}{3+2.5} = \frac{10}{5.5} = 1.818$ A

**Q 6. Explain with a proper diagram how an AC signal can be converted into DC (pulsating) signal with output frequency as double than the input frequency using *p-n* junction diode. Give its input and output waveforms.** *(CBSE SQP 2022 Term-2)*

**Ans.** AC signal can be converted into DC (pulsating) signal with output frequency as double than the input frequency using *p-n* junction diode as a full wave rectifier.

**Diode as a Full Wave Rectifier:** In full wave rectifier, two diodes and one center-tap transformer is used. This rectifier circuit gives output rectifier voltage corresponding to both the positive as well as negative half of the AC cycle. If two diodes $D_1$ and $D_2$ are connected in such a way that one diode conducts during one half cycle of the input voltage and the other one conducts during the next half cycle of the input voltage in a unidirectional current flow through the load during the full cycle of the input voltage.



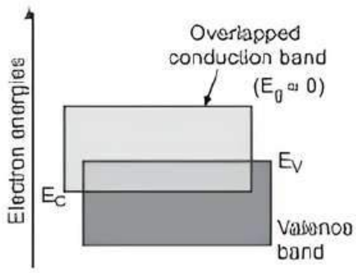



## Long Answer Type Questions

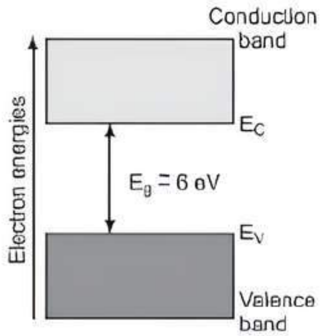
**Q 1. (i) Distinguish between a conductor, an insulator and a semiconductor on the basis of energy band diagrams.** *(CBSE 2016)*

**(ii) Compare the conductivities of *n*-type and *p*-type semiconductors at absolute zero temperature and at room temperature.**

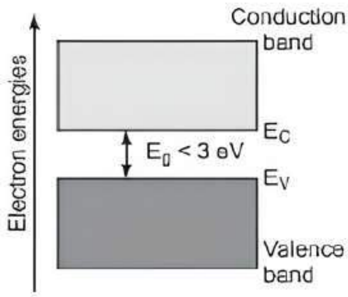
**Ans.** (i) Distinction between conductors (metals), insulators and semiconductors on the basis of energy bands:



(a) Conductors (Metals)



(b) Insulators



(c) Semiconductors

**COMMON ERR(!)R**

*Many students couldn't draw these diagrams correctly.*

**(a) Conductors (Metals):** In conductors, either conduction and valence band partially overlap each other or the conduction band is partially filled. Forbidden energy gap does not exist ($E_g \approx 0$). This makes a large number of free electrons available for electrical conduction. So, the metals have high conductivity.

**(b) Insulators:** In insulators, conduction band is empty and valence band is totally filled. $E_g$ is very large (≈6 eV). It is not possible to give such large amount of energy to electrons by any means. Hence, conduction band remains total empty and the crystal remains as insulator.

**(c) Semiconductors:** In semiconductors, conduction band is empty and valence band is totally filled. $E_g$ is quite small (< 3 eV). At 0 K, electrons are not able to cross this energy gap and semiconductor behaves as an insulator. But at room temperature, some electrons are able to jump to conduction band and semiconductor acquires small conductivity.

(ii) At absolute zero temperature, conductivities of both type of semiconductors are zero.

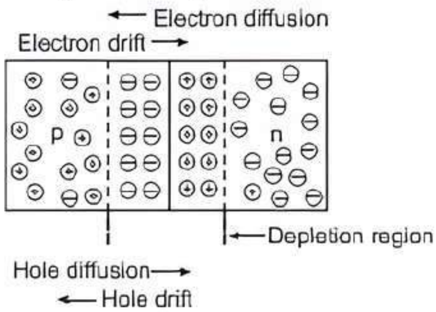
For equal doping, conductivity of *n*-type semiconductor is more than that of *p*-type semiconductor at room temperature.

**Q 2. Write the two processes that take place in the formation of a *p-n* junction. Explain with the help of a diagram, the formation of depletion region and barrier potential in a *p-n* junction.**

**Ans.** During the formation of *p-n* junction, the two processes that take place are diffusion and drift of charge carriers.

In an *n*-type semiconductor, the concentration of electrons is more than that of holes. Similarly, in a *p*-type semiconductor, the concentration of holes is more than that of electrons. Formation of depletion region during formation of *p-n* junction and due to the concentration gradient across *p* and *n*-sides, holes diffuse from *p*-side to *n*-side ($p \rightarrow n$) and electrons diffuse from *n*-side to *p*-side ($n \rightarrow p$). The diffused charge carriers combine with their counterparts in the immediate vicinity of the junction and neutralise each other.

Thus, near the junction, positive charge is built on *n*-side and negative charge on *p*-side.




**Process of *p-n* junction formation**

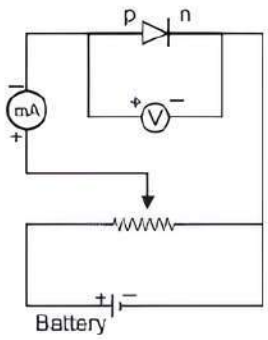
This sets up potential difference across the junction and an internal electric field $E_i$ directed from *n*-side to *p*-side. The equilibrium is established when the field $E_i$ becomes strong enough to stop further diffusion of the majority charge carriers (however, it helps the minority charge carriers to drift across the junction).

The region on either side of the junction which becomes depleted (free) from the mobile charge carriers is called depletion region or depletion layer. The potential difference developed across the depletion region is called the potential barrier.

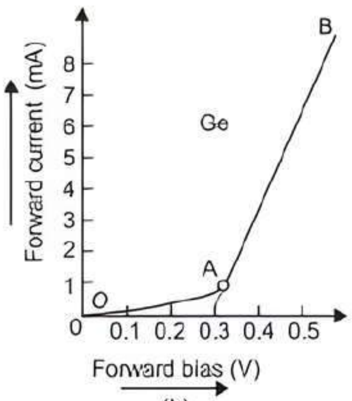
**Q 3. Draw the circuit arrangement for studying *V-I* characteristics of a *p-n* junction diode in (i) forward biasing and (ii) reverse biasing. Draw the typical *V-I* characteristics of a silicon diode. Describe briefly the following terms: (i) minority carrier injection in forward biasing and (ii) breakdown voltage in reverse biasing.** *(CBSE 2023)*

**Ans.** (i) Forward Biasing of *p-n* diode:

The circuit diagram for studying forward biased characteristics is shown in the figure. Starting from a low value, forward bias voltage is increased step-by-step (measured by voltmeter) and forward current is noted (by ammeter). A graph is plotted between voltage and current. The curve so obtained is the forward biased characteristic of the diode.



(a)

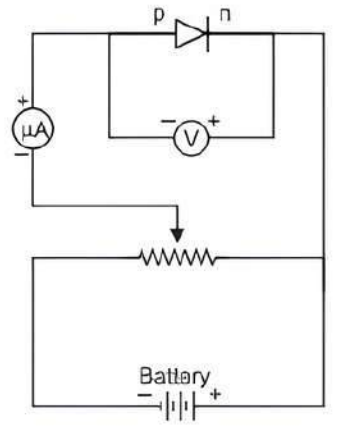


(b)

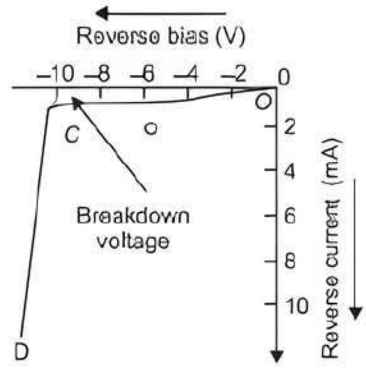
At the beginning, when applied voltage is low, the current through the diode is almost zero. It is because of the potential barrier, which opposes the applied voltage. Till the applied voltage exceeds the potential barrier, the current increases very slowly with increase in applied voltage (*OA* portion of the graph). With further increase in applied voltage, the current increases very rapidly (*AB* portion of the graph), in this situation, the diode behaves like a conductor. The forward voltage beyond which the current through the junction starts increasing rapidly with voltage is called knee voltage. If line *AB* is extended back, it cuts the voltage axis at potential barrier voltage.

(ii) **Reverse Biasing of *p-n* diode:**

The circuit diagram for studying reverse biased characteristics is shown in the figure.



(a)



(b)

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.

Motion of minority charge carriers is also supported by internal potential barrier, so all the minority carriers cross over the junction.

Therefore, 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 upto certain voltage known as breakdown voltage and this voltage independent current is called reverse saturation current.

**(i) Minority carrier injection:** Due to the applied voltage, electrons from *n*-side cross the depletion region and reach *p*-side (where they are minority carriers). Similarly, holes from *p*-side cross this junction and reach the *n*-side (where they are minority carriers). This process under forward bias is known as minority carrier injection.

**(ii) Breakdown voltage in reverse biasing:**

It is a critical reverse bias voltage at which current is independent of applied voltage.

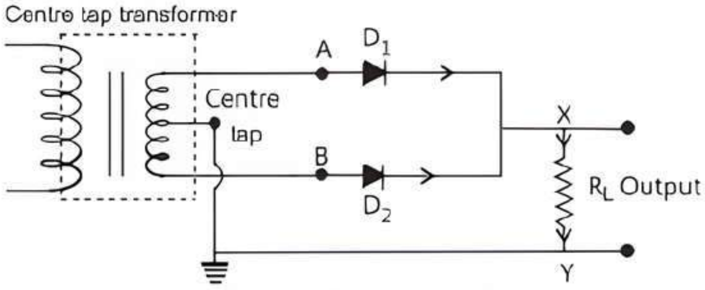
**Q 4. Name two important processes involved in the formation of a *p-n* junction diode. With the help of a circuit diagram, explain the working of junction diode as a full wave rectifier. Draw its input and output waveforms. State the characteristic**

**property of a junction diode that makes it suitable for rectification.** *(CBSE 2023)*

**Ans.** Two important processes involved in the formation of *p-n* junction diodes are diffusion and drift of charge carriers.

**Working of *p-n* junction diode as a full wave rectifier:**

A rectifier is used to convert alternating current into direct current, whose labelled circuit is as given below:

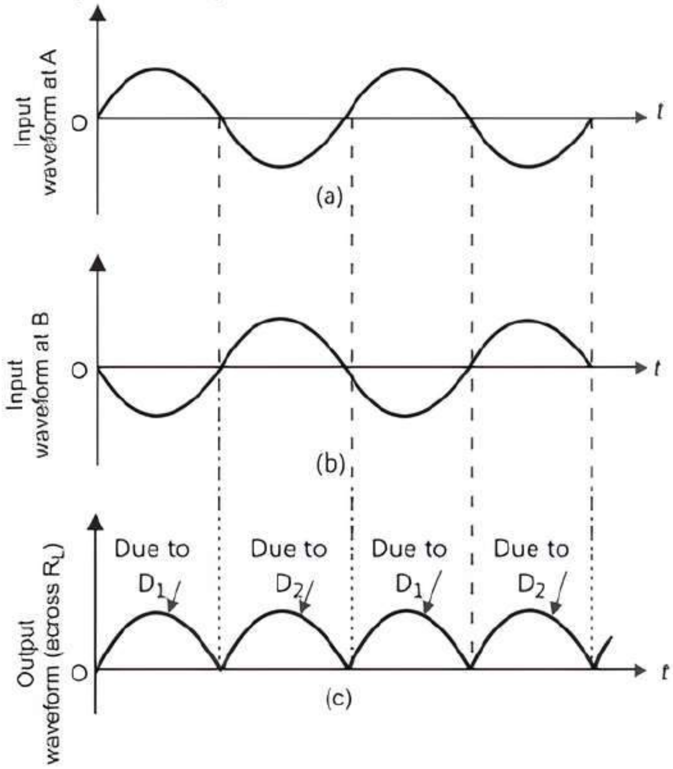



Circuit diagram of full wave rectifier

**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 of the input AC, 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.

Input and output waveforms:




**Characteristic properties of *p-n* junction diode in rectification:**

From forward and reverse characteristics, it is clear that current flows through the junction diode only in forward bias not in reverse bias *i.e.*, current flows only in one direction.

# Chapter Test

## Multiple Choice Questions

**Q 1. In an extrinsic semiconductor, the number density of holes is $4 \times 10^{20}$ m$^{-3}$. If the number density of intrinsic carriers is $1.2 \times 10^{13}$ m$^{-3}$, the number density of electrons in it is:** *(CBSE 2023)*

a. $1.8 \times 10^{9}$ m$^{-3}$

b. $2.4 \times 10^{10}$ m$^{-3}$

c. $3.6 \times 10^{9}$ m$^{-3}$

d. $3.2 \times 10^{10}$ m$^{-3}$

**Q 2. Pieces of copper and of silicon are initially at room temperature. Both are heated to temperature *T*. The conductivity of:** *(CBSE 2023)*

a. both increases

b. both decreases

c. copper increases and silicon decreases

d. copper decreases and silicon increases

## Assertion and Reason Type Questions

**Directions (Q.Nos. 3-4):** *In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:*

a. Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

b. Both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).

c. Assertion (A) is true but Reason (R) is false.

d. Both Assertion (A) and Reason (R) are false.

**Q 3. Assertion (A): The electrons in the conduction band have higher energy than those in the valence band of the semiconductor.**

**Reason (R): The conduction band is above the energy gap and valence band lies below the energy gap.**

**Q 4. Assertion (A): An *n*-type semiconductor has a large number of electrons but still it is electrically neutral.**

**Reason (R): An *n*-type semiconductor is obtained by doping an intrinsic semiconductor with a pentavalent impurity.**

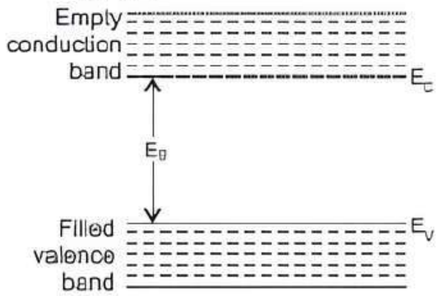
## Fill in the blanks

**Q 5. In *n*-type semiconductor, ............. are majority carriers.**

**Q 6. A semiconductor has equal electron and hole concentration of $6 \times 10^{8}$ per m$^{3}$. On doping with certain impurity, electron concentration increases to $9 \times 10^{12}$ per m$^{3}$. The new hole concentration is ..............**

## Case Study Based Question

Q 7. From Bohr's atomic model, we know that the electrons have well defined energy levels in an isolated atom. But due to interatomic interactions in a crystal, the electrons of the outer shells are forced to have energies different from those in isolated atoms. Each energy level splits into a number of energy levels forming a continuous band. The gap between top of valence band and bottom of the conduction band in which no allowed energy levels for electrons can exist is called energy gap.




*Read the given passage carefully and give the answer of the following questions:*

(i) What is the energy band gap in an insulator?

(ii) What is the separation between conduction and valence band in a semiconductor?

(iii) Based on the band theory of conductors, semiconductors and insulators, in which of the following the forbidden gap is smallest?

(iv) Draw the energy band diagram of conductors.

## Very Short Answer Type Questions

Q 8. What are the two types of semiconductors on the basis of purity?

Q 9. In full wave rectification, what is the output frequency if input frequency is 50 Hz?

## Short Answer Type-I Questions

Q 10. Answer the following giving reasons:

(i) A *p-n* junction diode is damaged by a strong current.

(ii) Impurities are added in intrinsic semiconductors.

*(CBSE 2023)*

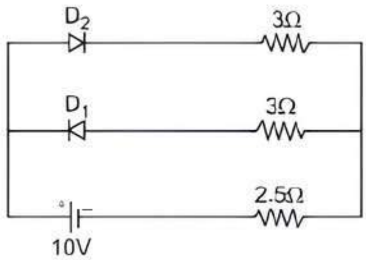
Q 11. Draw energy band diagrams of *n*-type and *p*-type semiconductors at temperature $T > 0$ K. Mark the donor and acceptor energy levels with their energies.

Q 12. C, Si and Ge have same lattice structure. Why is C insulator, while Si and Ge intrinsic semiconductors?

## Short Answer Type-II Questions

Q 13. Draw a circuit diagram of a full-wave rectifier. Explain its working principle. Draw the input/ output waveforms indicating clearly the functions of the two diodes used.

Q 14. Assuming that the two diodes $D_1$ and $D_2$ used in the electric circuit shown in the figure are ideal. Find out the value of the current flowing through 2.5 Ω resistor.




Q 15. Draw *I-V* characteristics of a *p-n* junction diode. Answer the following questions, giving reasons:

(i) Why is the current under reverse bias almost independent of the applied potential upto a critical voltage?

(ii) Why does the reverse current show a sudden increase at the critical voltage?

Name any semiconductor device which operates under the reverse bias in the breakdown region.

## Long Answer Type Questions

Q 16. Write the two processes that take place in the formation of a *p-n* junction. Explain with the help of a diagram, the formation of depletion region and barrier potential in a *p-n* junction.

Q 17. Draw the necessary energy band diagrams to distinguish between conductors, semiconductors and insulators. How does the changes in temperature affect the behaviour of these materials? Explain briefly.