Electronic Devices

basic concepts

1. Electronics

A device whose functioning is based on controlled movement of electrons through it is called an electronic device. Some of the present-day most common such devices include a semiconductor junction diode, a transistor and integrated circuits. The related branch in which we study the functioning and use of such devices is called Electronics.

2. Energy Bands in Solids

An isolated atom has well defined energy levels. However, when large number of such atoms get together to form a real solid, these individual energy levels overlap and get completely modified. Instead of discrete value of energy of electrons, the energy values lie in a certain range. The collection of these closely packed energy levels are said to form an energy band. Two types of such bands formed in solids are called Valence Band and Conduction Band. The band formed by filled energy levels is known as Valence Band whereas partially filled or unfilled band is known as Conduction Band. The two bands are generally separated by a gap called energy gap or forbidden gap. Depending upon the size of this energy gap, different materials behave as conductors, semi-conductors or insulators. The insulators have generally large energy gap whereas the conductors do not have any such gap. Semi-conductors have small energy gap.

3. Types of Semi-conductors—Intrinsic and Extrinsic

Common Semiconductors are of two types—intrinsic and extrinsic. Germanium and silicon are two most commonly used semiconductor material.

Intrinsic Semiconductor: Pure semiconductors is in which the conductivity is caused due to charge carriers made available from within the material are called *intrinsic semiconductors*. There are no free charge carriers available under normal conditions. However, when the temperature is raised slightly, some of the covalent bonds in the material get broken due to thermal agitation and few electrons become free. In order to fill the vacancy created by absence of electron at a particular location, electron from other position move to this location and create a vacancy (absence of electron) at another place called *hole*. The movement/shifting of electrons and holes within the material results in conduction.

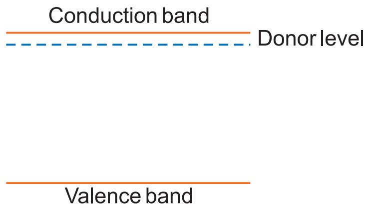
An intrinsic semiconductors behaves as a perfect insulator at temperature 0 K.

Extrinsic semiconductors: The semiconductors in which the conductivity is caused due to charge carriers made available from external source by adding impurity from outside are called extensive *extrinsic semiconductor*. The process of adding impurity is called doping. The impurity added is generally from third group or fifth group. There are two types of extrinsic semiconductors:

(*a*) n–Type or (*b*) p–Type.

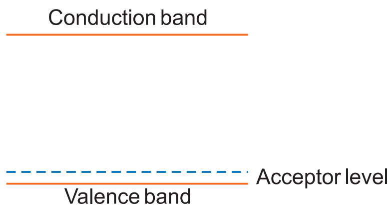
If n_i is the density of intrinsic charge carriers, n_e and n_h are densities of electrons and hole in extrinsic semiconductors, then the selection among them is $n_e n_h = n_i^2$

(*a*) **n-type semiconductors:** When a pentavalent impurity like Phosphorus, Antimony, Arsenic is doped in pure-Germanium (or Silicon), then the conductivity of crystal increases due to surplus electrons and such a crystal is said to be n-type semiconductor, while the impurity atoms are called *donors atoms*. Thus, in n-type semiconductors the charge carriers are negatively charged electrons and the donor level lies near the bottom of the conduction band.



(*a*) ***n*-type semiconductor**

(*b*) ***p*-type semiconductors:** When a trivalent impurity like Aluminium, Indium, Boron, Gallium, etc., is doped in pure Germanium (or silicon), then the conductivity of the crystal increases due to deficiency of electrons *i.e.*, holes and such a crystal is said to be p–type semiconductor while the impurity atoms are called acceptors. Thus in p–type semiconductors the charge carriers are holes. Acceptor level lies near the top of the valence band.



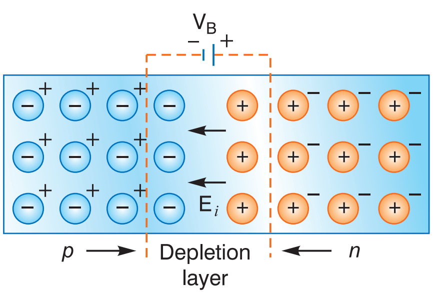
(*b*) ***p*-type semiconductor**

4. Semiconductor Diode: p-n Junction Diode

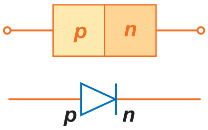
A semiconductor having p-type impurity at one end and n-type impurity at the other end is known as $p - n$ junction diode. The junction at which p-type and n-type semiconductors combine is called p-n junction.

In p-type region there is majority of holes and in n-type region there is majority of electrons.

Formation of Depletion Layer and Potential Barrier



At the junction, there is diffusion of charge carriers due to thermal agitation; therefore some of electrons of n-region diffuse to p-region while some of holes of p-region diffuse into n-region. Some charge carriers combine with opposite charges to neutralise each other. Thus, near the junction there is an excess of positively charged ions in n-region and an excess of negatively charged ions in p-region. This sets up a **potential difference** called potential barrier and hence an internal electric field E_i across the junction. The potential barrier is usually of the order of μV. The field E_i is directed from n-region to p-region. This field stops the further diffusion of charge carriers. Thus the layers ($\approx 10^{-4}$ cm to 10^{-6} cm) on either side of the junction becomes free from mobile charge carriers and hence is called the *depletion layer*. The symbol of p-n junction diode is shown in figure.



Forward and Reverse Bias

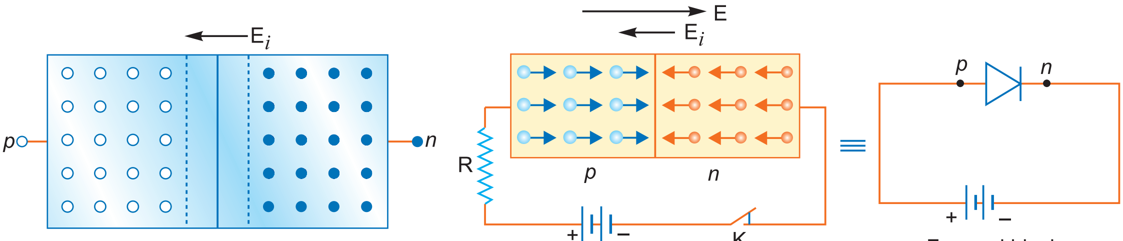
The external battery is connected across the junction in the following two ways:

(*i*) **Forward Bias:** In this arrangement the positive terminal of battery is connected to p-end and negative terminal to n-end of the crystal, so that an external electric field E is established directed from p to n-end to oppose the internal field E_i. Thus, the junction is said to conduct.

Under this arrangement the holes move along the field E from p-region to n-region and electrons move opposite to field E from n-region to p-region; eliminating the depletion layer. A current is thus set up in the junction diode. The following are the basic features of forward biasing:

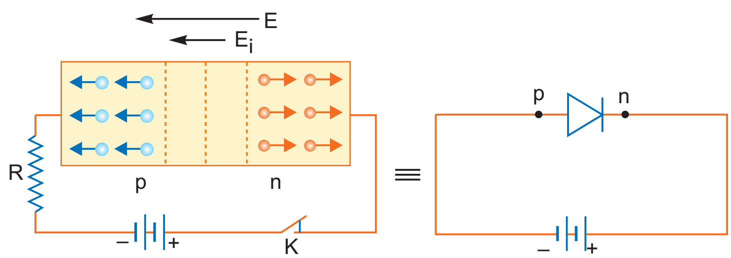
(*a*) Within the junction diode the current is due to both types of majority charge carriers but in external circuit it is due to electrons only.

(*b*) The current is due to diffusion of majority charge carriers through the junction and is of the order of milliamperes.



(*a*) No current (*b*) Forward current Forward biasing

(*ii*) Reverse Bias: In this arrangement the positive terminal of battery is connected to *n*-end and negative terminal to *p*-end of the crystal, so that the external field is established to support the internal field E_i as shown in fig. Under the biasing the holes in *p*-region and the electrons in *n*-region are pushed away from the junction to widen the depletion layer and hence increases the size of the potential barrier, therefore, the junction does not conduct.



(c) Reverse current Reverse biasing

When the potential difference across the junction is increased in steps, a very small reverse current of the order to micro-amperes flows. The reason is that due to thermal agitation some covalent bonds of pure semi-conductor break releasing a few holes in *n*-region and a few electrons in *p*-region called the *minority charge carriers*. The reverse bias opposes the majority charge carriers but aids the minority charge carriers to move across the junction. Hence a very small current flows.

The basic features of reverse bias are:

(*a*) Within the junction diode the current is due to both types of minority charge carriers but in external circuit it is due to electrons only.

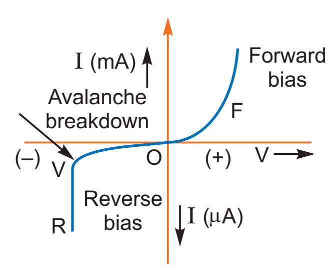
(*b*) The current is due to leakage of minority charge carriers through the junction and is very small of the order of μA.

Characteristics of a p–n junction diode:

The graph of voltage *V* versus current *I* in forward bias and reverse bias of a *p–n* junction is shown in the figure.

Avalanche Break Down:

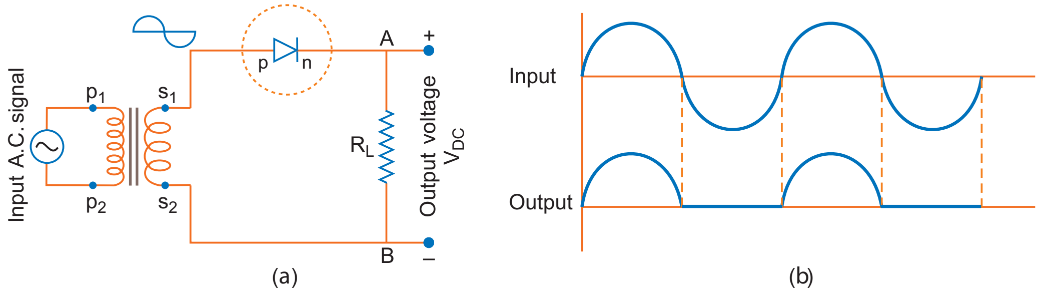
If the reverse bias is made sufficiently high, the covalent bonds near the junction break down releasing free electrons and holes. These electrons and holes gain sufficient energy to break other covalent bonds. Thus a large number of electrons and holes get free. The reverse current increases abruptly to high value. This is called avalanche break down and may damage the junction.



5. *p-n* Junction Diode as a Half-wave Rectifier

The conversion of ac into dc is called the rectification.

Half Wave Rectifier: The circuit diagram for junction diode as half wave rectifier is shown in fig. (*a*)

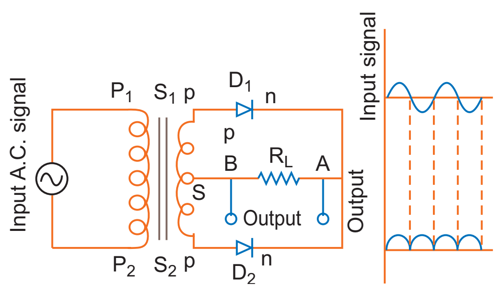


During first half of the input cycle, the secondary terminal S_1 of transformer be positive relative to S_2 then the junction diode is forward biased. Therefore, the current flows and its direction of current in load resistance R_L is from A to B. In next half cycle, the terminal S_1 becomes negative relative to S_2, then the diode is in reverse bias, therefore no current flows in diode and hence there is no potential difference across load R_L. The cycle repeats. The output current in load flows only when S_1 is positive relative to S_2 That is during first half cycles of input ac signal there is a current in circuit and hence a potential difference across load resistance R_L while no current flows, for next half cycle. The direction of current in load is always from A to B which is direct current. Thus, a *single p-n junction diode acts as a half wave rectifier*.

The input and output waveforms of half wave rectifier are shown in fig. (*b*).

Full Wave Rectifier: For full wave rectifier, we use two junction diodes. The circuit diagram for full wave rectifier using two junction diodes is shown in figure.

During first half cycle of input ac signal the terminal S_1 is positive relative to S and S_2 is negative relative to S, then diode D_1 is forward biased and diode D_2 is reverse biased. Therefore current flows in diode D_1 and not in diode D_2. The direction of current i_1 due to diode D_1 in load resistance R_L is directed from A to B. In next half cycle, the terminal S_1 is negative relative to S and S_2 is positive relative to S. Then diode D_1 is reverse biased and diode D_2 is forward biased. Therefore, current flows in diode D_2 and there is no current in diode D_1. The direction of current i_2 due to diode D_2 in load resistance is again from A to B Thus, for input ac signal the output current is a continuous series of unidirectional pulses. The input and output sequels are shown in the figure. This output current can be converted into steady current by the use of suitable filters.

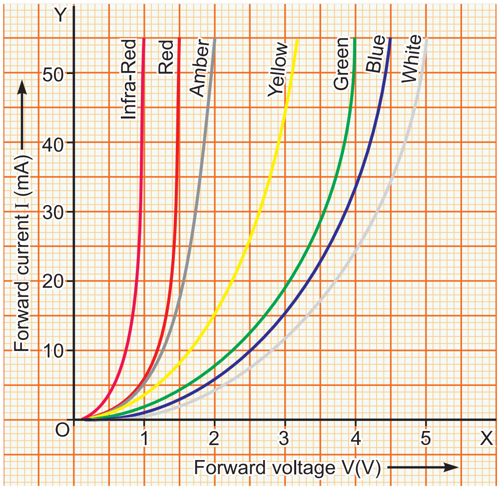


Remark: In full wave rectifier if the fundamental frequency of input ac signal is 50 Hz, then the fundamental frequency of output is 100 Hz.

6. Light Emitting Diode (LED)

The light emitting diode, represented by either of the two symbols shown here, is basically the same as a conventional *p-n* junction diode. Its actual shape is also shown here. The shorter, of its two leads, corresponds to its *n* **(or cathode side)** while the longer lead corresponds to its *p* **(or anode side)**.

The general shape of the *I-V* characteristics of a LED, is similar to that of a conventional *p-n* junction diode as shown in the figure. However, the 'barrier potential' changes slightly with the colour.



The colour of the light emitted by a given LED depends on its band-gap energy. The energy of the photons emitted is equal to or slightly less than this band gap energy. The other main characteristic of the emitted light, its intensity, is determined by the forward current conducted by the junction.

7. Photodiode

A photodiode is a junction diode fabricated by using a photo sensitive semiconductor material. When light of suitable frequency is made to fall on the junction, it starts conducting.

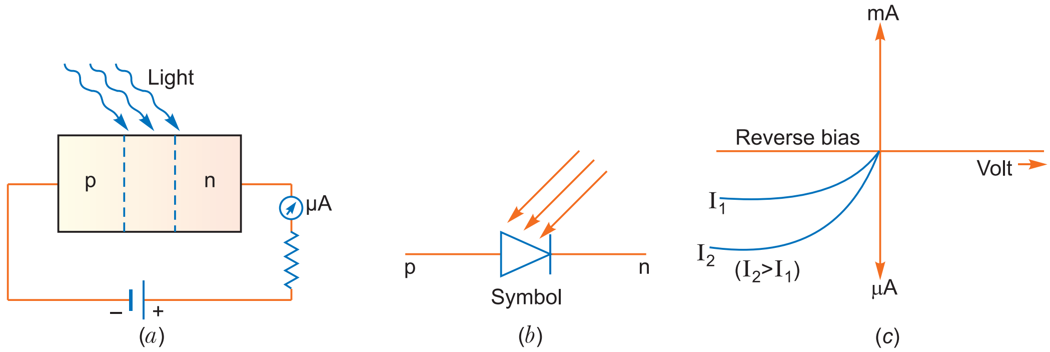


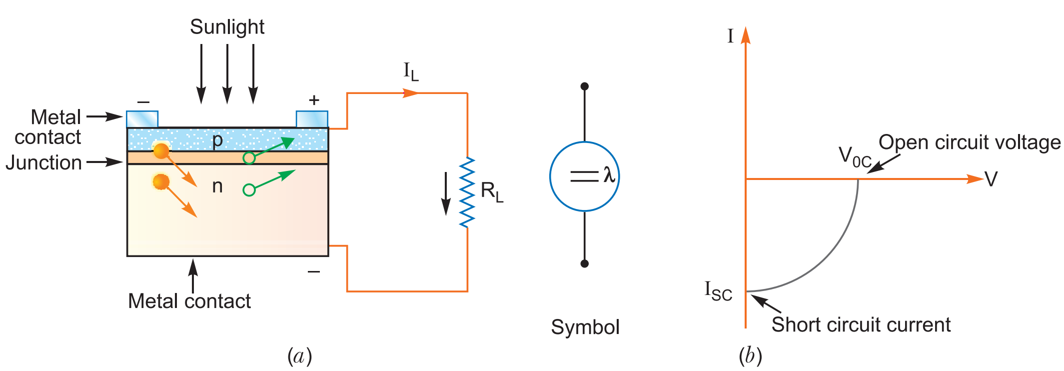
Fig. Photodiode

(*i*) A photodiode is used in reverse bias, although in forward bias current is more than current in reverse bias because in reverse bias it is easier to observe change in current with change in light intensity.

(*ii*) Photodiode is used to measure light intensity because reverse current increases with increase of intensity of light. The characteristic curves of a photodiode for two different illuminations I_1 and I_2 ($I_2 > I_1$) are shown in fig. (*c*).

8. Solar Cell

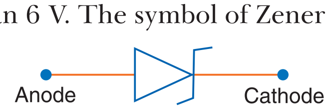
A solar cell is a junction diode which converts light energy into electrical energy. It is based on photovoltaic effect. The surface layer of *p*-region is made very thin so that the incident photons may easily penetrate to reach the junction which is the active region. In an operation in the photovoltaic mode (*i.e.*, generation of voltage due to bombardment of optical photons); the materials suitable for photocells are silicon (Si), gallium arsenide (GaAs), cadmium sulphide (CdS) and cadmium selenide (CdSe).



Working: When photons of energy greater than band gap energy ($h\nu > E_g$) are made to incident on the junction, electron-hole pairs are created which move in opposite directions due to junction field. These are collected at two sides of junction, thus producing photo-voltage; this gives rise to photocurrent. The characteristic curve of solar cell is shown above. Solar cells are used in satellites to recharge their batteries.

9. Zener Diode

A zener diode is a specially designed heavily doped *p-n* junction, having a very thin depletion layer and having a very sharp breakdown voltage. It is always operated in reverse breakdown region. Its breakdown voltage V_Z is less than 6 V. The symbol of Zener diode is



Selected NCERT Textbook Questions

Q. 1. In a half wave rectifier, what is the frequency of ripple in the output if the frequency of input ac is 50 Hz? What is the output ripple frequency of a full wave rectifier?

Ans. In half wave rectifier, the output ripple frequency is 50 Hz.

In full wave rectifier, the output ripple frequency is twice of input frequency of ac

i.e., $2 \times 50 = \mathbf{100\ Hz}$

Q. 2. A $p-n$ photodiode is fabricated from a semiconductor with band gap of 2.8 eV. Can it detect a wavelength of 6000 nm?

Ans. Energy corresponding to wavelength 6000 nm is

$$E = \frac{hc}{\lambda}$$

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{6000 \times 10^{-9}} \text{ joule} = 3.3 \times 10^{-20} \text{ J}$$

$$= \frac{3.3 \times 10^{-20}}{1.6 \times 10^{-19}} = \mathbf{0.2\ eV}$$

The photon energy ($E = 0.2$ eV) of given wavelength is much less than the band gap ($E_g = 2.8$ eV), hence it cannot detect the given wavelength.

Q. 3. The number of silicon atoms per m^3 is 5×10^{28}. This is doped simultaneously with 5×10^{22} atoms per m^3 of Arsenic and 5×10^{20} per m^3 atoms of Indium. Calculate the number of electrons and holes. Given that $n_i = 1.5 \times 10^{16}$ per m^3. Is the material n-type or p-type?

Ans. Arsenic is n-type impurity and indium is p-type impurity.

Number of electrons, $n_e = n_D - n_A$

$$= 5 \times 10^{22} - 5 \times 10^{20} = 4.95 \times 10^{22} \text{ m}^{-3}$$

Also $n_i^2 = n_e n_h$

Given $n_i = 1.5 \times 10^{16} \text{ m}^{-3}$

Number of holes, $$n_h = \frac{n_i^2}{n_e} = \frac{(1.5 \times 10^{16})^2}{4.95 \times 10^{22}}$$

$\Rightarrow$ $n_h = \mathbf{4.54 \times 10^9\ m^{-3}}$

As $n_e > n_h$; so the material is an n-type semiconductor.

Multiple Choice Questions [1 mark]

Choose and write the correct option(s) in the following questions.

1. The usual semiconductors are:

(*a*) germanium and silicon (*b*) germanium and copper

(*c*) silicon and glass (*d*) glass and carbon

2. The energy gap between the valence and conduction bands of a substance is 6 eV. The substance is a:

(*a*) conductor (*b*) semiconductor

(*c*) insulator (*d*) superconductor

3. In a *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 dopants.

(*c*) Holes are minority carriers and pentavalent atoms are dopants.

(*d*) Holes are majority carriers and trivalent atoms are dopants.

4. The conductivity of a semiconductor increases with increase in temperature because [*NCERT Exemplar*]

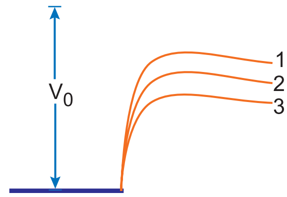
(*a*) number density of free current carriers increases.

(*b*) relaxation time increases.

(*c*) both number density of carriers and relaxation time increase.

(*d*) number density of current carriers increases, relaxation time decreases but effect of decrease in relaxation time is much less than increase in number density.

5. In given figure, V_0 is the potential barrier across a *p-n* junction, when no battery is connected across the junction [*NCERT Exemplar*]



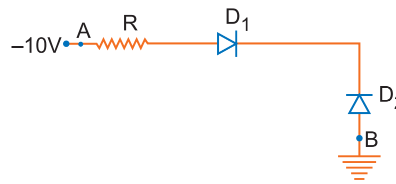
(*a*) 1 and 3 both correspond to forward bias of junction

(*b*) 3 corresponds to forward bias of junction and 1 corresponds to reverse bias of junction

(*c*) 1 corresponds to forward bias and 3 corresponds to reverse bias of junction.

(*d*) 3 and 1 both correspond to reverse bias of junction.

6. In given figure, assuming the diodes to be ideal, [*NCERT Exemplar*]



(*a*) D_1 is forward biased and D_2 is reverse biased and hence currentflows from A to B.

(*b*) D_2 is forward biased and D_1 is reverse biased and hence no current flows from B to A and vice versa.

(*c*) D_1 and D_2 are both forward biased and hence current flows from A to B.

(*d*) D_1 and D_2 are both reverse biased and hence no current flows from A to B and vice versa.

7. In a good conductor, the energy gap between the valence and conduction bands is

(*a*) 1 eV (*b*) 6 eV (*c*) infinite (*d*) zero

8. Electrical conduction in a semiconductor occurs due to

(*a*) electrons only (*b*) holes only

(*c*) electrons and holes both (*d*) neither electrons nor holes.

9. If n_e and n_h are the number of electrons and holes in pure germanium, then

(*a*) $n_e > n_h$ (*b*) $n_e < n_h$ (*c*) $n_e = n_h$ (*d*) n_e = finite and $n_h = 0$

10. When an electric field is applied across a semiconductor [*NCERT Exemplar*]

(*a*) electrons move from lower energy level to higher energy level in the conduction band.

(*b*) electrons move from higher energy level to lower energy level in the conduction band.

(*c*) holes in the valence band move from higher energy level to lower energy level.

(*d*) holes in the valence band move from lower energy level to higher energy level.

11. When trivalent impurity is mixed in a pure semiconductor, the conduction is mainly due to

(*a*) electrons (*b*) holes

(*c*) protons (*d*) positive ions

12. The example of *p*-type semiconductor is

(*a*) pure germanium (*b*) pure silicon

(*c*) germanium doped with arsenic (*d*) germanium doped with boron

13. The impurity atoms to be mixed in pure silicon to form *p*-type semiconductor are, of

(*a*) phosphorus (*b*) germanium

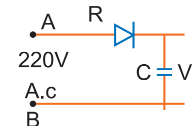
(*c*) antimony (*d*) aluminium

14. Holes are charge carriers in

(*a*) intrinsic semiconductor only (*b*) *p*-type semiconductor only

(*c*) intrinsic and *p*-type semiconductors (*d*) *n*-type semiconductor

15. A 220 V A.C. supply is connected between points *A* and *B* (shown in figure). What will be the potential difference *V* across the capacitor? [*NCERT Exemplar*]



(*a*) 220 V (*b*) 110 V

(*c*) 0 V (*d*) $220\sqrt{2}$ V

16. Hole is [*NCERT Exemplar*]

(*a*) an anti-particle of electron.

(*b*) a vacancy created when an electron leaves a covalent bond.

(*c*) absence of free electrons.

(*d*) an artificially created particle.

17. In the depletion region of a diode [*NCERT Exemplar*]

(*a*) there are no mobile charges

(*b*) equal number of holes and electrons exist, making the region neutral.

(*c*) recombination of holes and electrons has taken place.

(*d*) immobile charged ions exist.

18 The breakdown in a reverse biased *p-n* junction diode is more likely to occur due to [*NCERT Exemplar*]

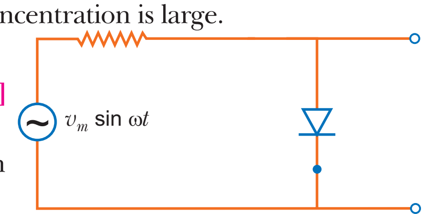
(*a*) large velocity of the minority charge carriers if the doping concentration is small.

(*b*) large velocity of the minority charge carriers if the doping concentration is large.

(*c*) strong electric field in a depletion region if the doping concentration is small.

(*d*) strong electric field in the depletion region if the doping concentration is large.

19. The output of the given circuit shown in figure. [*NCERT Exemplar*]



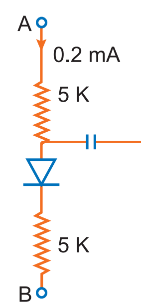
(*a*) would be zero at all times.

(*b*) would be like a half wave rectifier with positive cycles in output.

(*c*) would be like a half wave rectifier with negative cycles in output.

(*d*) would be like that of a full wave rectifier.

20. In the circuit shown in figure, if the diode forward voltage drop is 0.3 V, the voltage difference between *A* and *B* is [*NCERT Exemplar*]



(*a*) 1.3 V (*b*) 2.3 V

(*c*) 0 (*d*) 0.5 V

Answers

1. (*a*)	**2.** (*c*)	**3.** (*c*)	**4.** (*d*)	**5.** (*b*)	**6.** (*b*)	**7.** (*d*)
8. (*c*)	**9.** (*c*)	**10.** (*a*), (*c*)	**11.** (*b*)	**12.** (*d*)	**13.** (*d*)	**14.** (*c*)
15. (*d*)	**16.** (*b*)	**17.** (*a*), (*b*), (*d*)	**18.** (*a*), (*d*)	**19.** (*c*)	**20.** (*b*)	

Fill in the Blanks [1 mark]

1. The number of electron (n_e) is equal to the number of holes (n_h) in ____________ semiconductors.

2. The number of charge carriers can be changed by doping of a suitable impurity in pure semiconductors. Such semiconductors are known as ____________ semiconductors.

3. Valence band energies are ____________ as compared to conduction band energies.

4. For insulators ____________, for semiconductors E_g is 0.2 eV to 3 eV while for metals $E_g \approx 0$

5. ____________ can be used for rectifying an *ac* voltage.

6. In reverse bias, after a certain voltage, the current suddenly increases (breakdown voltage) in a Zener diode. This property has been used to obtain _______________.
7. LED works under ________________ bias.
8. The resistance of *p-n* junction is ________________ when reverse biased.
9. Hole density is ________________ compared to electron density in a *p* type semiconductor.
10. In half-wave rectification, if the input frequency is 50 Hz then the output frequency of the signal will be ______________ Hz.

Answers

1. intrinsic **2.** extrinsic **3.** low **4.** $E_g > 3$ eV **5.** Diodes
6. voltage regulation **7.** forward **8.** high **9.** greater **10.** 50

Very Short Answer Questions [1 mark]

Q. 1. Name two intrinsic semiconductors.

Ans. Germanium, silicon

Q. 2. Name charge carriers in *p*-type semiconductor.

Ans. Holes.

Q. 3. Name charge carriers in *n*-type semiconductor.

Ans. Free electrons

Q. 4. If n_i is density of intrinsic charge carriers; n_h and n_e are densities of hole and electrons in extrinsic semiconductor, what is the relation among them?

Ans. $n_e n_h = n_i^2$

Q. 5. What is the net charge on (*i*) *p*-type semiconductor (*ii*) *n*-type semiconductor?

Ans. (*i*) Zero (*ii*) Zero

Q. 6. Name the type of charge carriers in *p-n* junction diode when forward biased?

Ans. Majority charge carriers: electrons and holes.

Q. 7. Name the type of charge carriers in *p-n* junction when reverse biased.

Ans. Minority charge carriers: electrons and holes.

Q. 8. Which device is used as a voltage regulator?

Ans. Zener diode is used as a voltage regulator.

Q. 9. At what temperature would an intrinsic semiconductor behave like a perfect insulator? [*CBSE East 2010*]

Ans. An intrinsic semiconductor behaves as a perfect insulator at temperature 0 K.

Q. 10. How does the energy gap in a semiconductor vary, when doped with a pentavalent impurity?

Ans. The energy gap decreases by mixing pentavalent impurity.

Q. 11. What type of extrinsic semiconductor is formed when

(*i*) germanium is doped with indium?

(*ii*) silicon is doped with bismuth?

Ans. (*i*) Indium is trivalent, so germanium doped indium is a *p*-type semiconductor.

(*ii*) Bismuth is pentavalent, so silicon doped bismuth is an *n*-type semiconductor.

Q. 12. What happens to the width of depletion layer of a *p-n* junction when it is (*i*) forward biased, (*ii*) reverse biased? [*CBSE Delhi 2011*]

Ans. (*i*) When forward biased, the width of depletion layer decreases.

(*ii*) When reverse biased, the width of depletion layer increases.

Q. 13. Give the ratio of number of holes and number of conduction electrons in an intrinsic semiconductor.

Ans. Ratio 1: 1.

Q. 14. In a semiconductor the concentration of electrons is 8×10^{13} cm^{-3} and that of holes is 5×10^{12} cm^{-3}. Is it a *p*-type or *n*-type semiconductor?

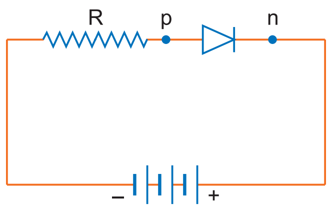
Ans. As concentration of electrons is more than the concentration of holes, the given extrinsic semiconductor is *n*-type.

Q. 15. State with reason why a photodiode is usually operated at a reverse bias.

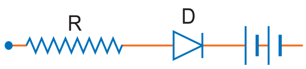
Ans. The fractional change due to incident light on minority charge carriers in reverse bias is much more than that over the majority charge carriers in forward bias. This charge in reverse bias current is more easily measurable. So, photodiodes are used to measure the intensity in reverse bias condition.

Q. 16. Draw a *p-n* junction with reverse bias.

Ans. The *p-n* junction with reverse bias is shown in fig.



Q. 17. In the given diagram, is the diode *D* forward or reverse biased?



Ans. The given diode is reverse biased.

Q. 18. The energy gaps in the energy band diagrams of a conductor, semiconductor and insulator are E_1, E_2 and E_3. Arrange them in increasing order.

Ans. The energy gap in a conductor is zero, in a semiconductor is ≈ 1 eV and in an insulator is ≥ 3 eV.

$\therefore \quad E_1 = 0, E_2 = 1 \text{ eV}, E_3 \geq 3 \text{ eV}$

$\therefore \quad E_1 < E_2 < E_3$

Q. 19. State the reason, why GaAs is most commonly used in making a solar cell.

Ans. For solar cell incident photon energy must be greater than band gap energy *i.e*, ($h\upsilon > E_g$). For GaAs, $E_g = 1.43$ eV and high optical absorption ≈ 10^4 cm^{-1}, which are main criteria for fabrication of solar cells.

Q. 20. Can the potential barrier across a *p-n* junction be measured by simply connecting a voltmeter across the junction? **[*HOTS*] [*NCERT Exemplar*]**

Ans. No, because the voltmeter must have a resistance very high compared to the junction resistance, the latter being nearly infinite.

Q. 21. Explain why elemental semiconductor cannot be used to make visible LEDs. **[*HOTS*] [*NCERT Exemplar*]**

Ans. Elemental semiconductor's band-gap is such that electromagnetic emissions are in infrared region.

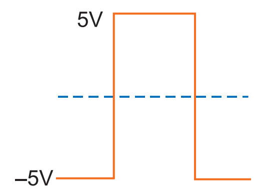
Q. 22. Why are elemental dopants for Silicon or Germanium usually chosen from group 13 or group 15? **[*NCERT Exemplar*]**

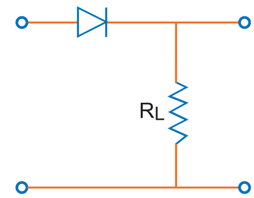
Ans. The size of dopant atoms should be such as not to distort the pure semiconductor lattice structure and yet easily contribute a charge carrier on forming covalent bonds with Si or Ge.

Q. 23. Sn, C, Si and Ge are all group 14 elements. Yet, Sn is a conductor, C is an insulator while Si and Ge are semiconductors. Why? **[*NCERT Exemplar*]**

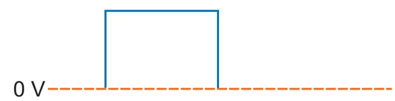
Ans. If the valance and conduction bands overlap (no energy gap), the substance is referred as a conductor. For insulator the energy gap is large and for semiconductor the energy gap is moderate. The energy gap for Sn is 0 eV, for C is 5.4 eV, for Si is 1.1 eV and for Ge is 0.7 eV, related to their atomic size.

Q. 24. Draw the output signal in a *p-n* junction diode when a square input signal of 10 V as shown in the figure is applied across it. *[CBSE 2019 (55/5/1)]*

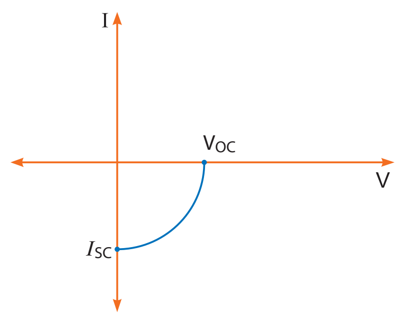




Ans.



Q. 25. Name the junction diode whose *I–V* characteristics are drawn below: *[CBSE Delhi 2017, 2019 (55/2/2)]*



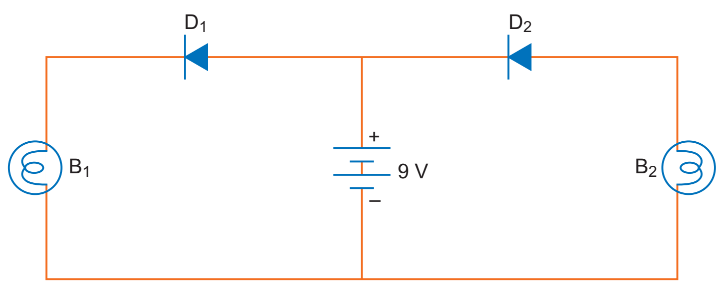
Ans. Solar cell

[**Note:** The *I-V* characteristics of solar cell is drawn in the fourth quadrant of the coordinate axis. This is because a solar cell does not draw current but supplies the same to the load.]

Q. 26. How does one understand the temperature dependance of resistivity of a semiconductor? *[CBSE (F) 2010]*

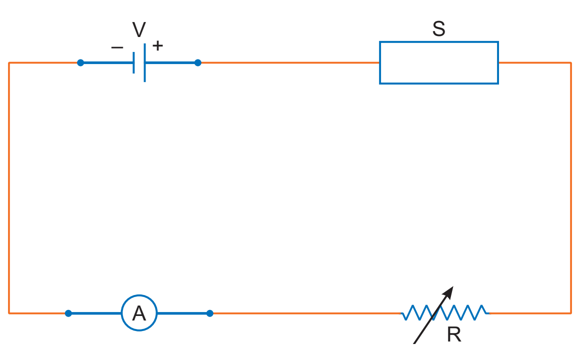
Ans. When temperature increases, covalent bonds of neighbouring atoms break and charge carrier become free to cause conduction, so resistivity of semi-conductor decreases with rise of temperature.

Q. 27. In the following diagram, which bulb out of B_1 and B_2 will glow and why? *[CBSE (AI) 2017]*



Ans. Bulb B_1 will glow as diode D_1 is forward biased.

Q. 28. In the following diagram '*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. *[CBSE (AI) 2017]*

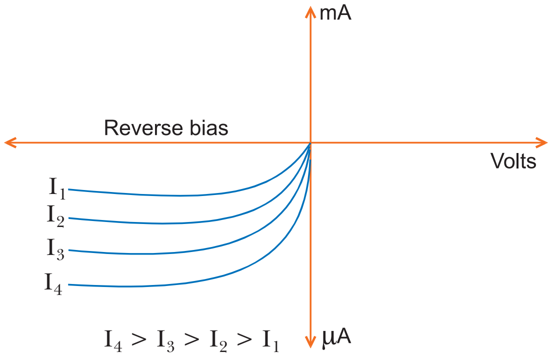


Ans. The value of *R* would be increased. On heating, the resistance of semiconductor (*S*) decreases.

Q. 29. What happens when a forward bias is applied to a *p-n* junction? [*CBSE Panchkula 2015*]

Ans. The direction of the applied voltage (V) is opposite to the built-in potential V_0. As a result, depletion layer width decreases and the barrier height is reduced to $V_0 - V$.

Q. 30. Identify the semiconductor diode whose *V-I* characteristics are as shown. [*CBSE 2019 (55/2/1)*]



Ans. It is photodiode.

Short Answer Questions–I [2 marks]

Q. 1. Distinguish between a metal and an insulator on the basis of energy band diagrams. [*CBSE (F) 2014*]

Ans.

	Metal	Insulators
(*i*)	Conduction band and valence band overlap each other.	There is large energy gap between conduction band and valence band.
(*ii*)	Conduction band is partially filled and valence band is partially empty.	Conduction band is empty. This is because no electrons can be excited to it from valence band.

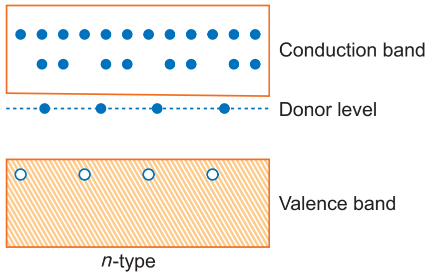
Q. 2. Write two characteristic features to distinguish between *n*-type and *p*-type semiconductors. [*CBSE (F) 2012*]

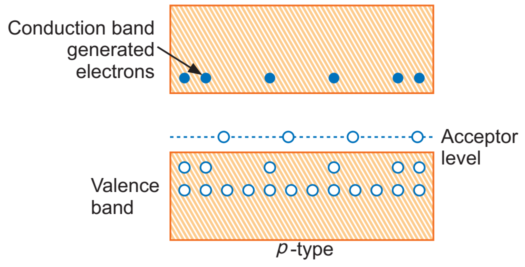
Ans.

	n-type Semiconductor	*p*-type Semiconductor
(*i*)	It is formed by doping pentavalent impurities.	It is doped with trivalent impurities.
(*ii*)	The electrons are majority carriers and holes are minority carriers ($n_e >> n_h$).	The holes are majority carriers and electrons are minority carriers ($n_h >> n_e$).

Q. 3. Draw energy band diagrams of an *n*-type and *p*-type semiconductor at temperature T > 0 K. Mark the donor and acceptor energy levels with their energies. [*CBSE (F) 2014*]

Ans.





Q. 4. How is forward biasing different from reverse biasing in a *p-n* junction diode? [*CBSE Delhi 2011*]

Ans. **1. Forward Bias:**

(*i*) Within the junction diode the direction of applied voltage is opposite to that of built-in potential.

(*ii*) The current is due to diffusion of majority charge carriers through the junction and is of the order of milliamperes.

(*iii*) The diode offers very small resistance in the forward bias.

2. Reverse Bias:

(*i*) The direction of applied voltage and barrier potential is same.

(*ii*) The current is due to leakage of minority charge carriers through the junction and is very small of the order of μA

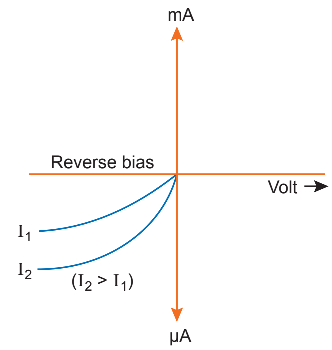
(*iii*) The diode offers very large resistance in reverse bias.

Q. 5. Name the optoelectronic device used for detecting optical signals and mention the biasing in which it is operated. Draw its *I-V* characteristics. [*CBSE Sample Paper 2018*]

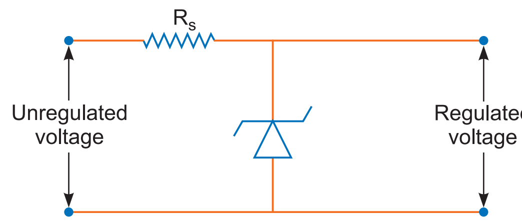
Ans. Photodiode is used for detecting optical signals.

It is operated in reverse biasing.

I-V Characteristics:



Q. 6. A Zener of power rating 1 W is to be used as a voltage regulator. If zener has a breakdown of 5 V and it has to regulate voltage which fluctuated between 3 V and 7 V, what should be the value of R_s for safe operation (see figure)? [*HOTS*][*NCERT Exemplar*]

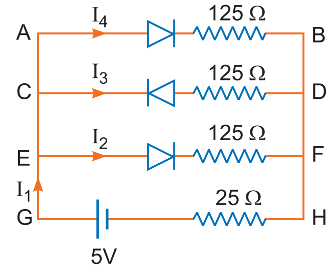


Ans. Here, $P = 1$ W, $V_z = 5$ V, $V_s = 3$ V to 7 V

$$I_{Z\,max} = \frac{P}{V_Z} = \frac{1}{5} = 0.2\text{ A} = \mathbf{200\text{ mA}}$$

$$R_S = \frac{V_S - V_z}{I_{Z\,max}} = \frac{7-5}{0.2} = \frac{2}{0.2} = \mathbf{10\ \Omega}$$

Q. 7. If each diode in figure has a forward bias resistance of 25 Ω and infinite resistance in reverse bias, what will be the values of current I_1, I_2, I_3 and I_4? [*HOTS*] [*NCERT Exemplar*]



Ans. I_3 is zero as the diode in that branch is reverse biased. Resistance in the branch *AB* and *EF* are each (125 + 25) Ω = 150 Ω

As *AB* and *EF* are identical parallel branches, their effective resistance is $\frac{150}{2} = 75\ \Omega$

∴ Net resistance in the circuit = (75 + 25) Ω = 100 Ω

∴ Current $I_1 = \frac{5}{100} = \mathbf{0.05\ A}$

As resistances of AB and EF are equal, and $I_1 = I_2 + I_3 + I_4$, $I_3 = \mathbf{0}$

$$\therefore \qquad I_2 = I_4 = \frac{0.05}{2} = \mathbf{0.025\ A}$$

Q. 8. Three photo diodes D_1, D_2 and D_3 are made of semiconductors having band gaps of 2.5 eV, 2 eV and 3 eV, respectively. Which ones will be able to detect light of wavelength 6000 Å?

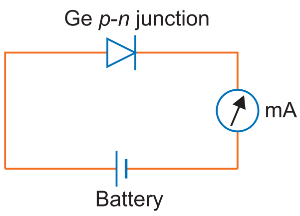
[HOTS][NCERT Exemplar]

Ans. Energy of incident light photon,

$$E = h\nu = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^{8}}{6\times10^{-7}\times1.6\times10^{-19}} = \mathbf{2.06\ eV}$$

For the incident radiation to be detected by the photodiode, energy of incident radiation photon should be greater than the band gap. This is true only for D_2. Therefore, only D_2 will detect this radiation.

Q. 9. A germanium *p-n* junction is connected to a battery with milliammeter in series. What should be the minimum voltage of battery so that current may flow in the circuit? *[HOTS]*



Ans. The internal potential barrier of germanium is 0.3 V, therefore to overcome this barrier the potential of battery should be equal to or more than 0.3 V.

Therefore, the minimum voltage of battery = **0.3 V.**

Short Answer Questions–II [3 marks]

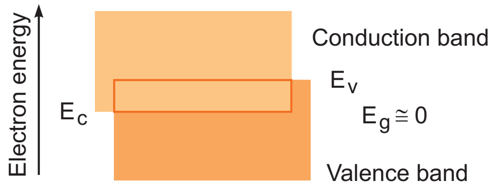
Q. 1. What are energy bands? Write any two distinguishing features between conductors, semiconductors and insulators on the basis of energy band diagrams.

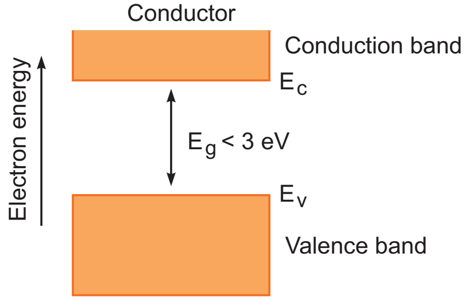
[CBSE (AI) 2014, North 2016]

OR

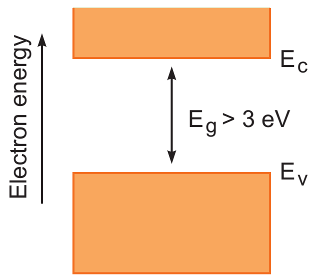
Draw the necessary energy band diagrams to distinguish between conductors, semiconductors and insulators. How does the change in temperature affect the behaviour of these materials? Explain briefly. *[CBSE Patna 2015]*

Ans. Energy Bands: In a solid, the energy of electrons lie within certain range. The energy levels of allowed energy are in the form of bands, these bands are separated by regions of forbidden energy called band gaps.





Semiconductor



Insulator

Distinguishing features:

(*a*) In conductors: Valence band and conduction band overlap each other.

In semiconductors: Valence band and conduction band are separated by a small energy gap.

In insulators: They are separated by a large energy gap.

(*b*) In conductors: Large number of free electrons are available in conduction band.

In semiconductors: A very small number of electrons are available for electrical conduction.

In insulators: Conduction band is almost empty *i.e.*, no electron is available for conduction.

Effect of Temperature:

(*i*) **In conductors:** At high temperature, the collision of electrons become more frequent with the atoms/molecules at lattice site in the metals as a result the conductivity decreases (or resistivity increases).

(*ii*) **In semiconductors:** As the temperature of the semiconducting material increases, more electron hole pairs becomes available in the conduction band and valance band, and hence the conductivity increases or the resistivity decreases.

(*iii*) **In insulators:** The energy band between conduction band and valance band is very large, so it is unsurpassable for small temperature rise. So, there is no change in their behaviour.

Q. 2. Distinguish between 'intrinsic' and 'extrinsic' semiconductors. **[*CBSE Delhi 2015, (F) 2017*]**

Ans.

	Intrinsic semiconductor	Extrinsic semiconductor
(*i*)	It is a semiconductor in pure form.	It is a semiconductor doped with trivalent or pentavalent impurity atoms.
(*ii*)	Intrinsic charge carriers are electrons and holes with equal concentration.	The two concentrations are unequal in it. There is excess of electrons in *n*-type and excess of holes in *p*-type semiconductors.
(*iii*)	Current due to charge carriers is feeble (of the order of μA).	Current due to charge carriers is significant (of the order of mA).

Q. 3. Distinguish between an intrinsic semiconductor and a *p*-type semiconductor. Give reason why a *p*-type semiconductor crystal is electrically neutral, although $n_h >> n_e$. **[*CBSE (F) 2013*]**

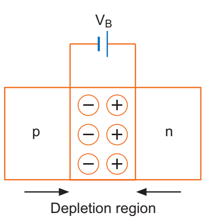
Ans.

	Intrinsic semiconductor	*p*-type semiconductor
(*i*)	It is a semiconductor in pure form.	It is a semiconductor doped with *p*-type (like Al, In) impurity.
(*ii*)	Intrinsic charge carriers are electrons and holes with equal concentration.	Majority charge carriers are holes and minority charge carriers are electrons.
(*iii*)	Current due to charge carriers is feeble (of the order of μA).	Current due to charge carriers is significant (of the order of mA).

p-type semiconductor is electrically neutral because every atom, whether it is of pure semiconductor (Ge or Si) or of impurity (Al) is electrically neutral.

Q. 4. Name the important process that occurs during the formation of a *p-n* junction. Explain briefly, with the help of a suitable diagram, how a *p-n* junction is formed. Define the term 'barrier potential'. **[*CBSE (F) 2011, Central 2016*]**

Ans. **Potential barrier:** During the formation of a *p-n* junction the electrons diffuse from *n*-region to *p*-region and holes diffuse from *p*-region to *n*-region. This forms recombination of charge carriers. In this process immobile positive ions are collected at a junction toward *n*-region and negative ions at a junction toward *p*-region. This causes a potential difference across the unbiased junction. This is called potential barrier.



Depletion region: It is a layer formed near the junction which is devoid of free charge carriers. Its thickness is about 1 μm.

Q. 5. Explain, with the help of a circuit diagram, the working of a photo-diode. Write briefly how it is used to detect the optical signals. *[CBSE Delhi 2013]*

OR

(*a*) How is photodiode fabricated?

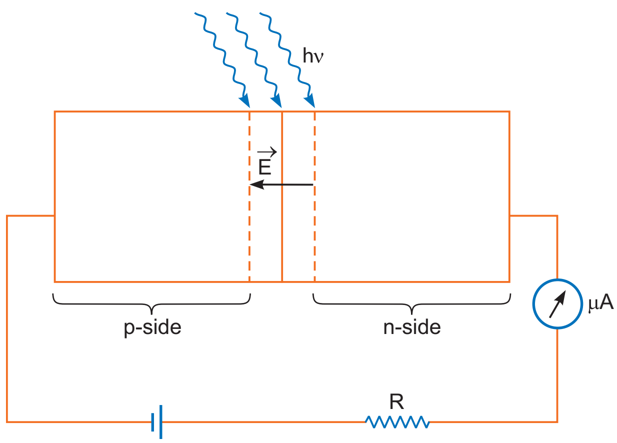
(*b*) Briefly explain its working. Draw its *V–I* characteristics for two different intensities of illumination. *[CBSE (F) 2014]*

OR

With what considerations in view, a photodiode is fabricated? State its working with the help of a suitable diagram.

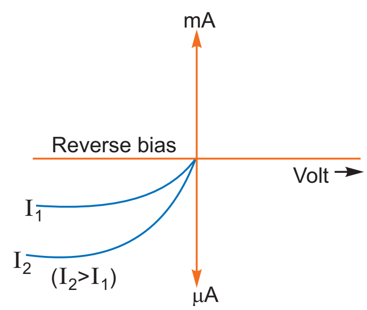
Even though the current in the forward bias is known to be more than in the reverse bias, yet the photodiode works in reverse bias. What is the reason? *[CBSE Delhi 2015, East 2016]*

Ans. A photo-diode is fabricated using photosensitive semiconducting material with a transparent window to allow light to fall on the junction of the diode.



Working: In diode (any type of diode), an electric field 'E' exists across the junction from n-side to p-side, when light with energy $h\nu$ greater than energy gap E_g ($h\nu > E_g$) illuminates the junction, then electron- hole pairs are generated due to absorption of photons, in or near the depletion region of the diode. Due to existing electric field, electrons and holes get separated. The free electrons are collected on n-side and holes are collected on p-side, giving rise to an emf.

Due to the generated emf, an electric current of μA order flows through the external resistance.



Detection of Optical Signals:

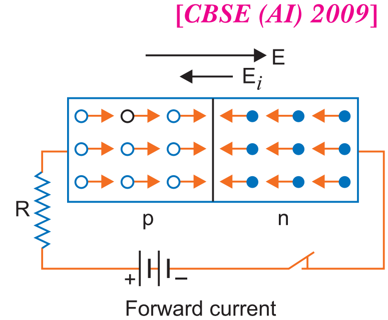
It is easier to observe the change in the current with change in the light intensity if a reverse bias is applied. Thus, photodiode can be used as a photodetector to detect optical signals.

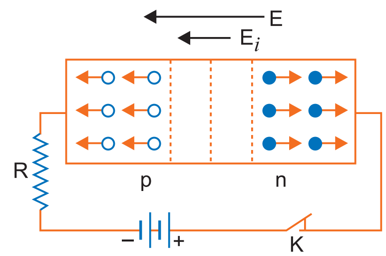
The characteristic curves of a photodiode for two different illuminations I_1 and I_2 ($I_2 > I_1$) are shown.

Q. 6. Explain how the width of depletion layer in a *p-n* junction diode changes when the junction is (*i*) forward biased (*ii*) reverse biased. *[CBSE (AI) 2009]*

Ans. (*i*) Under forward biasing the applied potential difference causes a field which acts opposite to the potential barrier. This results in reducing the potential barrier, and hence the width of depletion layer decreases.

(*ii*) Under reverse biasing the applied potential difference causes a field which is in the same direction as the field due to internal potential barrier. This results in an increase in barrier voltage and hence the width of depletion layer increases.

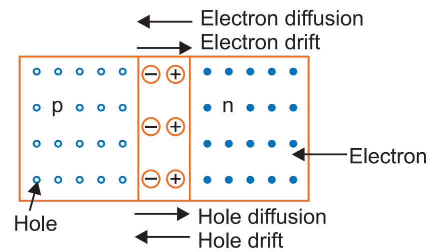




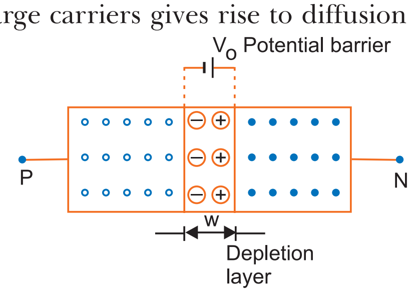
Reverse current

Q. 7. Describe briefly, with the help of a diagram, the role of the two important processes involved in the formation of a *p-n* junction. [*CBSE (AI) 2012, Bhubaneshwar 2015*]

Ans. Two important processes occurring during the formation of a *p-n* junction are (*i*) diffusion and (*ii*) drift.



(*i*) **Diffusion:** In *n*-type semiconductor, the concentration of electrons is much greater as compared to concentration of holes; while in *p*-type semiconductor, the concentration of holes is much greater than the concentration of electrons. When a *p-n* junction is formed, then due to concentration gradient, the 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.



(*ii*) **Drift:** The drift of charge carriers occurs due to electric field. Due to built in potential barrier, an electric field directed from *n*-region to *p*-region is developed across the junction. This field causes motion of electrons on *p*-side of the junction to *n*-side and motion of holes on *n*-side of junction to *p*-side. Thus a drift current starts. This current is opposite to the direction of **diffusion current.**

Q. 8. How is a light emitting diode fabricated? Briefly state its working. Write any two important advantages of LEDs over the conventional incandescent low power lamps.

[*CBSE Bhubaneshwar 2015, CBSE 2019*]

OR

(*a*) Explain briefly the process of emission of light by a Light Emitting Diode (LED).

(*b*) Which semiconductors are preferred to make LEDs and why?

(*c*) Give two advantages of using LEDs over conventional incandescent lamps. [*CBSE South 2016*]

Ans. LED is fabricated by

(*i*) heavy doping of both the *p* and *n* regions.

(*ii*) providing a transparent cover so that light can come out.

Working: When the diode is forward biased, electrons are sent from $n \rightarrow p$ and holes from $p \rightarrow n$. At the junction boundary, the excess minority carriers on either side of junction recombine with majority carriers. This releases energy in the form of photon $h\nu = E_g$.

GaAs (Gallium Arsenide): Band gap of semiconductors used to manufacture LED's should be 1.8 eV to 3 eV. These materials have band gap which is suitable to produce desired visible light wavelengths.

Advantages

(*i*) Low operational voltage and less power consumption.

(*ii*) Fast action and no warm-up time required.

(*iii*) Long life and ruggedness.

(*iv*) Fast on-off switching capability.

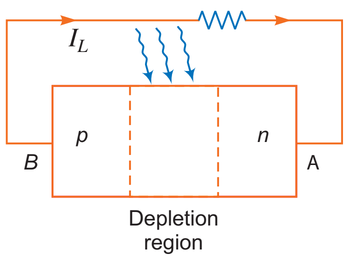
Q. 9. Describe briefly using the necessary circuit diagram, the three basic processes which take place to generate the emf in a solar cell when light falls on it. Draw the $I-V$ characteristics of a solar cell. Write two important criteria required for the selection of a material for solar cell fabrication. [*CBSE Guwahati 2015*]

OR

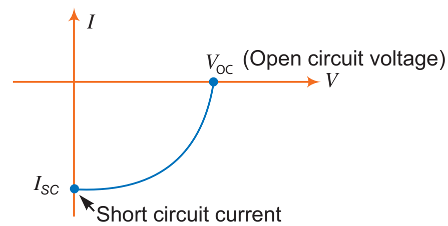
(*i*) Describe the working principle of a solar cell. Mention three basic processes involved in the generation of emf.

(*ii*) Why are Si and GaAs preferred materials for solar cells? [CBSE (F) 2016]

Ans. **Principle:** It is based on photovoltaic effect (generation of voltage due to bomardment of light photons). When solar cell is illuminated with light photons of energy ($h\nu$) greater than the energy gap (E_g) of the semiconductor, then electron-hole pairs are generated due to absorption of photons.



(a)



(b)

The three basic processes involved are: generation, separation and collection

(*a*) generation of electron-hole pairs due to light (with $h\nu > E_g$) close to the junction.

(*b*) separation of electrons and holes due to electric field of the depletion region. Electrons are swept to *n*-side and holes to *p*-side.

(*c*) the electrons reaching the *n*-side are collected by the front contact and holes reaching *p*-side are collected by the back contact. Thus, *p*-side becomes positive and *n*-side becomes negative giving rise to photovoltage.

Important criteria for the selection of a material for solar cell fabrication are:

(*i*) band gap (~1.0 to 1.8 eV), (*ii*) high optical absorption (–10^4 cm^{-1}),

(*iii*) electrical conductivity, (*iv*) availability of the raw material, and

(*v*) cost

Solar radiation has maximum intensity of photons of energy = 1.5 eV

Hence semiconducting materials Si and GaAs, with band gap ≈ 1.5 eV, are preferred materials for solar cells.

Q. 10. (*a*) Three photo diodes D_1, D_2 and D_3 are made of semiconductors having band gaps of 2.5 eV, 2 eV and 3 eV respectively. Which of them will not be able to detect light of wavelength 600 nm?

(*b*) Why photodiodes are required to operate in reverse bias? Explain. [*CBSE South 2019*]

Ans. (*a*) Energy of incident light photon

$$E = h\nu = \frac{hc}{\lambda}$$

$$= \frac{6.6\times10^{-34}\times3\times10^{8}}{6\times10^{-7}\times1.6\times10^{-19}} = 2.06 \text{ eV}$$

For the incident radiation to be detected by the photodiode, energy of incident radiation photon should be greater than the band gap. This is true only for D_2. Therefore, only D_2 will detect this radiation.

(*b*) When a photodiode is illuminated with energy $h\nu$ greater than the energy gap of the semiconductor, then electron hole pairs are generated due to absorption of photon. The photodiode is operated in reverse bias so that electric field applied at junction electrons and holes are separated before they re-combine.

Q. 11. Draw *V – I* characteristics of a *p–n* junction diode. Answer the following questions, giving reasons:

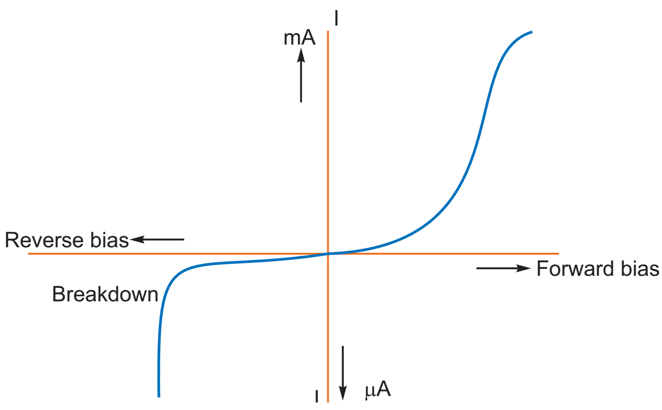
(*i*) Why is the current under reverse bias almost independent of the applied potential upto a critical voltage?

(*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. [*CBSE (AI) 2013, CBSE 2019*]

Ans. (*i*) In the reverse biasing, the current of order of μA is due to movement/drifting of minority charge carriers from one region to another through the junction.

A small applied voltage is sufficient to sweep the minority charge carriers through the junction. So, reverse current is almost independent of critical voltage.



(*ii*) At critical voltage (or breakdown voltage), a large number of covalent bonds break, resulting in the increase of large number of charge carriers. Hence, current increases at critical voltage.

Semiconductor device that is used in reverse biasing is zener diode.

Q. 12. The current in the forward bias is known to be more (~mA) than the current in the reverse bias (~μA). What is the reason, then, to operate the photodiode in reverse bias? [*HOTS*][*CBSE Delhi 2012*]

Ans. Consider the case of *n*-type semiconductor. The majority carrier (electron) density is larger than the minority hole density, *i.e.*, $n >> p$.

On illumination, the no. of both types of carriers would equally increase in number as

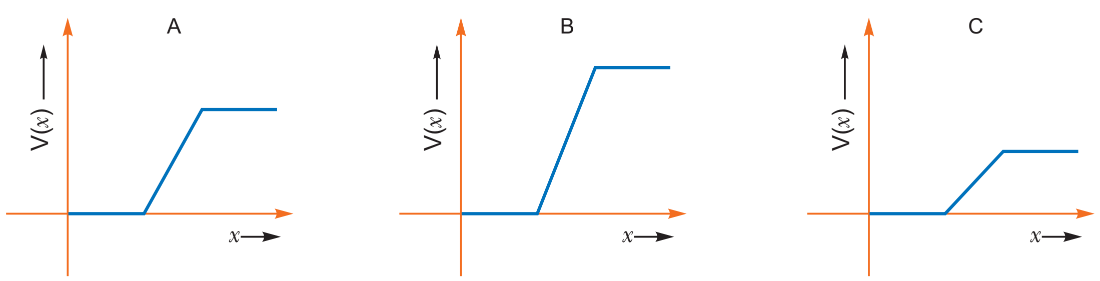
$n' = n + \Delta n,\ p' = p + \Delta p$

But $\Delta n = \Delta p$ and $n >> p$

Hence, the fractional change in majority carrier, *i.e*, $\frac{\Delta n}{n} << \frac{\Delta p}{p}$ (fractional change in minority carrier)

Fractional change due to photo-effects on minority carrier dominated reverse bias current is more easily measurable than the fractional change in majority carrier dominated forward bias current. Hence photodiodes are used in reverse bias condition for measuring light intensity.

Q. 13. The graph of potential barrier versus width of depletion region for an unbiased diode is shown in *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 Sample Paper 2016*]



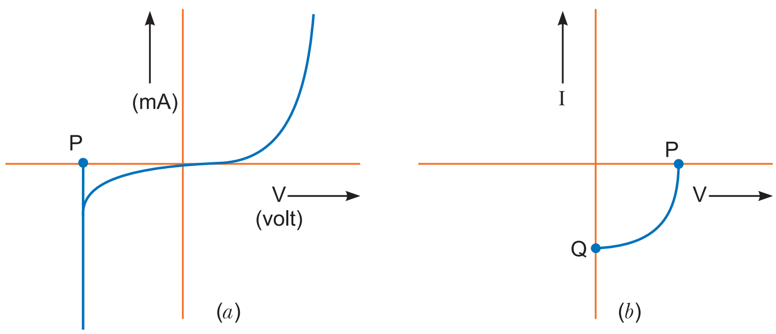
Ans. **B : Reverse biased**

Justification: When an external voltage V is applied across the semiconductor diode such that n-side is positive and p-side is negative, the direction of applied voltage is same as the direction of barrier potential. As a result, the barrier height increases and the depletion region widens due to the change in the electric field. The effective barrier height under reverse bias is (V_0+V).

C : Forward biased

Justification: When an external voltage V is applied across a diode such that p-side is positive and n-side is negative, the direction of applied voltage (V) is opposite to the barrier potential (V_0). As a result, the depletion layer width decreases and the barrier height is reduced. The effective barrier height under forward bias is $(V_0 - V)$.

Q. 14.



(*i*) Name the type of a diode whose characteristics are shown in fig (*a*) and (*b*).

(*ii*) What does the points *P* in fig. (*a*) represent?

(*iii*) What does the points *P* and *Q* in fig (*b*) represent? **[*HOTS*][*NCERT Exemplar*]**

Ans. (*i*) ZENER junction diode and solar cell.

(*ii*) Zener breakdown voltage.

(*iii*) Q-short circuit current

P-open circuit voltage.

Q. 15. Give reasons for the following:

(*i*) The Zener diode is fabricated by heavily doping both the *p* and *n* sides of the junction.

(*ii*) A photodiode, when used as a detector of optical signals is operated under reverse bias.

(*iii*) The band gap of the semiconductor used for fabrication of visible LED's must at least be 1.8 eV.

[*HOTS*]

Ans. (*i*) Heavy doping makes the depletion region very thin. This makes the electric field of the junction very high, even for a small reverse bias voltage. This in turn helps the Zener diode to act as a 'voltage regulator'.

(*ii*) When operated under reverse bias, the photodiode can detect changes in current with changes in light intensity more easily.

(*iii*) The photon energy, of visible light photons varies about 1.8 eV to 3 eV. Hence, for visible LED's, the semiconductor must have a band gap of 1.8 eV.

Q. 16. A semiconductor has equal electron and hole concentration of 2×10^8 / m^3. On doping with a certain impurity, the hole concentration increases to 4×10^{10} / m^3.

(*i*) What type of semiconductor is obtained on doping?

(*ii*) Calculate the new electron and hole concentration of the semiconductor.

(*iii*) How does the energy gap vary with doping?

Ans. Given $n_e = 2 \times 10^8 / \text{m}^3, n_h = 4 \times 10^{10} / \text{m}^3$

(*i*) The majority charge carriers in doped semiconductor are holes, so semiconductor obtained is p-type semiconductor.

(*ii*) $n_e n_h = n_i^2 \Rightarrow n_e = \dfrac{n_i^2}{n_h} = \dfrac{(2\times10^8)^2}{4\times10^{10}} = \mathbf{10^6/m^3}$

New electron concentration $= 10^6 / m^3$

hole concentration $= 4 \times 10^{10} / m^3$

(*iii*) Energy gap decreases on doping.

Long Answer Questions [5 marks]

Q. 1. (*a*) State briefly the processes involved in the formation of *p-n* junction explaining clearly how the depletion region is formed.

(*b*) Using the necessary circuit diagrams, show how the V–I characteristics of a *p-n* junction are obtained in (*i*) Forward biasing (*ii*) Reverse biasing

How are these characteristics made use of in rectification? [*CBSE Delhi 2014*]

OR

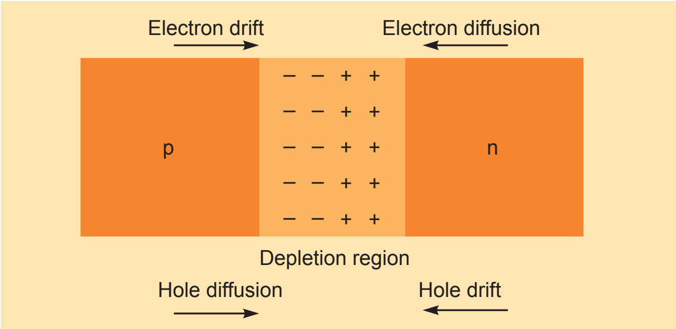
Draw the circuit arrangement for studying the *V–I* characteristics of a *p-n* junction diode (*i*) in forward bias and (*ii*) in reverse bias. Draw the typical *V–I* characteristics of a silicon diode.

Describe briefly the following terms:

(*i*) "minority carrier injection" in forward bias

(*ii*) "breakdown voltage" in reverse bias. [*CBSE Chennai 2015*]

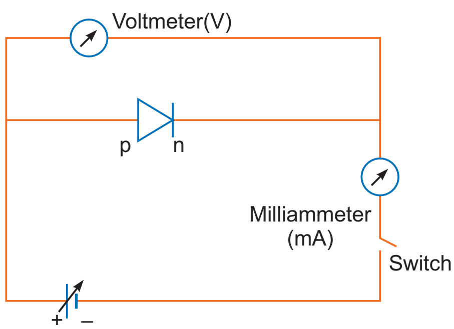
Ans. (*a*)



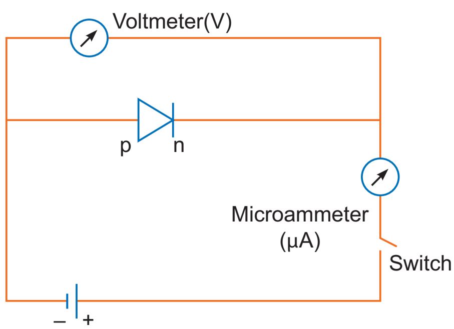
Two processes occur during the formation of a *p-n* junction are diffusion and drift. Due to the concentration gradient across *p* and *n*-sides of the junction, holes diffuse from *p*-side to *n*-side ($p \to n$) and electrons diffuse from *n*-side to *p*-side ($n \to p$). This movement of charge carriers leaves behind ionised acceptors (negative charge immobile) on the *p*-side and donors (positive charge immobile) on the *n*-side of the junction. This space charge region on either side of the junction together is known as depletion region.

(*b*) The circuit arrangement for studying the *V–I* characteristics of a diode are shown in Fig. (*a*) and (*b*). For different values of voltages the value of current is noted. *A* graph between *V* and *I* is obtained as in Figure (*c*).

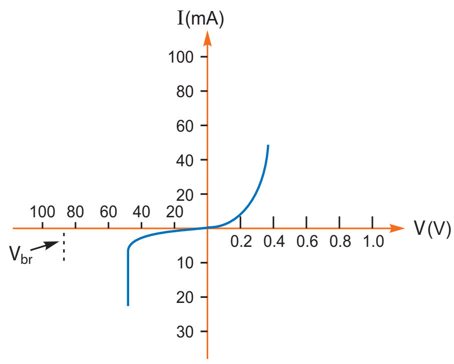
From the *V–I* characteristic of a junction diode it is clear that it allows current to pass only when it is forward biased. So if an alternating voltage is applied across a diode the current flows only in that part of the cycle when the diode is forward biased. This property is used to rectify alternating voltages.



(a)



(b)



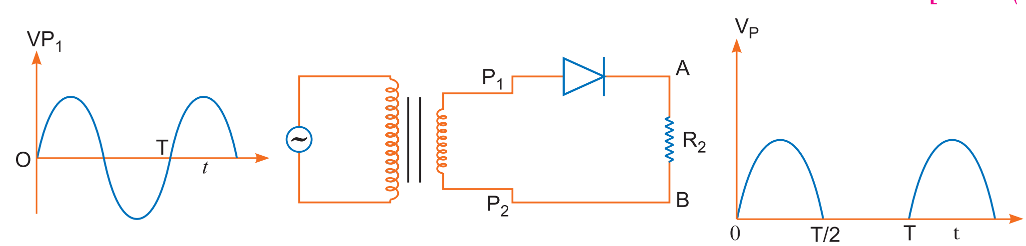
(c)

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

Q. 2. Explain, with the help of a circuit diagram, the working of a *p-n* junction diode as a half-wave rectifier. **[*CBSE (AI) 2014*]**

Ans.



Working

(*i*) During positive half cycle of input alternating voltage, the diode is forward biased and a current flows through the load resistor R_L and we get an output voltage.

(*ii*) During other negative half cycle of the input alternating voltage, the diode is reverse biased and it does not conduct (under break down region).

Hence, *ac* voltage can be rectified in the pulsating and unidirectional voltage.

Q. 3. State the principle of working of *p-n* diode as a rectifier. Explain with the help of a circuit diagram, the use of *p-n* diode as a full wave rectifier. Draw a sketch of the input and output waveforms. **[*CBSE Delhi 2012*]**

OR

Draw a circuit diagram of a full wave rectifier. Explain the working principle. Draw the input/output waveforms indicating clearly the functions of the two diodes used. **[*CBSE (AI) 2011*]**

OR

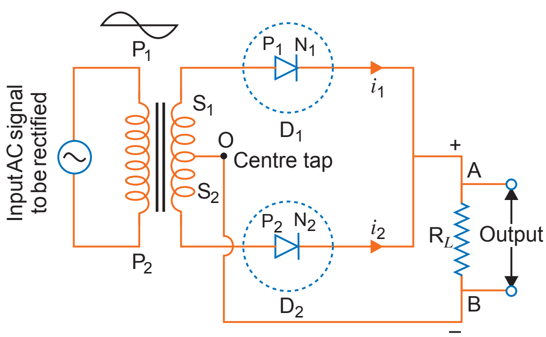
With the help of a circuit diagram, explain the working of a junction diode as a full wave rectifier. Draw its input and output waveforms. Which characteristic property makes the junction diode suitable for rectification? **[*CBSE Ajmer 2015, North 2016*]**

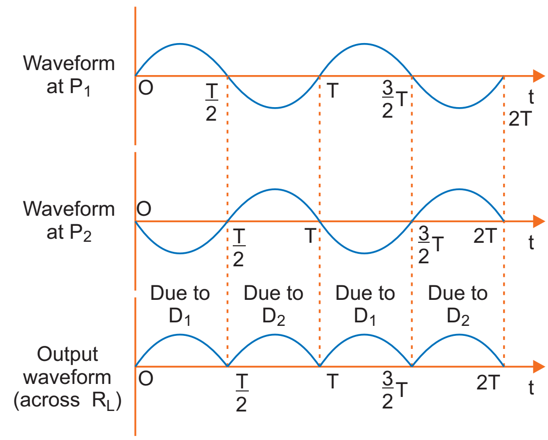
OR

Draw the circuit diagram of a full wave rectifier and explain its working. Also, give the input and output waveforms. **[*CBSE Delhi 2019*]**

Ans. **Rectification:** Rectification means conversion of *ac* into *dc*. A *p-n* diode acts as a rectifier because an *ac* changes polarity periodically and a *p-n* diode allows the current to pass only when it is forward biased. This makes the diode suitable for rectification.

Working: The ac input voltage across secondary S_1 and S_2 changes polarity after each half cycle. Suppose during the first half cycle of input ac signal, the terminal S_1 is positive relative to centre tap O and S_2 is negative relative to O. Then diode D_1 is forward biased and diode D_2 is reverse biased. Therefore, diode D_1 conducts while diode D_2 does not. The direction of current (i_1) due to diode D_1 in load resistance R_L is directed from A to B In next half cycle, the terminal S_1 is negative and S_2 is positive relative to centre tap O. The diode D_1 is reverse biased and diode D_2 is forward biased. Therefore, diode D_2 conducts while D_1 does not. The direction of current (i_2) due to diode D_2 in load resistance R_L is still from A to B. Thus, the current in load resistance R_L is in the same direction for both half cycles of input ac voltage. Thus *for input ac signal the output current is a continuous series of unidirectional pulses.*





In a full wave rectifier, if input frequency is f hertz, then output frequency will be $2f$ hertz because for each cycle of input, two positive half cycles of output are obtained.

Q. 4. (*a*) Distinguish between an intrinsic semiconductor and a *p*-type semiconductor. Give reason why a *p*-type semiconductor is electrically neutral, although $n_h >> n_e$.

(*b*) Explain, how the heavy doping of both *p*-and *n*-sides of a *p-n* junction diode results in the electric field of the junction being extremely high even with a reverse bias voltage of a few volts. [*CBSE (F) 2013*]

Ans. (*a*) Refer to Q. 3 Page 561.

(*b*) If *p*-type and *n*-type semiconductor are heavily doped. Then due to diffusion of electrons from *n*-region to *p*-region, and of holes from *p*-region to *n*-region, a depletion region formed of size of order less than 1 μm. The electric field directing from *n*-region to *p*-region produces a reverse bias voltage of about 5 V and electric field becomes very large.

$$E = \frac{\Delta V}{\Delta x} = \frac{5\text{V}}{1\,\mu\text{m}} \approx \mathbf{5 \times 10^6\ V/m}$$

Q. 5. Why is a Zener diode considered as a special purpose semiconductor diode?

Draw the *I–V* characteristic of a zener diode and explain briefly how reverse current suddenly increases at the breakdown voltage.

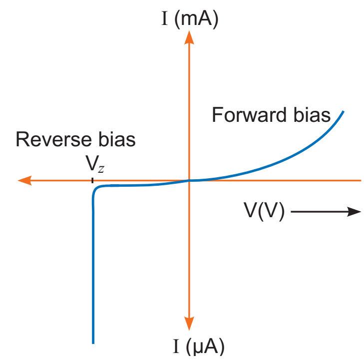
Describe briefly with the help of a circuit diagram how a Zener diode works to obtain a constant dc voltage from the unregulated dc output of a rectifier. [*CBSE (F) 2012*]

OR

How is Zener diode fabricated? What causes the setting up of high electric field even for small reverse bias voltage across the diode?

Describe with the help of a circuit diagram, the working of Zener diode as a voltage regulator. *[CBSE Panchkula 2015]*

Ans. A Zener diode is considered as a special purpose semiconductor diode because it is designed to operate under reverse bias in the breakdown region.



Zener diode is fabricated by heavy doping of its p and n sections. Since doping is high, depletion layer becomes very thin.

Hence, electric field $\left(= \frac{V}{l}\right)$ becomes high even for a small reverse bias.

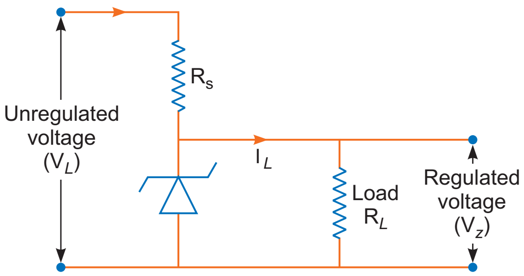
We know that reverse current is due to the flow of electrons (minority carriers) from $p \rightarrow n$ and holes from $n \rightarrow p$. As the reverse bias voltage is increased, the electric field at the junction becomes significant. When the reverse bias voltage $V = V_Z$, then the electric field strength is high enough to pull valence electrons from the host atoms on the p-side which are accelerated to n-side. These electrons causes high current at breakdown.

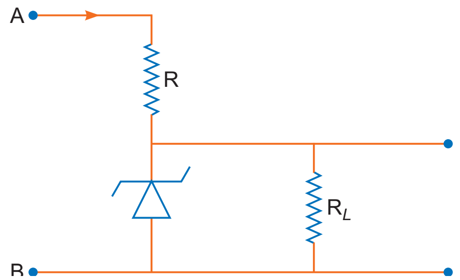
Working:

The unregulated dc voltage output of a rectifier is connected to the zener diode through a series resistance R_s such that the Zener diode is reverse biased. Now, any increase/decrease in the input voltage results in increase/decrease of the voltage drop across R_s without any change in voltage across the Zener diode. Thus, the Zener diode acts as a voltage regulator.

Explanation of voltage regulator.

If reverse bias voltage V reaches the breakdown voltage V_Z of zener diode, there is a large change in the current. After that (just above V_Z there is a large change in the current by almost insignificant change in reverse bias voltage. This means diode voltage remains constant.





For example: If unregulated voltage is supplied at terminals A and B, and input voltage increases, the current through resistor R and diode also increases. This current increases the voltage drop across R without any change in the voltage across diode. Thus, we have a regulated voltage across load resistor R_L.

Self-Assessment Test

Time allowed: 1 hour **Max. marks: 30**

1. Choose and write the correct option in the following questions. **(3 × 1 = 3)**

(*i*) 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 statement 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*) $(E_g)_C = (E_g)_{Si} = (E_g)_{Ge}$

(*ii*) In an unbiased *p*-*n* junction, holes diffuse from *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 compared to *n*-region

(*d*) all of the above

(*iii*) 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

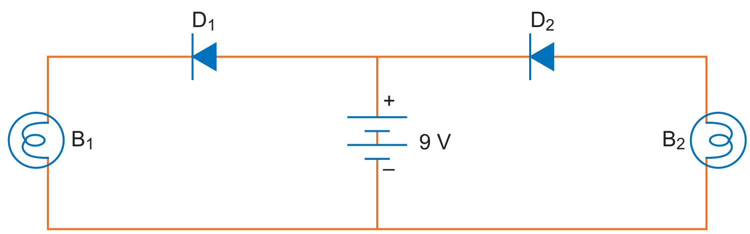
(*d*) none of the above

2. Fill in the blanks. **(2 × 1 = 2)**

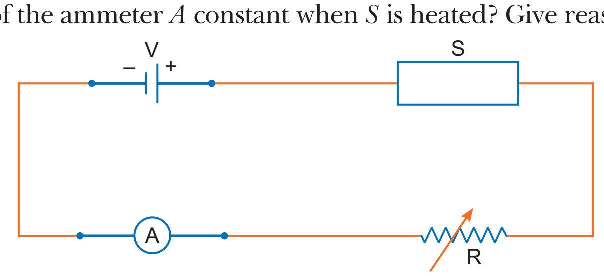
(*i*) In *p*-*n* junction diode there is a ________________ of majority carriers across the junction in forward bias.

(*ii*) In full-wave rectification, if the input frequency is 50 Hz then the output frequency of the signal will be ________________ Hz.

3. In the following diagram, which bulb out of B_1 and B_2 will glow and why? **1**

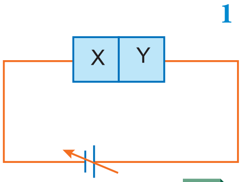


4. In the following diagram '*S*' is a semiconductor. Would you increase or decrease the value of *R* to keep the reading of the ammeter *A* constant when *S* is heated? Give reason for your answer. **1**



5. What happens when a forward bias is applied to a *p*-*n* junction? **1**

6. Two semiconductor materials *X* and *Y* shown in the alongside figure, are made by doping a germanium crystal with indium and arsenic respectively. The two are joined end to end and connected to a battery as shown.



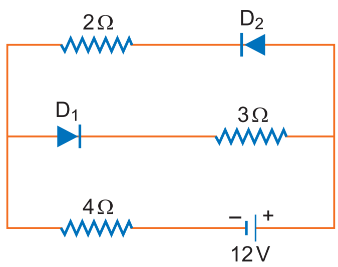
(*i*) Will the junction be forward biased or reverse biased?

(*ii*) Sketch a *V-I* graph for this arrangement. **2**

7. Describe, with the help of a circuit diagram, the working of a photo diode. **2**

8. Draw a circuit diagram of an illuminated photodiode in reverse bias. How is a photodiode used to measure the light intensity? **2**

9. The circuit shown in the figure has two oppositely connected ideal diodes connected in parallel. Find the current flowing through each diode in the circuit. **2**



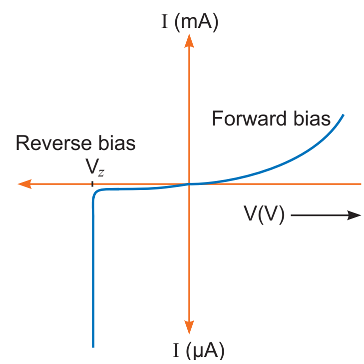
10. A student wants to use two *p-n* junction diodes to convert alternating current into direct current. Draw the labelled circuit diagram she would use and explain how it works. **3**

11. The figure shows the *V-I* characteristic of a semiconductor diode designed to operate under reverse bias.

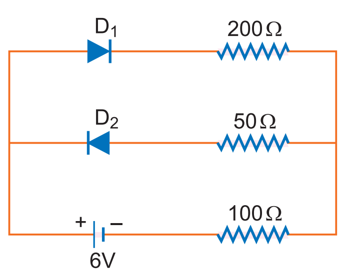
(*a*) Identify the semiconductor diode used.

(*b*) Draw the circuit diagram to obtain the given characteristics of this device.

(*c*) Briefly explain one use of this device. **3**



12. The circuit shown in the figure contains two diodes each with a forward resistance of 50 Ω and infinite backward resistance. Calculate the current in the 100 Ω resistance. **3**



13. How is Zener diode fabricated? What causes the setting up of high electric field even for small reverse bias voltage across the diode?

Describe with the help of a circuit diagram, the working of Zener diode as a voltage regulator. **5**

Answers

1. (*i*) (*c*) (*ii*) (*c*) (*iii*) (*c*)

2. (*i*) diffusion (*ii*) 100