CHAPTER 14

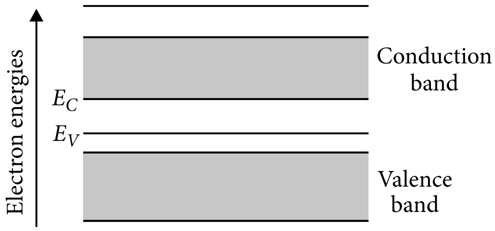
Semiconductor Electronics : Materials, Devices and Simple Circuits

Recap Notes

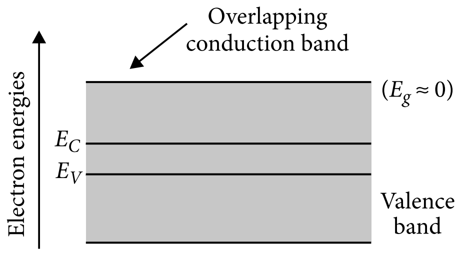
- **Classification of solids on the basis of their conductivity :** On the basis of the relative values of electrical conductivity (σ) and resistivity ($\rho = 1/\sigma$), the solids are broadly classified as,
  - **Metals** : Those solids which have high conductivity and very low resistivity. The value of conductivity for metals lies in between 10^2 to 10^8 S m^{-1} and of resistivity in between 10^{-2} to 10^{-8} Ω m.
  - **Insulators** : Those solids which have low conductivity and high resistivity. The value of conductivity for insulators lies between 10^{-11} to 10^{-19} S m^{-1} and of resistivity between 10^{11} to 10^{19} Ω m.
  - **Semiconductors** : Those solids which have conductivity and resistivity intermediate to metals and insulators. The value of conductivity for semiconductors lies in between 10^5 to 10^{-6} S m^{-1} and of resistivity between 10^{-5} to 10^6 Ω m.
- **Energy bands of solids or band theory of solids**
  - **Valence band :** This band contains valence electrons. This band may be partially or completely filled with electrons. This band is never empty. Electrons in this band do not contribute to electric current.
  - **Conduction band :** In this band, electrons are rarely present. This band is either empty or partially filled. Electrons in the conduction band are known as free electrons. These electrons contribute to the electric current.
  - **Forbidden energy gap or forbidden band :** The energy gap between the valence band and conduction band is known as forbidden energy gap or forbidden band. No electrons are present in this gap. It is a measure of energy band gap.
  - The minimum energy required for shifting electrons from valence band to conduction band is known as energy band gap.
  - If λ is the wavelength of radiation used in shifting the electron from valence band to conduction band, then energy band gap is

    $$E_g = h\upsilon = \frac{hc}{\lambda}$$

    where h is called Planck's constant and c is the speed of light.
  - The forbidden energy gap E_g in a semiconductor depends upon temperature.
  - Fermi energy : It is the maximum possible energy possessed by free electrons of a material at absolute zero temperature (*i.e.,* 0 K)
- **Differences between metals, insulators and semiconductors on the basis of band theory**
  - **Metals**
    - In metals either the conduction band is partially filled or conduction band and valence band partially overlap each other.
    - In metals, there is no forbidden energy gap between the valence and conduction bands.

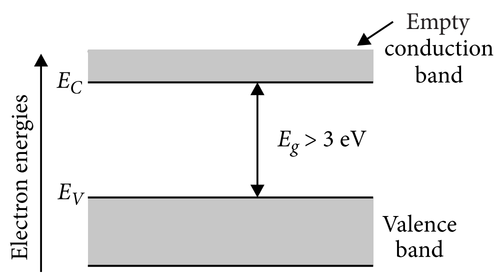


(i)

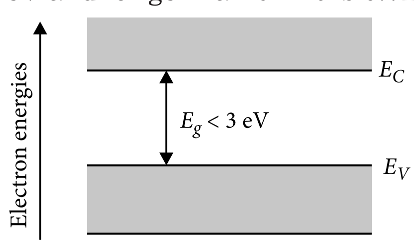


(ii)

- **Insulators**
  - In insulators, valence band is completely filled and conduction band is completely empty.
  - In insulators, there is a very wide forbidden energy gap between the valence and conduction bands. It is of the order of 5 eV or more.



- **Semiconductors**
  - In semiconductors, valence band is completely filled and the conduction band is empty.
  - In semiconductors, there is a small forbidden energy gap between the valence and the conduction bands. It is of the order of 1 eV. For silicon, it is 1.1 eV and for germanium it is 0.72 eV.



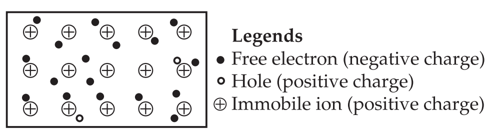
  - At absolute zero, semiconductors behave as a perfect insulator.
  - Hole : It is a seat of positive charge which is produced when an electron breaks away from a covalent bond in a semiconductor. Hole has a positive charge equal to that of electron. Mobility of hole is smaller than that of electron.

- **Intrinsic semiconductor :** A pure semiconductor which is free from every impurity is known as intrinsic semiconductor. Germanium (Ge) and silicon (Si) are the important examples of intrinsic semiconductors.
  - In intrinsic semiconductor, $n_e = n_h = n_i$ where n_e , n_h are number density of electrons in conduction band and number density of holes in valence band, n_i is the intrinsic carrier concentration.
  - When an electric field is applied across an intrinsic semiconductor, electrons and holes move in opposite directions so that total current (I) through the pure semiconductor is given by
    $I = I_e + I_h$
    where I_e is the free electron current and I_h is the hole current.
  - **Effect of temperature on conductivity of intrinsic semiconductor**
    - An intrinsic semiconductor will behave as a perfect insulator at absolute zero.
    - With increasing temperature, the density of hole-electron pairs increases and hence the conductivity of an intrinsic semiconductor increases with increase in temperature. In other words, the resistivity (inverse of conductivity) decreases as the temperature increases.
    - The semiconductors have negative temperature coefficient of resistance.

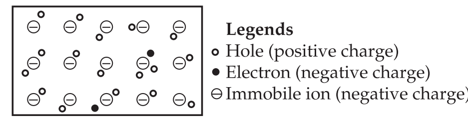
- **Doping :** It is a process of deliberate addition of a desirable impurity to a pure semiconductor in order to increase its conductivity. The impurity atoms added are known as dopants.

- **Extrinsic semiconductor :** A doped semiconductor is known as extrinsic semiconductor. Extrinsic semiconductors are of two types :

- ***n*-type semiconductor**
  - When a pure semiconductor of Si or Ge (tetravalent) is doped with a group V pentavalent impurities like arsenic (As), antimony (Sb), phosphorus (P) etc, we obtain a n-type semiconductor. The pentavalent impurity atoms are known as donor atoms.
  - It is called n-type semiconductor because the conduction of electricity in such semiconductor is due to motion of electrons *i.e.*, negative charges.
  - It is called donor type semiconductor, because the doped impurity atom donates one free electron to semiconductor for conduction.
  - In n-type semiconductor electrons are majority carriers and holes are minority carriers.
  - The representation of n-type semiconductor is as shown in the figure.

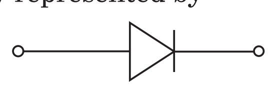


  - n-type semiconductor is neutral.
  - In n-type semiconductor
    $n_e \approx N_d >> n_h$
    where N_d is the density of donor atoms.
- ***p*-type semiconductor :** When a pure semiconductor of Si or Ge (tetravalent) is doped with a group III trivalent impurities like aluminium (Al), boron (B), indium (In) etc, we obtain a p-type semiconductor. The trivalent impurity atoms are known as acceptor atoms.
  - It is called p-type because the conduction of electricity in such semiconductor is due to motion of holes *i.e.*, positive charges.
  - It is called acceptor type semiconductor because the doped impurity atom creates a hole in semiconductor which accepts the electron, resulting conduction in p-type semiconductor.
  - In p-type semiconductor, holes are majority carriers and electrons are minority carriers.
  - The representation of p-type semiconductor is as shown in the figure.



  - p-type semiconductor is neutral.
  - In p-type semiconductor
    $n_h \approx N_a >> n_e$
    where N_a is the density of acceptor atoms.

- **Mass action law :** Under thermal equilibrium, the product of the free negative and positive concentrations is a constant independent of the amount of donor and acceptor impurity doping. This relationship is known as the mass action law and is given by
  $n_e n_h = n_i^2$
  where n_e , n_h are the number density of electrons and holes respectively and n_i is the intrinsic carriers concentration.
  - **Electrical conductivity in semiconductor :** The conductivity of the semiconductor is given by $\sigma = e(n_e\mu_e + n_h\mu_h)$
    where μ_e and μ_h are the electron and hole mobilities, n_e and n_h are the electron and hole densities, e is the electronic charge.
    - The conductivity of an intrinsic semiconductor is $\sigma_i = n_i e(\mu_e + \mu_h)$
    - The conductivity of n-type semiconductor is $\sigma_n = eN_d\mu_e$
    - The conductivity of p-type semiconductor is $\sigma_p = eN_a\mu_h$
- ***p-n* junction :** When donor impurities are introduced into one side and acceptors into the other side of a single crystal of an intrinsic semiconductor, a p-n junction is formed. It is also known as junction diode. The most important characteristic of a p-n junction is its ability to conduct current in one direction only. In the other (reverse) direction it offers very high resistance. It is symbolically represented by



  - **Depletion region :** In the vicinity of junction, the region containing the uncompensated acceptor and donor ions is known as depletion region. There is a depletion of mobile charges (holes and free electrons) in this region. Since this region has immobile (fixed) ions which are electrically charged it is also known as the space charge region. The electric field between the acceptor and the donor ions is known as a barrier. The physical distance from one side of the barrier to the other is known as the width of the barrier. The difference of potential from one side of the barrier to the other side is known as the height of the barrier.

- For a silicon *p-n* junction, the barrier potential is about 0.7 V, whereas for a germanium *p-n* junction it is approximately 0.3 V.
- The width of the depletion layer and magnitude of potential barrier depend upon the nature of the material of semiconductor and the concentration of impurity atoms. The thickness of the depletion region is of the order of one tenth of a micrometre.

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

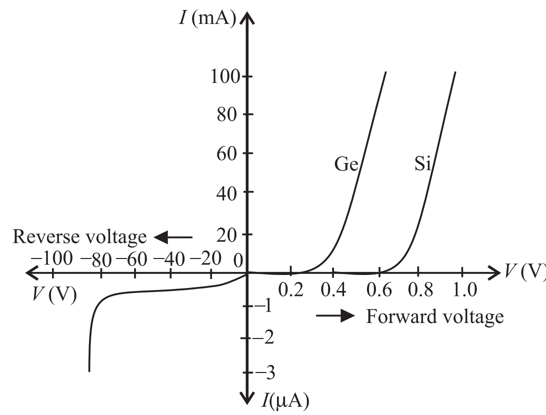
- In forward biasing, the width of the depletion region decreases and barrier height reduces.
- The resistance of the *p-n* junction becomes low in forward biasing.

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

- In reverse biasing, the width of the depletion region increases and barrier height increases.
- The resistance of the *p-n* junction becomes high in reverse biasing.

▶ **Breakdown voltage :** A very small current flows through *p-n* junction, when it is reverse biased. The flow of the current is due to the movement of minority charge carriers. The reverse current is almost independent of the applied voltage. However, if the reverse bias voltage is continuously increased, for a certain reverse voltage, the current through the *p-n* junction will increase abruptly. This reverse bias voltage is thus known as breakdown voltage. There can be two different causes for the breakdown. One is known as zener breakdown and the other is known as avalanche breakdown.

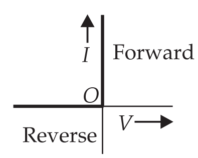
▶ ***I-V* characteristics of a *p-n* junction :** The *I-V* characteristics of a *p-n* junction do not obey Ohm's law. The *I-V* characteristics of a *p-n* junction are as shown in the figure.



- **Knee voltage :** In forward biasing, the voltage at which the current starts to increase rapidly is known as cut-in or knee voltage. For germanium it is 0.3 V while for silicon it is 0.7 V.
- **Dynamic resistance :** It is defined as the ratio of a small change in voltage (ΔV) applied across the *p-n* junction to a small change in current ΔI through the junction.

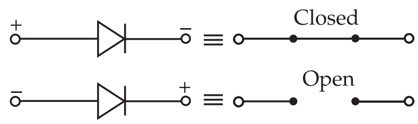
$$r_d = \frac{\Delta V}{\Delta I}$$

- **Ideal diode :** A diode permits only unidirectional conduction. It conducts well in the forward direction and poorly in the reverse direction. It would have been ideal if a diode acts as a perfect conductor (with zero voltage across it) when it is forward biased, and as a perfect insulator (with no current flows through it) when it is reverse biased. The *I-V* characteristics of an ideal diode as shown in figure.

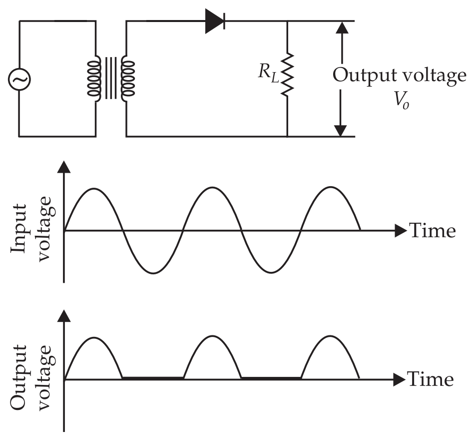


▶ An ideal diode acts like an automatic switch.

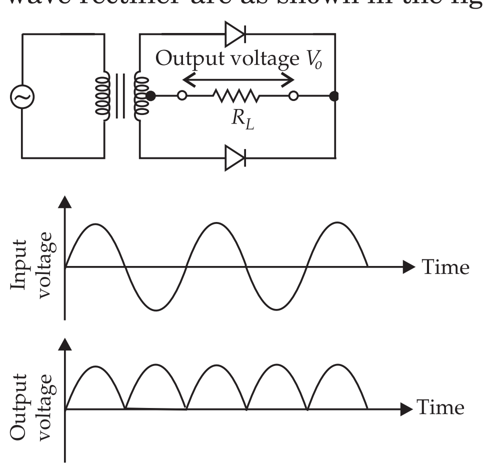
- In forward bias, it acts as a closed switch whereas in reverse bias it acts as an open switch as shown in the figure.



- **Rectifier :** It is a device which converts ac voltage to dc voltage. Diode is used as a rectifier. Rectifier is based on the fact that, a forward bias *p-n* junction conducts and a reverse bias *p-n* junction does not conduct.
  - **Half wave rectifier :** Diode conducts corresponding to positive half cycle and does not conduct during negative half cycle. Hence, *AC* is converted by diode into undirectional pulsating *DC*. This action is known as half-wave rectification.



  - **Full wave rectifier :** The circuit diagram, input and output waveforms for a full wave rectifier are as shown in the figure.

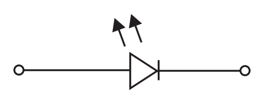


  - **Ripple factor :** The ripple factor is a measure of purity of the dc output of a rectifier, and is defined as

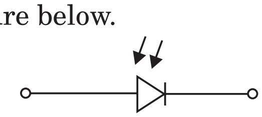
$$r = \frac{\text{rms value of the components of wave}}{\text{average or dc value}}$$

$$r = \sqrt{\left(\frac{I_{\text{rms}}}{I_{\text{dc}}}\right)^2 - 1}$$

- **Special Purpose *p-n* Junction Diodes :**
  - **Light emitting diode (LED) :** It converts electrical energy into light energy. It is a heavily doped *p-n* junction which operates under forward bias and emits spontaneous radiation.
    - The *I-V* characteristics of a LED is similar to that of Si junction diode. But the threshold voltages are much higher and slightly different for each colour. The reverse breakdown voltages of LEDs are very low, typically around 5 V.
    - The semiconductor used for fabrication of visible LEDs must at least have a band gap of 1.8 eV. The compound semiconductor gallium arsenide phosphide (GaAsP) is used for making LEDs of different colours. GaAs is used for making infrared LED.
    - The symbol of a LED is shown in the figure.



  - **Photodiode :** A photodiode is a special type *p-n* junction diode fabricated with a transparent window to allow light to fall on the diode. It is operated under reverse bias. When it is illuminated with light of photon energy greater than the energy gap of the semiconductor, electron-hole pairs are generated in near depletion region.
    - The symbol of a photodiode is shown in the figure below.



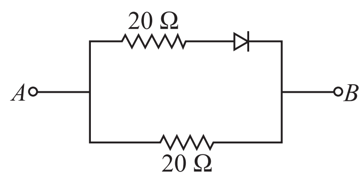
  - **Solar cell :** It converts solar energy into electrical energy. A solar cell is basically a *p-n* junction which generates emf when solar radiation falls on the *p-n* junction. It works on the same principle (photovoltaic effect) as the photodiode, except that no external bias is applied and the junction area is kept large.

Practice Time

OBJECTIVE TYPE QUESTIONS

Multiple Choice Questions (MCQs)

1. The equivalent resistance of the circuit shown in figure between the points A and B if $V_A < V_B$ is



(a) 10 Ω
(b) 20 Ω
(c) 5 Ω
(d) 40 Ω

2. Which of the following statements is correct?
(a) Hole is an antiparticle of electron.
(b) Hole is a vacancy created when an electron leaves a covalent bond.
(c) Hole is the absence of free electrons.
(d) Hole is an artificially created particle.

3. Which of the following statements is incorrect for the depletion region of a diode?
(a) There are 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 these.

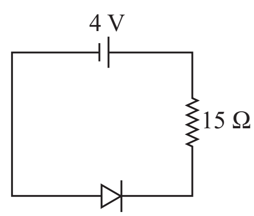
4. In an unbiased *p-n* junction, holes diffuse from the *p*-region to *n*-region because
(a) free electrons in the *n*-region attract them
(b) they move across the junction by the potential difference
(c) hole concentration in *p*-region is more as compared to *n*-region
(d) all of these.

5. A potential barrier of 0.3 V exists across a p-n junction. If the depletion region is 1 μm wide, what is the intensity of electric field in this region?
(a) 2×10^5 V m^{-1} (b) 3×10^5 V m^{-1}
(c) 4×10^5 V m^{-1} (d) 5×10^5 V m^{-1}

6. The dominant mechanism for motion of charge carriers in forward and reverse biased silicon *p-n* junction are
(a) drift in forward bias, diffusion in reverse bias
(b) diffusion in forward bias, drift in reverse bias
(c) diffusion in both forward and reverse bias
(d) drift in both forward and reverse bias.

7. When the voltage drop across a *p-n* junction diode is increased from 0.65 V to 0.70 V, the change in the diode current is 5 mA. The dynamic resistance of the diode is
(a) 20 Ω (b) 50 Ω (c) 10 Ω (d) 80 Ω

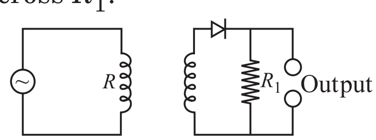
8. In the circuit shown if drift current for the diode is 20 μA, the potential difference across the diode is



(a) 2 V
(b) 4.5 V
(c) 4 V
(d) 2.5 V

9. If a small amount of antimony is added to germanium crystal
(a) its resistance is increased
(b) it becomes a *p*-type semiconductor
(c) there will be more free electrons than holes in the semiconductor
(d) none of these.

10. A sinusoidal voltage of rms value 220 V is applied to a diode and a resistor R in the circuit shown in figure, so that half wave rectification occurs. If the diode is ideal, what is the rms voltage across R_1?

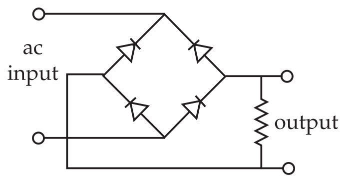


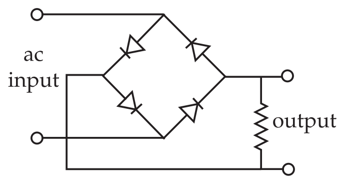
(a) $55\sqrt{2}$ V (b) 110 V
(c) $110\sqrt{2}$ V (d) $220\sqrt{2}$ V

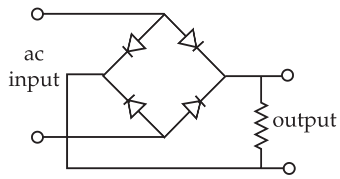
11. If the energy of a proton of sodium light (λ = 589 nm) equals the band gap of semiconductor, the minimum energy required to create hole electron pair

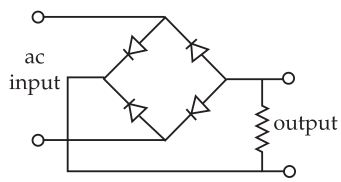
(a) 1.1 eV (b) 2.1 eV (c) 3.2 eV (d) 1.5 eV

12. Which of the following circuits provides full wave rectification of an ac input?

(a)


(b)


(c)


(d)


13. 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) $(E_g)_C > (E_g)_{Si} > (E_g)_{Ge}$

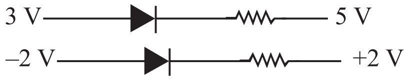
(d) $(E_g)_C = (E_g)_{Si} = (E_g)_{Ge}$

14. A forward biased diode is

(a)


(b)


(c)


(d)


15. Which of the following equations correctly represents the temperature variation of energy gap between the conduction and valence bands for Si?

(a) $E_g(T) = 0.70 - 2.23 \times 10^{-4}T$ eV

(b) $E_g(T) = 0.70 + 2.23 \times 10^{-4}T$ eV

(c) $E_g(T) = 1.10 - 3.60 \times 10^{-4}T$ eV

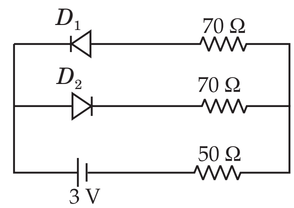
(d) $E_g(T) = 1.10 + 3.60 \times 10^{-4}T$ eV

16. The maximum wavelength of electromagnetic radiation, which can create a hole-electron pair in germanium. (Given that forbidden energy gap in germanium is 0.72 eV)

(a) 1.7×10^{-6} m (b) 1.5×10^{-5} m

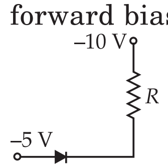
(c) 1.3×10^{-4} m (d) 1.9×10^{-5} m

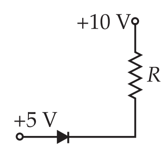
17. The circuit shown in the figure contains two diodes each with a forward resistance of 30 Ω and with infinite backward resistance. If the battery is 3 V, the current through the 50 Ω resistance (in ampere) is

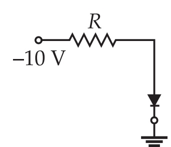


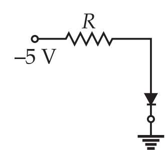
(a) zero (b) 0.01 (c) 0.02 (d) 0.03

18. Which of the junction diodes shown below are forward biased?

(a)


(b)


(c)


(d)


19. A potential barrier of 0.50 V exists in a *p-n* junction. If the depletion region is 5.0×10^{-7} m thick, what is the electric field in this region?

(a) 1×10^3 V m^{-1} (b) 1.0×10^6 V m^{-1}

(c) 1×10^2 V m^{-1} (d) 1×10^4 V m^{-1}

20. The breakdown in a reverse biased *p-n* junction diode is more likely to occur due to

(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

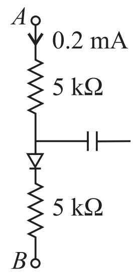
(c) strong electric field in a depletion region if the doping concentration is small

(d) none of these

21. In a full wave junction diode rectifier the input ac has rms value of 20 V. The transformer used is a step up transformer having primary and secondary turn ratio 1 : 2. The dc voltage in the rectified output is

(a) 12 V (b) 24 V (c) 36 V (d) 42 V

22. In a circuit as shown in the figure, if the diode forward voltage drop is 0.3 V, the voltage difference between A and B is



(a) 1.3 V
(b) 2.3 V
(c) 0
(d) 0.5 V

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

(a) 2×10^4 per m^3 (b) 2×10^2 per m^2
(c) 4×10^4 per m^3 (d) 4×10^2 per m^3

24. A p-n photodiode is made of a material with a band gap of 2 eV. The minimum frequency of the radiation that can be absorbed by the material is nearly (Take hc = 1240 eV nm)

(a) 1×10^{14} Hz (b) 20×10^{14} Hz
(c) 10×10^{14} Hz (d) 5×10^{14} Hz

25. A p-n photodiode is fabricated from a semiconductor with a band gap of 2.5 eV. The signal wavelength is

(a) 6000 Å (b) 6000 nm
(c) 4000 nm (d) 5000 Å

26. Potential barrier developed in a junction diode opposes the flow of

(a) minority carrier in both regions only
(b) majority carriers only
(c) electrons in p region
(d) holes in p region

27. In pure semiconductor, the number of conduction electrons is 6×10^{18} per cubic metre. How many holes are there in a sample of size 1 cm × 1 cm × 1 mm ?

(a) 3×10^{10} (b) 6×10^{11}
(c) 3×10^{11} (d) 6×10^{10}

28. Mobilities of electrons and holes in a sample of intrinsic germanium at room temperature are 0.54 m^2 V^{-1} s^{-1} and 0.18 m^2 V^{-1} s^{-1} respectively. If the electron and hole densities are equal to 3.6×10^{19} m^{-3}, the germanium conductivity is

(a) 4.14 S m^{-1} (b) 2.12 S m^{-1}
(c) 1.13 S m^{-1} (d) 5.6 S m^{-1}

29. The probability of electrons to be found in the conduction band of an intrinsic semiconductor of finite temperature

(a) increases exponentially with increasing band gap.
(b) decreases exponentially with increasing band gap.
(c) decreases with increasing temperature.
(d) is independent of the temperature and band gap.

30. 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

31. The following table provides the set of values of V and I obtained for a given diode. Let the characteristics to be nearly linear, over this range, the forward and reverse bias resistance of the given diode respectively are

	V	I
Forward biasing	2.0 V	60 mA
	2.4 V	80 mA
Reverse biasing	0 V	0 μA
	–2 V	–0.25 μA

(a) 10 Ω, 8×10^6 Ω (b) 20 Ω, 4×10^5 Ω
(c) 20 Ω, 8×10^6 Ω (d) 10 Ω, 10 Ω

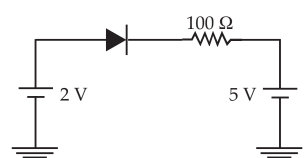
32. The mean free path of conduction electrons in copper is about 4×10^{-8} m. The electric field which can give on an average 2 eV energy to a conduction electron in a block of copper is

(a) 4×10^6 V m^{-1} (b) 5×10^7 V m^{-1}
(c) 10×10^7 V m^{-1} (d) 2.5×10^7 V m^{-1}

33. The value of ripple factor for full wave rectifier is

(a) 41% (b) 141%
(c) 48.2% (d) 121%

34. Current through the ideal diode as shown in figure is



(a) zero (b) 20 A (c) $\frac{1}{20}$ A (d) $\frac{1}{50}$ A

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

(a) 25 Hz (b) 50 Hz (c) 70.7 Hz (d) 100 Hz

Case Based MCQs

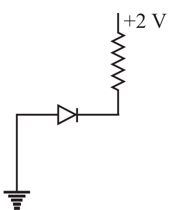
Case I : Read the passage given below and answer the following questions from 36 to 40.

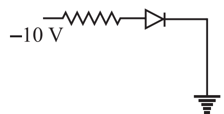
Biasing of Diode

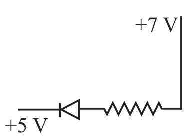
When the diode is forward biased, it is found that beyond forward voltage $V = V_k$, called knee voltage, the conductivity is very high. At this value of battery biasing for *p-n* junction,the potential barrier is overcome and the current increases rapidly with increase in forward voltage.

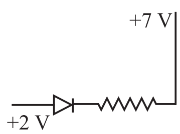
When the diode is reverse biased, the reverse bias voltage produces a very small current about a few microamperes which almost remains constant with bias. This small current is reverse saturation current.

36. In which of the following figures, the *p-n* diode is forward biased.

(a)


(b)


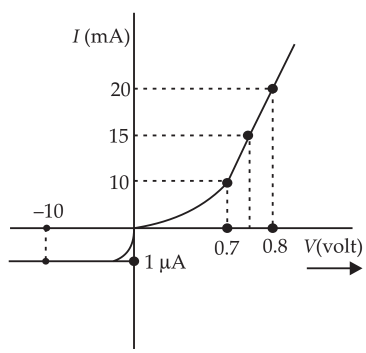
(c)


(d)


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

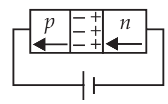
(a) bi-directional device
(b) ohmic device
(c) non-ohmic device
(d) passive element

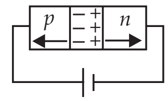
38. The *V-I* characteristic of a diode is shown in the figure. The ratio of forward to reverse bias resistance is

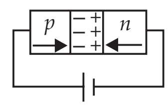


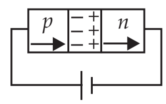
(a) 100 (b) 10^6 (c) 10 (d) 10^{-6}

39. In the case of forward biasing of a *p-n* junction diode, which one of the following figures correctly depicts the direction of conventional current (indicated by an arrow mark)?

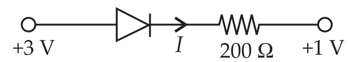
(a)


(b)


(c)


(d)


40. If an ideal junction diode is connected as shown, then the value of the current *I* is

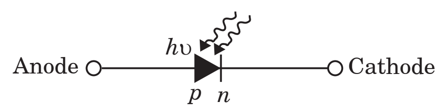


(a) 0.013 A (b) 0.02 A
(c) 0.01 A (d) 0.1 A

Case II : Read the passage given below and answer the following questions from 41 to 43.

Photodiode

A photodiode is an optoelectronic device in which current carriers are generated by photons through photo-excitation *i.e.*, photoconduction by light. It is a *p-n* junction fabricated from a photosensitive semiconductor and provided with a transparent window so as to allow light to fall on its junction. A photodiode can turn its current ON and OFF in nanoseconds. So, it can be used as a fastest photo-detector.



41. Photodiode is a device

(a) which is always operated in reverse bias.
(b) which is always operated in forward bias.
(c) in which photocurrent is independent of intensity of incident radiation.
(d) which may be operated in both forward or reverse bias.

42. To detect light of wavelength 500 nm, the photodiode must be fabricated from a semiconductor of minimum bandwidth of

(a) 1.24 eV (b) 0.62 eV
(c) 2.48 eV (d) 3.2 eV

43. Photodiode can be used as a photodetector to detect

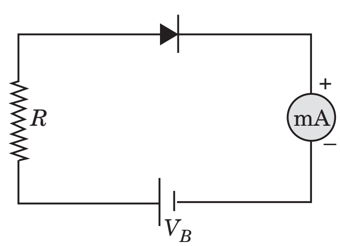
(a) optical signals (b) electrical signals
(c) both (a) and (b) (d) none of these.

Case III : Read the passage given below and answer the following questions from 44 to 48.

p-n Junction Diode

A silicon *p-n* junction diode is connected to a resistor R and a battery of voltage V_B through a milliammeter (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 *I-V* 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.



44. If $V_B = 5$ V, the maximum value of R so that the voltage V is above the knee point voltage is

(a) 40 kΩ (b) 4.3 kΩ
(c) 5.0 kΩ (d) 5.7 kΩ

45. If $V_B = 5$ V, the value of R in order to establish a current to 6 mA in the circuit is

(a) 833 Ω (b) 717 Ω
(c) 950 Ω (d) 733 Ω

46. If $V_B = 6$ V, the power dissipated in the resistor R, when a current of 6 mA flows in the circuit is

(a) 30.2 mW (b) 30.8 mW
(c) 31.2 mW (d) 31.8 mW

47. When the diode is reverse biased with a voltage of 6 V and $V_{bi} = 0.63$ V. Calculate the total potential.

(a) 9.27 V (b) 6.63 V
(c) 5.27 V (d) 0.63 V

48. Which of the below mentioned statement is false regarding a *p-n* junction diode?

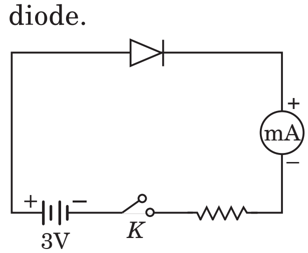
(a) Diodes are uncontrolled devices.
(b) Diodes are rectifying devices.
(c) Diodes are unidirectional devices.
(d) Diodes have three terminals.

Case IV : Read the passage given below and answer the following questions from 49 to 52.

Potential Barrier

The potential barrier in the *p-n* junction diode is the barrier in which the charge requires additional force for crossing the region. In other words, the barrier in which the charge carrier stopped by the obstructive force is known as the potential barrier.

When a *p*-type semiconductor is brought into a close contact with *n*-type semiconductor, we get a *p-n* junction with a barrier potential of 0.4 V and width of depletion region is 4.0×10^{-7} m. This *p-n* junction is forward biased with a battery of voltage 3 V and negligible internal resistance, in series with a resistor of resistance R, ideal millimeter and key K as shown in figure. When key is pressed, a current of 20 mA passes through the diode.



49. The intensity of the electric field in the depletion region when *p-n* junction is unbiased is

(a) 0.5×10^6 V m^{-1} (b) 1.0×10^6 V m^{-1}
(c) 2.0×10^6 V m^{-1} (d) 1.5×10^6 V m^{-1}

50. The resistance of resistor R is

(a) 150 Ω (b) 300 Ω
(c) 130 Ω (d) 180 Ω

51. If the voltage of the potential barrier is V_0. A voltage V is applied to the input, at what moment will the barrier disappear?

(a) $V < V_0$ (b) $V = V_0$
(c) $V > V_0$ (d) $V << V_0$

52. If an electron with speed 4.0×10^5 m s^{-1} approaches the *p-n* junction from the *n*-side, the speed with which it will enter the *p*-side is

(a) 1.39×10^5 m s^{-1} (b) 2.78×10^5 m s^{-1}
(c) 1.39×10^6 m s^{-1} (d) 2.78×10^6 m s^{-1}

Assertion & Reasoning Based MCQs

For question numbers 53-60, two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.

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

(b) Both A and R are true but R is NOT the correct explanation of A

(c) A is true but R is false

(d) A is false and R is also false

53. Assertion (A) : The conductivity of a semiconductor increases with rise of temperature.
Reason (R) : On rising temperature covalent bonds of semiconductor breaks.

54. Assertion (A) : *p-n* junction diode can be used even at ultra high frequencies.
Reason (R) : Capacitative reactance of a *p-n* junction diode increases as frequency increases.

55. Assertion (A) : The resistance of *p-n* junction is low when forward biased and is high when reverse biased.
Reason (R) : In reversed biased, the depletion layer is reduced.

56. Assertion (A) : The direction of diffusion current in a junction diode is from *n*-region to *p*-region.
Reason (R) : The majority current carriers diffuse from a region of lower concentration to a region of higher concentration.

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

58. 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.

59. Assertion (A) : The ratio of free electrons to holes in intrinsic semiconductor is greater than one.
Reason (R) : The electrons are lighter particles and holes are heavy particles.

60. Assertion (A) : In a semiconductor diode, the reverse biased current is due to drift of free electrons and holes.
Reason (R) : The drift of electrons and holes is due to thermal excitations.

SUBJECTIVE TYPE QUESTIONS

Very Short Answer Type Questions (VSA)

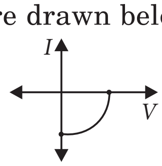
1. What is the difference between an *n*-type and a *p*-type extrinsic semiconductor?

2. What happens to the width of depletion layer of a *p-n* junction when it is (i) forward biased, (ii) reverse biased ?

3. Why cannot we use Si and Ge in fabrication of visible LEDs?

4. What is the function of a photodiode ?

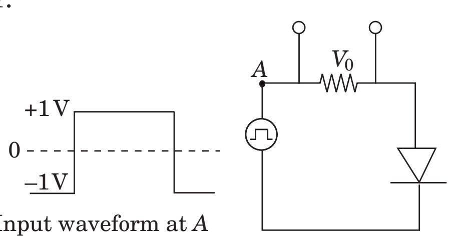
5. Name the junction diode whose I-V characteristics are drawn below :



6. In an *n*-type semiconductor, where does the donor energy level lies.

7. Can the potential barrier across a *p-n* junction be measured by simply connecting a voltmeter across the junction?

8. Draw the output waveform across the resistor.



Input waveform at *A*

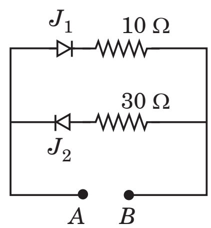
9. Why are elemental dopants for Silicon or Germanium usually chosen from group XIII or group XV?

10. How does an increase in doping concentration affect the width of depletion layer of a *p*-*n* junction diode?

Short Answer Type Questions (SA-I)

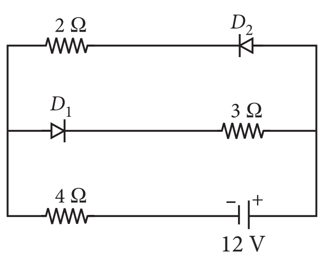
11. The number densities of electrons and hole in pure Si at 27°C is 2×10^{16} m^{-3}. When it is doped with indium, the hole density increases to 4×10^{22} m^{-3}, find the electron density in doped silicon.

12. A 3 V battery may be connected across the points *A* and *B* as shown. Assuming ideal diode, find the current supplied by battery if the positive terminal of the battery is connected to the point *A*.



13. Why photodiodes are required to operate in reverse bias ? Explain.

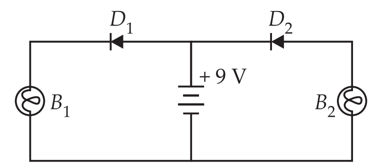
14. The circuit shown in the figure has two oppositely connected ideal diodes connected in parallel. Find the current flowing through each diode in the circuit.



15. Draw *V*-*I* characteristics of a *p*-*n* junction diode. Explain, why the current under reverse bias is almost independent of the applied voltage up to the critical voltage.

16. (a) Mention the important considerations required while fabricating a *p*-*n* junction diode to be used as a light emitting diode (LED).
(b) What should be the order of band gap of an LED if it is required to emit light in the visible range?

17. (a) In the following diagram, which bulb out of B_1 and B_2 will glow and why?

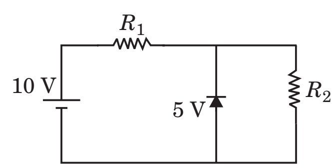


(b) If the forward voltage in a semiconductor diode is changed from 0.5 V to 0.7 V, then the forward current changes by 1.0 mA. Find the forward resistance of diode junction.

18. 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?

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

20. What is the current flowing in R_2 in the circuit shown in figure? Given : R_1 = 500 Ω and R_2 = 1 kΩ

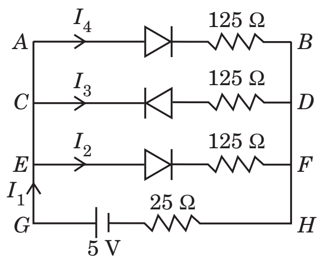


Short Answer Type Questions (SA-II)

21. (a) Distinguish between *n*-type and *p*-type semiconductors on the basis of energy band diagrams.
(b) Compare their conductivities at absolute zero temperature and at room temperature.

22. Name the important process that occur 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'.

23. 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 the current I_1, I_2, I_3 and I_4?



24. Suppose a 'n'-type wafer is created by doping Si crystal having 5×10^{28} atoms/m^3 with 1 ppm concentration of As. On the surface 200 ppm Boron is added to create 'p' region in this wafer. Considering $n_i = 1.5 \times 10^{16}$ m^{-3},

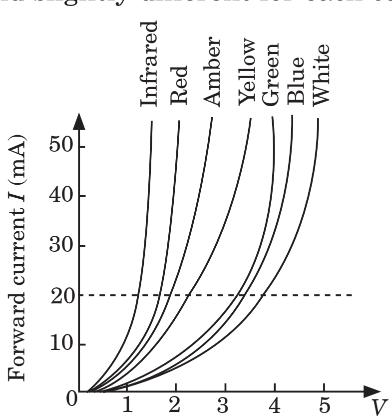
(a) Calculate the densities of the charge carriers in the n and p regions.

(b) Comment which charge carriers would contribute largely for the reverse saturation current when diode is reverse biased.

25. With the help of a simple diagram, explain the working of a silicon solar cell giving all three basic processes involved.

26. Direction : Read the following and answer the questions given below.

Light emitting diode is a photoelectric device which converts electrical energy into light energy. It is a heavily doped p-n junction diode which under forward biased emits spontaneous radiation. The general shape of the I-V characteristics of an LED is similar to that of a normal p-n junction diode, as shown. The barrier potentials are much higher and slightly different for each colour.

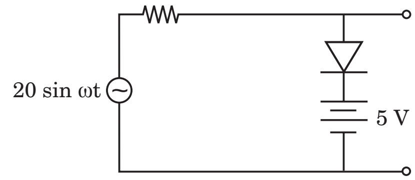


(i) Draw the I-V characteristic of an LED.

(ii) Draw the schematic symbol of light emitting diode (LED).

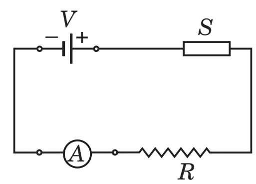
(iii) An LED is constructed from a p-n junction based on a certain Ga-As-P semiconducting material whose energy gap is 1.9 eV. Identify the colour of the emitted light.

(iv) Assuming the ideal diode, draw the output waveform for the circuit given in figure. Explain the waveform.



27. In half-wave rectification, what is the output frequency if the input frequency is 50 Hz. What is the output frequency of a full-wave-rectifier for the same input frequency?

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.



29. (a) Why are Si and GaAs preferred materials for fabrication in solar cells?

(b) Draw V-I characteristic of solar cell and mention its significance.

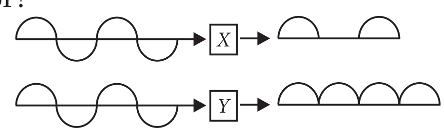
30. Explain, with the help of a circuit diagram, the working of a photodiode. Write briefly how it is used to detect the optical signals.

31. 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 $n_i = 1.5 \times 10^{16}$ m^{-3}. Is the material n-type or p-type?

32. In the case of n-type Si-semiconductor, the donor energy level is slightly below the bottom of conduction band whereas in p-type semiconductor, the acceptor energy level is slightly above the top of valence band. Explain, giving examples, what role do these energy levels play in conduction and valence bands.

Long Answer Type Questions (LA)

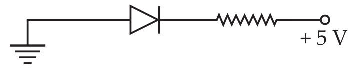
33. An a.c. signal is fed into two circuits 'X' and 'Y' and the corresponding output in the two cases have the waveforms as shown in figure.
(a) Identify the circuits 'X' and 'Y'. Draw their labelled circuit diagrams.
(b) Briefly explain the working of circuit Y.
(c) How does the output waveform from circuit Y get modified when a capacitor is connected across the output terminals parallel to the load resistor?



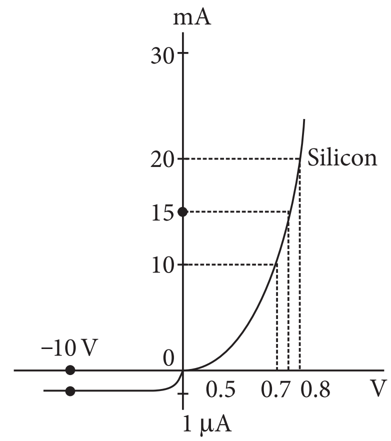
34. Draw the circuit arrangement for studying the V-I characteristics of a p-n junction diode in (i) forward and (ii) reverse bias. Briefly explain how the typical V-I characteristics of a diode are obtained and draw these characteristics.

35. Draw the circuit diagram of a p-n diode used as a half-wave rectifier. Explain its working.

36. (a) In the following diagram, is the junction diode forward biased or reverse biased?



(b) The V-I characteristic 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



ANSWERS

OBJECTIVE TYPE QUESTIONS

1. (b) : When $V_A < V_B$, the diode gets reverse biased and offers infinite resistance. No current flows through the upper branch

$\therefore$ $R = 20\ \Omega$

2. (b) : A vacancy created when an electron leaves a covalent bond. This vacancy is known as hole.

3. (a)

4. (c) : In an unbiased p-n junction, the diffusion of charge carriers across the junction takes place from higher concentration to lower concentration. Thus, option (c) is correct.

5. (b) : Electric field

$$E = \frac{V}{d} = \frac{0.3}{1\times10^{-6}} = 3 \times 10^5\ \text{V m}^{-1}$$

6. (b) : 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 it is reverse biased.

7. (c) : Dynamic resistance, $r_d = \dfrac{\Delta V}{\Delta I}$

$$r_d = \frac{0.7\ \text{V} - 0.65\ \text{V}}{5\times10^{-3}\ \text{A}} = \frac{0.05\times1000}{5}\ \Omega = 10\ \Omega$$

8. (c) : Since the diode is reversed biased, only drift current exists in circuit which is 20 μA. Potential drop across 15 Ω resistor

$= 15\ \Omega \times 20\ \mu\text{A} = 300\ \mu\text{V} = 0.0003\ \text{V}$

Potential difference across the diode = 4 – 0.0003 $= 3.99 \simeq 4$ V

9. (c) : Adding fifth group element to germanium makes it an n-type semiconductor. Antimony is a fifth group element and so germanium becomes n-type semiconductor.

10. (c)

11. (b) : Using, $E = E_g = \dfrac{hc}{\lambda} = \dfrac{6.6\times10^{-34}\times3\times10^{8}}{589\times10^{-9}}$ J

$$= \frac{6.6\times10^{-34}\times3\times10^{8}}{589\times10^{-9}\times1.6\times10^{-19}}\ \text{eV} = 2.1\ \text{eV}$$

12. (d) **13. (c)**

14. (a) : A diode is said to be forward biased if p-type semiconductor of p-n junction is at high potential with respect to n-type semiconductor of p-n junction. It is so for circuit (a).

15. (c) : The energy gap E_g depends on the temperature.
For silicon, $E_g(T) = 1.10 - 3.60 \times 10^{-4} T$ eV
For germanium, $E_g(T) = 0.70 - 2.23 \times 10^{-4} T$ eV

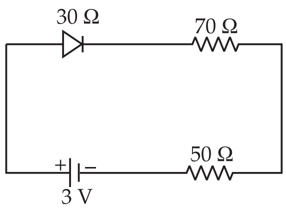
16. (a) : Here, $E_g = 0.72$ eV $= 0.72 \times 1.6 \times 10^{-19}$ J

If λ is the maximum wavelength of electromagnetic radiation which can create a hole-electron pair in germanium, then

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

or $$\lambda = \frac{hc}{E_g} = \frac{6.62\times10^{-34}\times3\times10^{8}}{0.72\times1.6\times10^{-19}} = 1.7\times10^{-6}\,\text{m}$$

17. (c) : In the circuit, the upper diode D_1 is reverse biased and the lower diode D_2 is forward biased. Thus there will be no current across upper diode junction. The effective circuit will be as shown in figure.



Total resistance of circuit

$R = 50 + 70 + 30 = 150\ \Omega$

Current in circuit, $I = \frac{V}{R} = \frac{3\text{ V}}{150\ \Omega} = 0.02$ A

18. (a) : The *p-n* junction diode is forward biased when *p* is at high potential with respect to *n*. Hence option (a) is correct.

19. (b) : Electric field, $E = \frac{V}{d} = \frac{0.50\text{ V}}{5\times10^{-7}} = 1.0\times10^{6}\ \text{V m}^{-1}$

20. (b) : In reverse biasing, the minority charge carriers will be accelerated due to reverse biasing, which on striking with atoms cause ionisation resulting in secondary electrons and thus produce more number of charge carriers.

When doping concentration is large, there will be large number of ions in the depletion region, which will give rise to a strong electric field.

21. (c) : Here, input $V_{\text{rms}} = 20$ V

Peak value of input voltage

$V_o = \sqrt{2}\,V_{rms} = \sqrt{2}\times20 = 28.28$ V

Since the transformer is a step up transformer having transformer ratio 1 : 2, the maximum value of output voltage of the transformer applied to the diode will be

$$V_0' = 2\times V_o = 2\times28.28\ \text{V}$$

$\therefore$ dc voltage $= \frac{2V_0'}{\pi} = \frac{2\times2\times28.28}{22/7} = 36$ V

22. (b) : Let V be the potential difference between A and B, then

$V - 0.3 = (5 + 5) \times 10^3 \times (0.2 \times 10^{-3}) = 2$

or $V = 2 + 0.3 = 2.3$ V

23. (c) : As, $n_e n_h = n_i^2$

Here, $n_i = 6 \times 10^8$ per m^3 and $n_e = 9 \times 10^{12}$ per m^3

$$\therefore\ n_h = \frac{n_i}{n_e} = \frac{(6\times10^{8})^2}{9\times10^{12}} = 4\times10^{4}\ \text{per m}^3$$

24. (d) : Here, $E_g = 2$ eV

Wavelength of radiation corresponding to this energy is

$$\lambda = \frac{hc}{E_g} = \frac{1240\text{ eV nm}}{2\text{ eV}} = 620\text{ nm}$$

Frequency $\upsilon = \frac{c}{\lambda} = \frac{3\times10^{8}\text{ m s}^{-1}}{620\times10^{-9}\text{m}} = 5 \times 10^{14}$ Hz

25. (d) : The detection occurs only when the energy of incident photon greater than or equal to the energy band gap

$$\frac{hc}{\lambda} = 2.5\text{ eV}$$

$$\therefore\ \lambda = \frac{hc}{2.5\text{ eV}} = \frac{1240\text{ eV}}{2.5\text{ eV}}\text{nm} = 496\text{ nm} \simeq 5000\text{ Å}$$

26. (b) : Potential barrier developed in a junction diode opposes the majority carriers only.

27. (b) : Here, $n_e = 6 \times 10^{18}$ m^{-3}

Volume of the sample = 1 cm × 1 cm × 1 mm = 10^{-7} m^3

Number of holes in the sample = Number of electrons in the sample

$= n_e \times V = 6 \times 10^{18} \times 10^{-7} = 6 \times 10^{11}$

28. (a) : As $\sigma = e(n_e\mu_e + n_h\mu_h) = en_i(\mu_e + \mu_h)$

$= 1.6 \times 10^{-19} \times 3.6 \times 10^{19}(0.54 + 0.18) = 4.147$ S m^{-1}

29. (b)

30. (c) : $E_g = \frac{hc}{\lambda} = \frac{1240\text{ eV nm}}{2480\text{ nm}} = 0.5$ eV

31. (c) : For forward biasing,

$\Delta V = 2.4 - 2.0 = 0.4$ V; $\Delta I = 80 - 60 = 20$ mA

$$\therefore\ r_{fb} = \frac{\Delta V}{\Delta I} = \frac{0.4}{20\times10^{-3}} = 20\ \Omega$$

For reverse biasing, $\Delta V = -2 - 0 = -2$ V

$\Delta I = -0.25 - 0 = -0.25\ \mu$A

$$r_{rb} = \frac{-2}{-0.25\times10^{-6}} = 8\times10^{6}\ \Omega$$

32. (b) : The work done on an electron when it moves through distance, $d = eEd$

Work done is equal to the energy transferred to the electron

$\therefore\ eEd = 2$ eV

$$\Rightarrow\ E = \frac{2\text{ V}}{d} = \frac{2\text{ V}}{4\times10^{-8}\text{ m}} = 5\times10^{7}\ \text{V m}^{-1}$$

33. (c) : Ripple factor for full wave rectifier = 0.482.

Expressed in %, it is 48.2%.

34. (a) : Here, *p-n* junction is reverse biased. Therefore, the current flowing through *p-n* junction is zero.

35. (b) : Since the output voltage obtained in a half-wave rectifier circuit has single variation in one cycle of ac voltage, hence the fundamental frequency in the ripple of output voltage would be 50 Hz.

36. (c) : The *p-n* diode is forward biased when *p*-side is at a higher potential than *n*-side.

37. (c)

38. (d) : Forward bias resistance,

$$R_1 = \frac{\Delta V}{\Delta I} = \frac{0.8-0.7}{(20-10)\times10^{-3}} = \frac{0.1}{10\times10^{-3}} = 10$$

Reverse bias resistance, $R_2 = \dfrac{10}{1\times10^{-6}} = 10^7$

Then, the ratio of forward to reverse bias resistance,

$$\frac{R_1}{R_2} = \frac{10}{10^7} = 10^{-6}$$

39. (d) : In *p*-region the direction of conventional current is same as flow of holes.

In *n*-region the direction of conventional current is opposite to the flow of electrons.

40 (c) : In the given circuit the junction diode is forward biased and offers zero resistance.

$\therefore$ The current, $I = \dfrac{3\,\text{V}-1\,\text{V}}{200\,\Omega} = \dfrac{2\,\text{V}}{200\,\Omega} = 0.01\,\text{A}$

41. (a) : Photodiode is a device which is always operated in reverse bias.

42. (c) : Let E_g be the required bandwidth. Then

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

Here, hc = 1240 eV nm, λ = 500 nm

$$\therefore \quad E_g = \frac{1240\,\text{eV nm}}{500\,\text{nm}} = 2.48\,\text{eV}$$

43. (a) : A photodiode is a device which is used to detect optical signals.

44. (b) : Voltage drop across R,

$V_R = V_B - V_N = 5 - 0.7 = 4.3$ V

Here, $I_{min} = 1 \times 10^{-3}$ A

$$\therefore \quad R_{max} = \frac{V_R}{I_{min}} = \frac{4.3}{1\times10^{-3}} = 4.3\times10^3\,\Omega = 4.3\text{ k}\Omega$$

45. (b) : I = 6 mA = 6×10^{-3} A;

$V_R = V_B - V_N = 5 - 0.7 = 4.3$ V

$$R = \frac{V_R}{I} = \frac{4.3}{6\times10^{-3}} = 717\,\Omega$$

46. (d) : Here, V_B = 6 V; V_N = 0.7 V,

$V_R = 6 - 0.7 = 5.3$ V

Power dissipated in $R = I \times V_R$

$= (6 \times 10^{-3}) \times 5.3 = 31.8 \times 10^{-3}$ W = 31.8 mW

47. (b) : $V_t = V_{bi} + V_R = 0.63 + 6 = 6.63$ V

48. (d) : Diode is two terminal device, anode and cathode are the two terminals.

49. (b) : $E = \dfrac{V_B}{d} = \dfrac{0.4}{4.0\times10^{-7}} = 1.0\times10^6\text{ V m}^{-1}$

50. (c) : Potential difference across R = 3 – 0.4 = 2.6 V

Resistance $R = \dfrac{\text{Potential difference}}{\text{Current}} = \dfrac{2.6}{20\times10^{-3}} = 130\ \Omega$

51. (b) : When the voltage will be the same as that of the potential barrier, the potential barrier will disappear resulting in flow of current.

52. (a) : $\dfrac{1}{2}mv_1^2 = eV_B + \dfrac{1}{2}mv_2^2$

$$\Rightarrow \quad \frac{1}{2}\times(9.1\times10^{-31})\times(4\times10^5)^2$$

$$= 1.6\times10^{-19}\times(0.4) + \frac{1}{2}\times9.1\times10^{-31}\times v_2^2$$

On solving, we get

$v_2 = 1.39 \times 10^5$ m s^{-1}

53. (c) : At 0 K, all semiconductors are insulators. The valence band at 0 K is completely filled and there are no free electrons in conduction band. At room temperature due to thermal energy, the electron jump to the conduction band. When the temperature increases, a large number of electrons cross over the forbidden gap and jump from valence band to conduction band. Thus with rise in temperature conductivity increases. The covalent bonds of semiconductor breaks only when it is heated up extremely either by increasing temperature or by supplying strong current. After which it behaves like conductor and no longer possesses the property of low conduction, hence it is said to be damaged.

54. (c) : As capacitative reactance,

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi\upsilon C} \textit{ i.e., } X_C \propto \frac{1}{\upsilon}$$

Thus, capacitative reactance decreases on increase in frequency.

55. (c) : A small increase in forward voltage across *p-n* junction shows large increase in forward current. Hence the resistance (= voltage / current) of *p-n junction* is low when forward biased. Also the width of depletion layer of *p-n* junction decreases in forward bias.

A large increase in reverse voltage across *p-n* shows small increase in reverse current. Hence the resistance of *p-n* junction is high when reverse biased. Also the width of the depletion layer of *p-n* junction increases in reverse biased.

56. (d) : The direction of diffusion current is that when positively charged particles move from *p*-type to *n*-type of diode.

57. (d) : With the increase of temperature, the average energy exchanged in a collision increases and so more valence electrons can cross the energy gap, thereby increasing the electron-hole pairs. As in a semiconductor, conduction occurs mainly through electron-hole pairs, so conductivity increases with increase of temperature. Which in turn implies that the resistivity of a semiconductor decreases with rise in temperature.

58. (a) : In half wave rectifier, the one diode is biased only when ac is in positive half of its cycle. For negative half of the 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.

59. (b) : In intrinsic semiconductor $n_e/n_h = 1$ and holes are not particles but vacancies created due to breakage of covalent bond.

60. (b) : A reverse bias on a *p*-*n* junction opposes the movement of the majority charge carriers thus stopping the diffusion current. It makes the free electrons and holes to drift cross the junction. Therefore a small current in μA flows even when the *p*-*n* junction is reverse biased. The drift current is due to the thermal excitations of the electrons and holes.

SUBJECTIVE TYPE QUESTIONS

1.

	n-type Semiconductor	*p*-type Semiconductor
(i)	It is formed by doping pentavalent impurities.	It is formed by doping 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. ($n_h >> n_e$)

2. (i) Forward biased : As forward voltage opposes the potential barrier and effective barrier potential decreases. It makes the width of the depletion layer smaller.

(ii) Reverse biased : As reverse voltage supports the potential barrier and effective barrier potential increases. It makes the width of the depletion layer larger.

3. LED's must have band gap in the order of 1.8 eV to 3 eV but Si and Ge have band gap less than 1.8 eV.

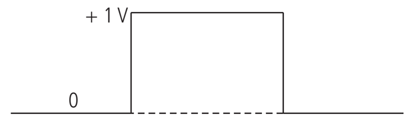
4. Photodiode is used to detect the light signal and to measure light intensity.

5. The junction diode is solar cell.

6. (b) : In *n*-type semiconductor, the donor energy level lies just below the conduction band.

7. No, the voltmeter should have a very high resistance as compared to the resistance of *p*-*n* junction, which is nearly infinite.

8.



The diode acts as half wave rectifier, it offers low resistance when forward biased and high resistance when reverse biased.

9. Size of the dopant atom should be compatible in the pure semiconductor and contribute a charge carrier by forming covalent bond with Si or Ge atoms. Elemental dopants from group XIII and group XV fulfil this condition.

10. When there is an increase in doping concentration, the applied potential difference causes an electric field which acts opposite to the potential barrier. This results in reducing the potential barrier and hence the width of depletion layer decreases.

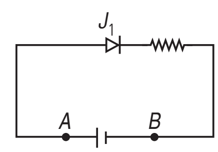
11. For extrinsic or doped semiconductor

$$n_e \cdot n_h = n_i^2 \Rightarrow n_e = \frac{n_i^2}{n_h}$$

Here $n_i = 2 \times 10^{16}$ m^{-3} and $n_h = 4 \times 10^{22}$ m^{-3}

$$\Rightarrow \quad n_e = \frac{(2\times10^{16}\,\text{m}^{-3})^2}{4\times10^{22}\,\text{m}^{-3}} = 10^{-10}\ \text{m}^{-3}.$$

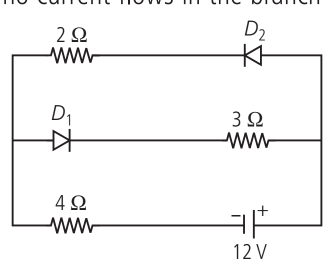
12. If *A* is positive and *B* is negative, J_1 is forward biased and J_2 is reverse biased, so effective current is



$\Rightarrow \quad i_a = = 0.3$ A.

13. In reverse bias condition of photodiode, the change in saturation reverse current is directly proportional to the change in the incident light flux or light intensity, which can be measured accurately. It is not so when photodiode is forward biased.

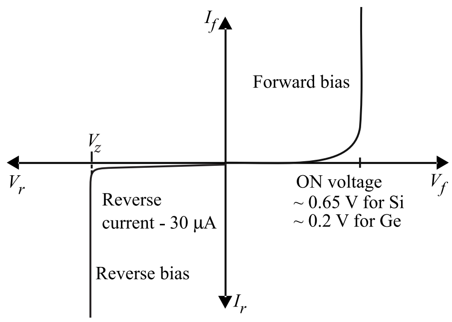
14. Diode D_1 is reverse biased,so it offers an infinite resistance. So no current flows in the branch of diode D_1.



Diode D_2 is forward biased, and offers negligible resistance in the circuit. So current in the branch

$$I = \frac{V}{R_{eq}} = \frac{12\text{V}}{2\Omega + 4\Omega} = 2\text{A}$$

15.



The reverse current is due to minority charge carriers and even a small voltage is sufficient to sweep the minority carriers from one side of the junction to the other side of the junction. Here the current is not limited by the magnitude of the applied voltage but is limited due to the concentration of the minority carrier on either side of the junction.

16. (a) (i) There is very little resistance to limit the current in LED. Therefore, a resistor must be used in series with the LED to avoid any damage to it.

(ii) The reverse breakdown voltages of LEDs are very low, typically around 5 V. So care should be taken while fabricating a *p-n*-junction diode so that the *p* side should only attached to the positive of battery and vice versa as LED easily get damaged by a small reverse voltage.

(b) The semiconductor used for fabrication of visible LEDs must have at least a band gap of 1.8 eV because spectral range of visible light is about 0.4 mm to 0.7 mm, *i.e.*, about 3 eV to 1.8 eV.

17. (a) Bulb B_1 will glow, as diode D_1 is forward biased. Bulb B_2 will not glow as diode D_2 is reverse biased.

(b) Forward resistance = $\dfrac{\Delta V}{\Delta I}$

$$\therefore \quad \frac{\Delta V}{\Delta I} = \frac{0.7-0.5}{1.0\times10^{-3}} = 200\ \Omega.$$

18. We know that, energy of incident photon, $E = \dfrac{hc}{\lambda}$

λ = 6000 Å = 600 nm (given)

$$E = \frac{1242\text{ eV nm}}{600\text{ nm}} = 2.07\text{ eV}$$

D_2 will detect these radiations because energy of incident radiation is greater than the band gap.

19. Energy of the incident photon with a band gap of 6000 nm.

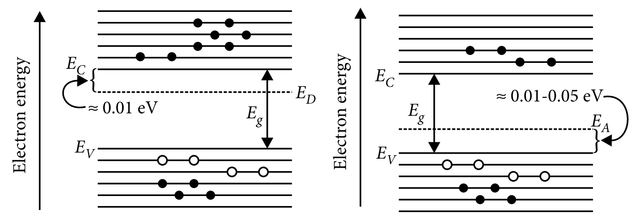
$$E = \frac{hc}{\lambda}\text{ J} = \frac{hc}{e\lambda}\text{eV} = \frac{6.63\times10^{-34}\times3\times10^{8}}{1.6\times10^{-19}\times6\times10^{-6}} = 0.207\text{ eV}$$

The photodiode need an energy of 2.8 eV to give response to incident light.

As $E < E_g$, the given photodiode cannot detect the radiation of wavelength 6000 nm.

20. The diode is reverse biased, but the voltage across it is given as 5 V. R_2 is in parallel with the diode, so current in R_2 $= \dfrac{5\text{ V}}{1000\ \Omega} \Rightarrow$ Current in R_2 = 5 mA.

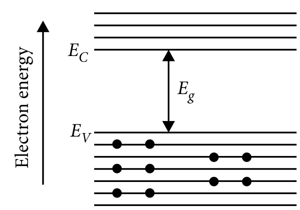
21. (a) The required energy band diagrams are given below:



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

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

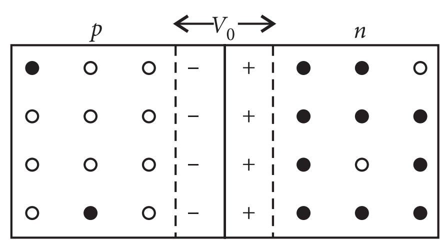
(b)



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

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

22. Two processes that take place in the formation of a *p-n* junction are diffusion and drift.



When *p-n* junction is formed, then at the junction, free electrons from *n*-type diffuse over to *p*-type, thereby filling in the holes in *p*-type. Due to this a layer of positive charge is built on *n*-side and a layer of negative charge is built on *p*-side of the *p-n* junction. This layer sufficiently grows up within a very short time of the junction being formed, preventing any further movement of charge carriers (*i.e.*, electrons and holes) across the junction. Thus a potential difference V_0 of the order of 0.1 to 0.3 V is set up across the *p-n* junction called potential barrier or junction barrier. The thin region around the junction containing immobile positive and negative charges is known as depletion layer.

23. Let R be the effective resistance of the circuit, then

$R = R_{AB} || R_{EF} + 25$

$R_{AB} = 125 + 25 = 150\ \Omega$

$R_{EF} = 125 + 25 = 150\ \Omega$

$\therefore\quad R = 25 + \dfrac{150}{2} = 100\ \Omega$

Since diode in the branch CD is reverse biased. $I_3 = 0$.

Current, $I_1 = \dfrac{5}{100} = 0.05$ A

According to Kirchhoff's current rule,

$I_1 = I_2 + I_3 + I_4$ or $I_2 + I_4 = I_1 = 0.05$

$\because\quad R_{AB} = R_{EF}$, so, $I_4 = I_2$

$2I_4 = 2I_2 = 0.05$

$I_4 = I_2 = \dfrac{0.05}{2} = 0.025$ A

24. (a) For n-type region,

$$n_e = N_D = \frac{1}{10^6} \times 5 \times 10^{28} = 5 \times 10^{22}\ \text{m}^{-3} \qquad \left(\because\ 1\ \text{ppm} = \frac{1}{10^6}\right)$$

As $n_e n_h = n_i^2$,

$$n_h = \frac{n_i^2}{n_e} = \frac{(1.5 \times 10^{16}\ \text{m}^{-3})^2}{5 \times 10^{22}\ \text{m}^{-3}} = 0.45 \times 10^{10}\ \text{m}^{-3}$$

For p-type region,

$$n_h = N_A = \frac{200}{10^6} \times 5 \times 10^{28} = 1 \times 10^{25}\ \text{m}^{-3}$$

Now, $n_e = \dfrac{n_i^2}{n_h} = \dfrac{(1.5 \times 10^{16}\ \text{m}^{-3})^2}{1 \times 10^{25}\ \text{m}^{-3}} = 2.25 \times 10^7\ \text{m}^{-3}$

(b) The minority carrier holes of n-region wafer ($n_h = 0.45 \times 10^{10}\ \text{m}^{-3}$) would contribute more to reverse saturation current than minority carrier electrons of p–region wafer ($n_e = 2.25 \times 10^7\ \text{m}^{-3}$) when $p - n$ junction is reverse biased.

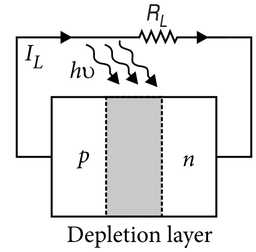
25. Principle : A solar cell works on the principle of photovoltaic effect according to which when light photons of energy greater than energy band gap of a semiconductor are incident on p-n junction of that semiconductor, electron-hole pairs are generated which give rise to an emf.

Generation of emf : Three basic processes are involved in the generation of emf by a solar cell when solar radiations are incident on it. These are:

(i) The generation of electron-hole pairs close to the junction due to incidence of light with photo energy $h\upsilon \geq E_b$.

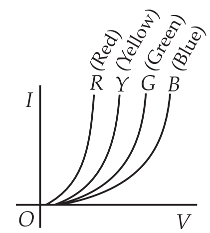
(ii) The separation of electrons and holes due to the electric field of the depletion region. So, electrons are swept to n-side and holes to p-side.

(iii) 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 become negative giving rise to a photovoltage.

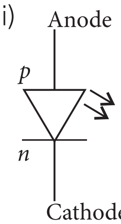


When an external load R_L is connected as shown in figure, a photocurrent I_L begins to flow through the load.

26. (i) The I-V characteristics of an LED is similar to that of a Si junction diode. But the threshold voltages are much higher and slightly different for each colour.



(ii)



(iii) As $E_g = \dfrac{hc}{\lambda}\quad \therefore\ \lambda = \dfrac{hc}{E_g}$

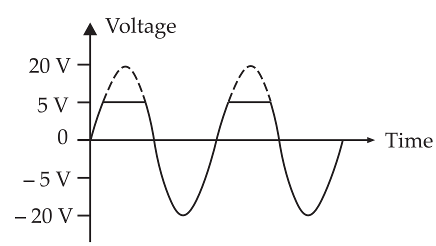
Here, $E_g = 1.9$ eV, $hc = 1240$ eV nm

$\therefore\quad \lambda = \dfrac{1240\ \text{eV nm}}{1.9\ \text{eV}} = 652.6$ nm

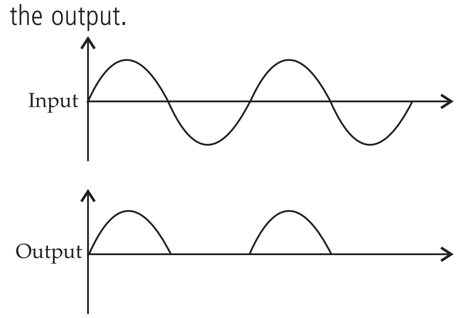
Hence, the emitted light is of red colour.

(iv) For the voltage less than 5 V, the diode is reverse biased and circuit will act as open circuit.

When input voltage is greater than 5 V, diode is in conducting state.



27. In half wave rectification, only one ripple is obtained per cycle in the output.

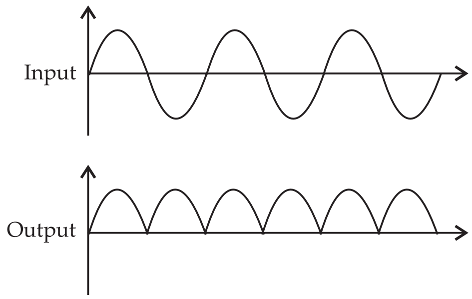


Output frequency of a half wave rectifier = input frequency = 50 Hz

In full wave rectification, two ripples are obtained per cycle in the output.

Output frequency = 2 × input frequency

= 2 × 50 = 100 Hz

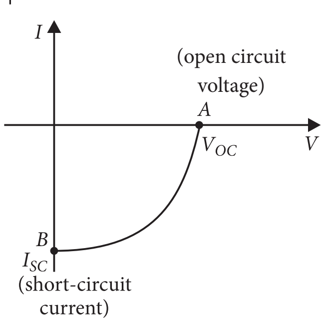


28. We will increase the value of R. On heating a semiconductor, its resistance decreases with rise in temperature. As the semiconductor, S is in series, so net resistance of the circuit also decreases. So by increasing the value of R we can keep the resistance of circuit constant and hence the current in the circuit or the reading of ammeter A can be kept constant.

29. (a) The energy for the maximum intensity of the solar radiation is nearly 1.5 eV. In order to have photo excitation the energy of radiation ($h\upsilon$) must be greater than energy band gap (E_g), *i.e.*, $h\upsilon > E_g$. Therefore, the semiconductor with energy band gap about 1.5 eV or lower and with higher absorption coefficient, is likely to give better solar conversion efficiency.

The energy band gap for Si is about 1.1 eV, while for GaAs, it is about 1.53 eV. The gas GaAs is better inspite of its higher bandgap than Si because it absorbs relatively more energy from the incident solar radiations being of relatively higher absorption coefficient.

(b)

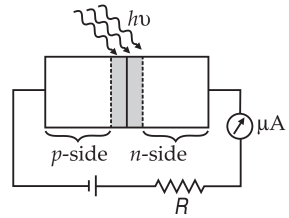


(i) *V-I* curve is drawn in the fourth quadrant, because a solar cell does not draws current but supply current to the load.

(ii) In *V-I* curve, the point A indicates the maximum voltage V_{OC} being supplied by the given solar cell when no current is being drawn from it. V_{OC} is called the open circuit voltage.

(iii) In *V-I* curve, the point B indicates the maximum current I_{SC} which can be obtained by short circuiting the solar cell without any load resistance. I_{SC} is called the short circuit current.

30. Working of photodiode : A junction diode made from light sensitive semiconductor is called a photodiode. A photodiode is a *p-n* junction diode arranged in reverse biasing.



The number of charge carriers increases when light of suitable frequency is made to fall on the *p-n* junction, because new electron-hole pairs are created by absorbing the photons of suitable frequency. Intensity of light controls the number of charge carriers. Due to this property photodiodes are used to detect optical signals.

31. We know that for each atom doped with Arsenic, one free electron is received. Similarly, for each atom doped with indium, a vacancy is created.

So, the number of free electrons introduced by pentavalent impurity added,

$$n_e = N_{As} = 5 \times 10^{22}\ \text{m}^{-3}$$

The number of holes introduced by trivalent impurity added

$$n_h = N_{In} = 5 \times 10^{20}\ \text{m}^{-3}$$

We know the relation, $n_e n_h = n_i^2$ ...(i)

Now net electrons,

$$n'_e = n_e - n_h = 5 \times 10^{22} - 5 \times 10^{20}$$
$$= 4.95 \times 10^{22}\ \text{m}^{-3} \quad \text{...(ii)}$$

Now using equation (i), net holes

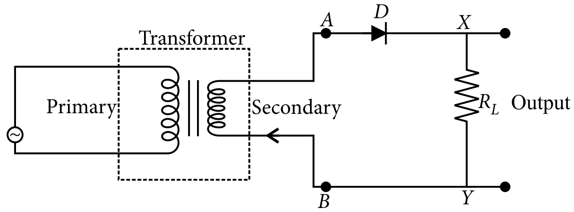
$$n'_h = \frac{n_i^2}{n'_e} = \frac{(1.5 \times 10^{16})^2}{4.95 \times 10^{22}} = 4.5 \times 10^9\ \text{m}^{-3}$$

So, $n'_e >> n'_h$, the material is of *n*-type.

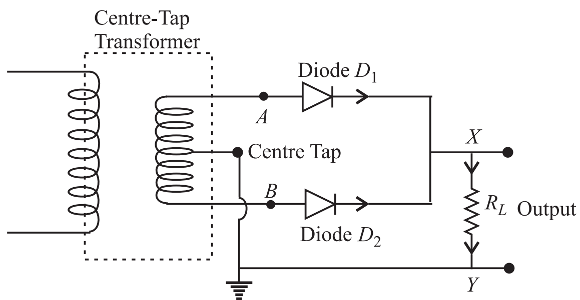
32. In *n*-type extrinsic semiconductors, the number of free electrons in conduction band is much more than the number of holes in valence band. The donor energy level lies just below the conduction band. In *p*-type extrinsic semiconductor, the number of holes in valence band is much more than the number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

33. (a) X = Half wave rectifier

Y = Full wave rectifier

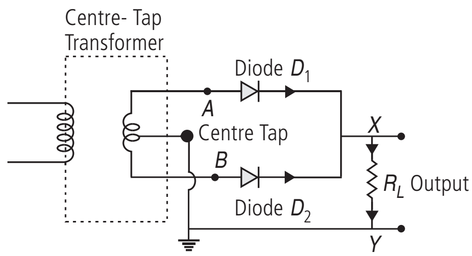


(Half wave rectifier)



(Full wave rectifier)

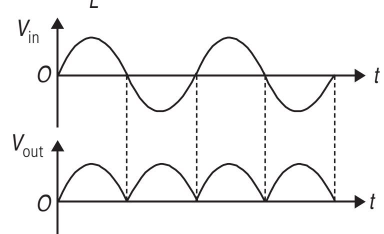
(b) Two *p–n* junction diodes can be used to make full wave rectifier which is used to convert alternating current into direct current.



A full wave rectifier consists of two diodes connected in parallel across the ends of secondary winding of a center tapped step down transformer. The load resistance R_L is connected across secondary winding and the diodes between *A* and *B* as shown in the circuit.

During positive half cycle of input a.c., end *A* of the secondary winding becomes positive and end *B* negative. Thus diode D_1 becomes forward biased, whereas diode D_2 reverse biased. So diode D_1 allows the current to flow through it, while diode D_2 does not, and current in the circuit flows from D_1 and through load R_L from *X* to *Y*.

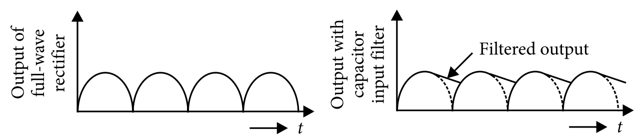
During negative half cycle of input a.c., end *A* of the secondary winding becomes negative and end *B* positive, thus diode D_1 becomes reverse biased, whereas diode D_2 forward biased. So diode D_1 does not allow the current to flow through it but diode D_2 does, and current in the circuit flows from D_2 and through load R_L from *X* to *Y*.



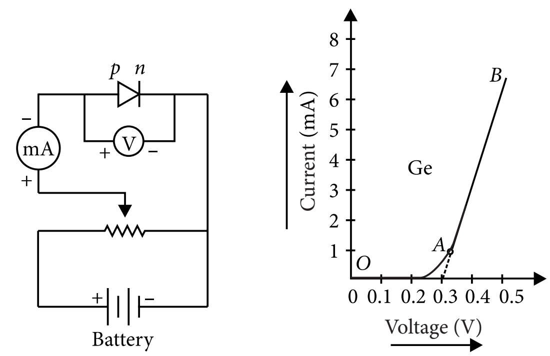
Input-Output waveforms

Since in both the half cycles of input a.c., electric current through load R_L flows in the same direction, so d.c. is obtained across R_L. Although direction of electric current through R_L remains same, but its magnitude changes with time, so it is called pulsating d.c.

(c) A capacitor of large capacitance is connected in parallel to the load resistor R_L. When the pulsating voltage supplied by the rectifier is rising, the capacitor *C* gets charged. If there is no external load, the capacitor would have remained charged to the peak voltage of the rectified output. However, when there is no load and the rectified voltage starts falling, the capacitor gets discharged through the load and the voltage across capacitor begins to fall slowly.



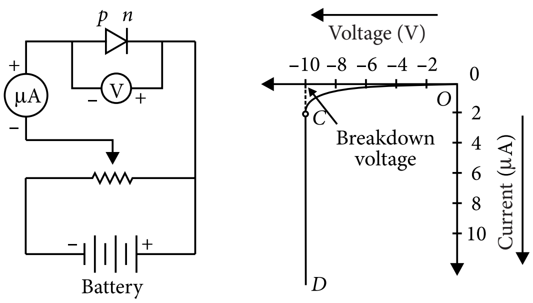
34. Forward biased characteristics : The circuit diagram for studying forward biased characteristics is shown in the figure. Starting from a low value, forward bias voltage is increased step by step (measured by voltmeter) and forward current is noted (by ammeter). A graph is plotted between voltage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



(a) (b)

At the start 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 threshold or cut-in voltage. If line *AB* is extended back, it cuts the voltage axis at potential barrier voltage.

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



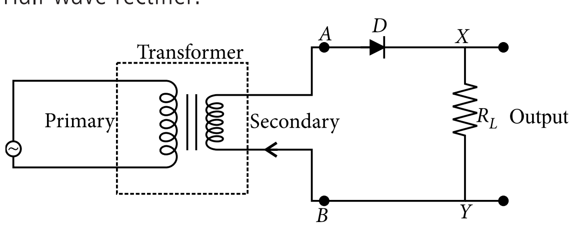
(a) (b)

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.

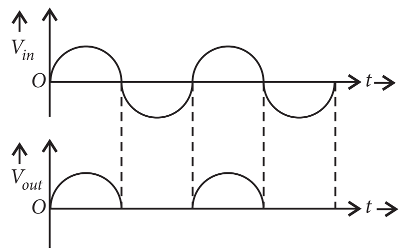
Therefore, the small reverse current remains almost constant over a sufficiently long range of reverse bias, increasing very little with increasing voltage (*OC* portion of the graph). This reverse current is voltage independent upto certain voltage known as breakdown voltage and this voltage independent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

35. Half wave rectifier:



It consists of a diode *D* connected in series with load resistor R_L across the secondary windings of a step-down transformer.

Primary of transformer is connected to a.c. supply. During positive half cycle of input a.c., end *A* of the secondary winding becomes positive and end *B* negative. Thus, diode *D* becomes forward biased and conducts the current through it. So, current in the circuit flows from *A* to *B* through load resistor R_L.



During negative half cycle of input a.c., end *A* of the secondary winding becomes negative and end *B* positive. Thus, diode *D* becomes reverse biased and does not conduct any current. So, no current flows in the circuit. Since electric current through load R_L flows only during positive half cycle, in one direction only *i.e.*, from *A* to *B*, so d.c. is obtained across R_L.

36. (a) Voltage at *p* side is less than voltage at *n* side of the diode so it is in reverse bias.

(b) (i) From the given curve, we have

voltage, $V = 0.8$ volt for current, $I = 20$ mA

voltage, $V = 0.7$ volt for current, $I = 10$ mA

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

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

$\therefore$ Resistance, $R = \dfrac{\Delta V}{\Delta I} \Rightarrow R = \dfrac{0.1}{10 \times 10^{-3}} \Rightarrow R = 10\ \Omega$

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

$I = -1\ \mu\text{A} = -1 \times 10^{-6}\ \text{A} \Rightarrow R = \dfrac{10}{1 \times 10^{-6}} = 1.0 \times 10^{7}\ \Omega$

☺☺☺