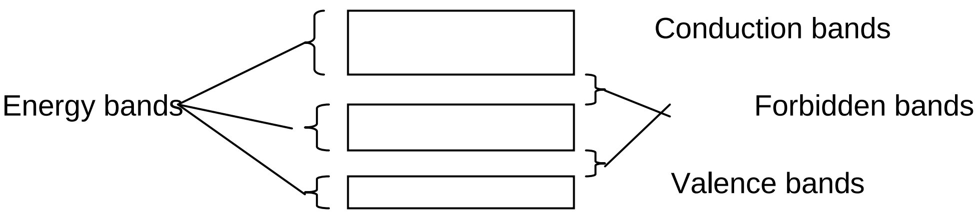
Chapter-14: Semiconductor Devices and Digital Circuits

1. **Classification of conductors, semiconductors and insulators** on the basis of the order of electrical conductivity (σ) and resistivity ($\rho = \frac{1}{\sigma}$) are given below in tabular form as:

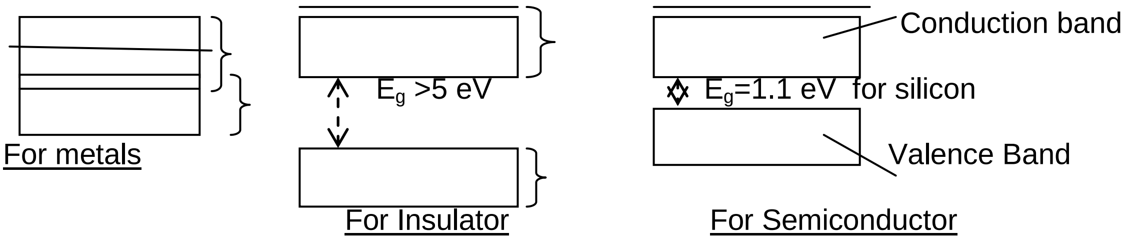
S.N.	Types of solids	$\rho(\Omega - m))$	$\sigma\left(\frac{1}{\Omega m}\right)$
1	Metals	10^{-2} to 10^{-8}	10^{2} to 10^{8}
2	Semiconductors	10^{-5} to 10^{6}	10^{5} to 10^{-6}
3	Insulators	10^{11} to 10^{19}	10^{-11} to 10^{-19}

2. **Classifications of conductors, insulators and semiconductors on the basis of energy bands**:

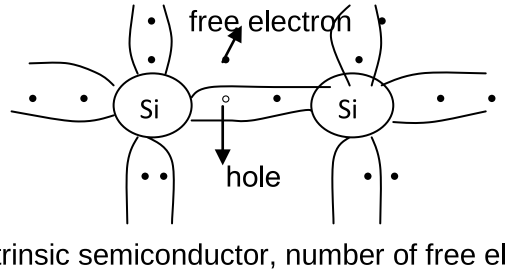
Different energy levels with continuous energy variation are called energy bands.
The difference between the highest energy in a band and the lowest energy in the next higher band is called the band gap between the two energy bands.
Valence Band: The highest energy band filled with valence electrons is called valence band. That is, the energy bands which includes the energy levels of valance electrons is called valence band.
Conduction band: The lowest unfilled allowed energy band next to valence band is called conduction band. That is, energy band above valence band is called conduction band.
Energy gap or energy band gap: It is defined as the difference between the highest valence band energy (E_V) and lowest conduction band energy (E_C). That is, $E_g = E_C - E_V$
The energy gap for different materials is different.
Note: If λ is the wavelength of radiation used in shifting the electron from valence band to conduction band, then energy band gap is $E_g = hf = \frac{hc}{\lambda}$
Note: One can have a metal when the conduction band is partially filled or when the conduction and valence bands overlap in energy.
The last occupied band of energy level is called conduction band.
The energy band gap of Si is 1.1 eV and for Ge, it is 0.7 eV.
In a good conductor, the energy gap between conduction band and valence band is zero. Energy gap minimum means number of free electrons is maximum. This further means that conduction is very fast or it allows the most conduction.
Forbidden bands or forbidden energy gap:
The various energy bands in a solid may or may not overlap depending upon the structure of solid. If they do not overlap, then interval between them represents energies which the electrons in the solid cannot have. These intervals are called forbidden bands. It is also called forbidden energy gap because free electrons cannot exist in this gap.
Note: As temperature increases, forbidden energy gap decreases.



Fermi energy: It is the maximum possible energy possessed by free electrons of a material at absolute zero temperature. The value of Fermi energy is different for different materials.
Energy band diagram



For conductors (metals): Either the conduction band is partially filled or valence band is partially empty, or conduction band and valence band overlap. In case of overlapping, electrons from valence band can easily move into conduction band, thus large number of electrons available for conduction. In case valence bands empty, electrons from lower level can move to higher level making conduction possible. This is the reason why resistance of metal is low or the conductivity high.
In insulator, valence band is completely filled whereas the conduction band is completely empty.. As there is no electron in conduction band, so no conduction is possible. The energy gap between conduction band and valence band is so large ($E_g > 3\ eV$} that no electron in valence band can be provided so much from any external source that it can jump this energy gap.
Semiconductor: It is similar to that of insulator but with a comparatively small energy gap. At absolute zero temperature, the conduction band of semiconductors is totally empty and valence band is completely filled. . Therefore, they are insulators at low temperatures. Its resistance is not as as high as that of insulators.
Q. 1: The maximum wavelength at which solid begin to absorb energy 10000 Å. Calculate the energy gap of solid. [Ans. 1.24 eV]
Type of semiconductors:
For Si, energy gap is 1.1 eV and for Ge, energy gap is 0.7 eV. However, at 0 K, they behave as an insulator.
On the basis of purity, semiconductors are divided in two groups. (a) Intrinsic semiconductor and (b) extrinsic semiconductor
Intrinsic semiconductor:
A pure (free from impurity) semiconductor which has a valency 4 is called an intrinsic semiconductor. Pure Ge and Si in their natural state are intrinsic semiconductor.
At room temperature, few of the covalent bonds are broken due to thermal agitation and thus some of the valence electrons become free. This valence electrons shifted to conduction band leaving a vacancy of electron in valence band. This vacancy is called hole and carries a positive charge.



In intrinsic semiconductor, number of free electrons per unit volume (n_e) is equal to number of holes per unit volume (n_h) and is also equal to number of intrinsic charge carrier (n_i). Mathematically, we have the relation $n_e = n_h = n_i$

Here, n_i is also called intrinsic carrier concentration.

At equilibrium, $\boxed{n_e n_h = {n_i}^2}$ ---- (1) this equation (1) is known as **mass-action law**.

Under the action of electric field, holes move towards negative potential, giving hole current I_h and electrons move towards positive potential giving electron current I_e. The total current is the sum of electron current and hole current. That is, $I = I_e + I_h$

Q. 2: In an intrinsic semiconductor, the number of conduction electrons is 7 X 10^{19} per m^3. Find the total number of current carriers (electrons and holes) in the same semiconductor of size 1 cm X 1 cm X 1 mm. [Since, $n_e = 7 \times 10^{19}$ /m^3 so, $n_e = n_h$ = 7×10^{19} /m^3, so, total current carrier density =$n_e + n_h = 14 \ \times 10^{19}$ /m^3, now total number of current carrier = Number density x volume = 1.4 x 10^{13}]

Extrinsic Semiconductor: The conductivity of an intrinsic semiconductor is very poor unless temperature is very high. At ordinary temperature, only one covalent bond breaks in 10^9 atoms of Ge. It means that only one atom is available for conduction. Conductivity of intrinsic semiconductor is increased if some pentavalent or trivalent impurity is mixed. So, doping pure semiconductor with impurities is called extrinsic semiconductor.

There are two types of dopant used in doping tetravalent Si or Ge.

(a) Trivalent atoms (valency 3) e. g. In, B, Al and (b) pentavalent atoms (valency 5) e. g. Arsenic (As), antimony (Sb) and phosphorus (P) etc. The extrinsic semiconductor is of two types_ (i) p-type and (ii) n-type

Difference between Intrinsic semiconductor and extrinsic semiconductor:

Intrinsic Semiconductor	Extrinsic Semiconductor
1. It is in pure form.	1. It is in impure for. That is, some impurities are added in Si or Ge.(adding impurities to Si or Ge, is called doping)
2. In it, $n_e = n_h = n_i$ where n_e is number density of electron, n_h is number density of hole and n_i is intrinsic charge carrier concentration.	2. It is p-type and n-type. In p-type, $n_h \gg n_e$ and in n-type $n_e \gg n_h$
3.Holes are positive charge, filling in place of electrons	

When trivalent impurity is added in pure semiconductor, it becomes p-type and when pentavalent impurity is added to pure semiconductor, it becomes n-type semiconductor. Trivalent impurity atoms are called acceptor atoms because it accepts electrons and creates holes.

Difference between n-type and p-type semiconductor:

P-type semiconductor	n-type semiconductor
1.It is formed by adding trivalent impurities (B, Al, In, Ga etc.) to Si or Ge. [Outermost orbit Si or Ge has 4 electrons sharing as co-valent bond with 3 outermost electrons of Al, fulfilling one electron as hole]	1.It is formed by adding pentavalent (Sb, P, As etc.) to Si or Ge. [Outermost orbit Si or Ge has 4 electrons sharing as co-valent bond with 5 outermost electrons of Phosphorous, thus leaving one electron free]
2.It is acceptor type.	2.It is donar type.
3.It has majority carriers hole and minority carriers electrons	3.It has majority carriers electrons and minority carriers hole.

Electrical conduction through semiconductor:

Conductivity of semiconductors is given by $\sigma = n_e e \mu_e + n_h e \mu_h$

Where n_e and n_h are densities of conduction electrons and holes respectively and μ_e, μ_h are respective mobilities. Here, $\mu_e = \frac{V_e}{E}$ and $\mu_h = \frac{V_h}{E}$ where, E is the electric field.

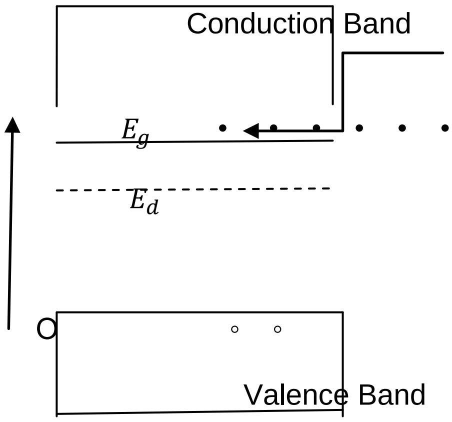
Effect of temperature on conductivity of semiconductor: The conductivity of semiconductor increases with rise in temperature. This is because, as temperature rises, more and more covalent bonds break, thus creating more and more charge carriers (electron –hole pairs). This results in increasing conductivity. It increases exponentially with rise in temperature.

$$n_i \propto e^{-\frac{E_g}{2kT}}$$

Where, n_i is the number of electron-hole pair, E_g is the energy gap, k is the Boltzmann's constant and T is the absolute temperature.

Electron and hole concentration: Electron concentration (n_e) and hole concentration (n_h) are not equal and can be given as $n_e n_h = n_i^2$. In this, the concentration of electrons is nearly equal to the concentration of donor atoms (N_d) and is very large compared to the concentration of holes in the valence band. That is, $n_e \approx N_d \gg n_h$

0.01 eV (Ge), 0.05 eV (Si)



Donor Level

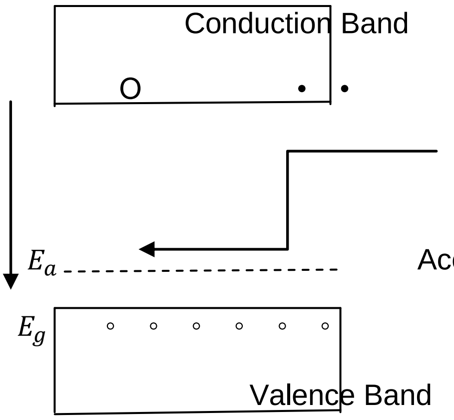
Fig-1: **Energy band diagram**

For n-type semiconductor

Electron and hole concentration:

In this, the concentration of holes is nearly equal to the concentration of acceptor atoms (N_a) and is very large compared to the concentration of electrons in the valence band. That is, $n_h \approx N_a \gg n_e$

0.01 eV (Ge), 0.05 eV (Si)

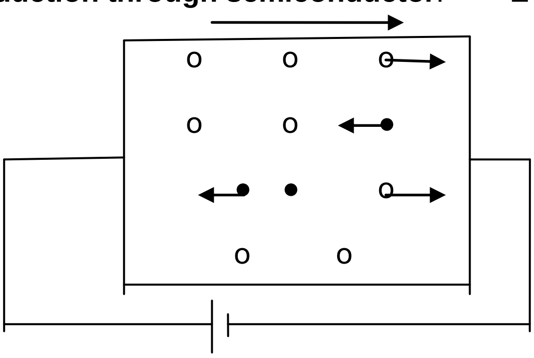


Acceptor levels

Fig-2: Energy band diagram

for p-type semiconductor

Electrical conduction through semiconductor:

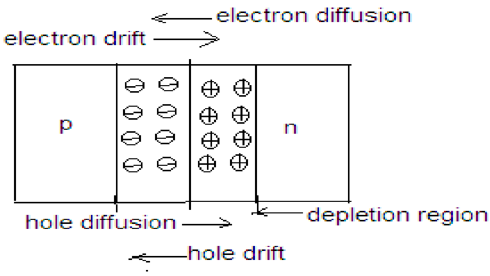


When a battery is connected across a semiconductor (whether intrinsic or extrinsic), a potential difference is developed across its ends. Due to the potential difference, an electric field is produced inside the semiconductor. A current although very small starts flowing through the semiconductor. This current may be due to the motion of (i) free electrons and (ii) holes. Electrons move in opposite direction of electric field while holes move in the same direction.
The motion of holes towards right takes place because electrons from right side come to fill these holes, creating a new hole in their own position. Thus, it can be said that holes are moving from left to right. . Hence, current in a semiconductor can be written as $I = I_e + I_h$. But it should be noted that mobility of holes is less than mobility of electrons.
Q.3. Carbon, Silicon and Ge have same lattice structure. Why is C insulator and Si or Ge a semiconductor? Answer: Because energy gap for carbon is the highest among three mentioned here. Also, number of free electrons is negligible for carbon.
Q.4. Suppose a pure Si crystal has 5 x 10^{28} atoms per m^3. It is doped by 1 ppm (parts per million) concentration of pentavalent As. Calculate the number of electrons and holes. Given that n_i= 1.5 x 10^{16} per m^3. [CBSE D 07]
Answer: $n_e = N_D$, Here, $N_D = \frac{5x10^{25}}{10^6} = 5x10^{22}$ atoms/m^3 Ans.
$Given, n_i = 1.5x10^{16}$ /m^3, therefore, $from\, n_e n_h = {n_i}^2$
$n_h = 4.5x10^9$ /m^3 (Ans.)
Points to be remembered:
(i)The expected energy of the electrons at absolute zero is called Fermi energy.
(ii)The conduction band in a solid partially filled at 0 K is a conductor.
(iii)The valence band and conduction band of a solid overlap at low temperature is a metal.
(iv)Forbidden energy gap between valence band and conduction band in an insulator is of the order of 5eV.
(v)If the forbidden energy band gap in conductors, semiconductors, and insulators is as E_{g_1} , $E_{g_2}$and E_{g_3}respectively, then $E_{g_1} < E_{g_2} < E_{g_3}$.
(vi)Doping of intrinsic semiconductor is done to increase the concentration of majority charge carriers.
(vii)The majority charge carriers in p-type semiconductors are holes and in n-type, it is electrons.
(viii)A p-type semiconductor can be obtained by adding indium, gallium, boron, aluminium etc. and n-type by arsenic, antimony, phosphorus etc.
(ix)The charge on a hole is equal to the charge of proton.
(x)When semiconductor is heated, its resistance decreases.
(xi)Ge and Si are negative temperature coefficient of resistance.
(xii) Number of electrons in a valence shell of semiconductor is 4.
(xiii)Hole is a vacancy created when an electron leaves a covalent bond.
(xiv)In a semiconductor, the separation between conduction band and valence band is of the order of 1 eV.
(xv)In a good conductor, the energy gap between valence band and conduction band is zero.
(xvi)In a semiconductor at room temperature, the valence band is partially empty and conduction band is partially filled.
p-n Junction diode: **How p-n junction diode is formed**?
When n type Si crystal is cut into slices, called wafers and Al powder is laid on these wafers and then it is heated in the oven at about 600^0 C, the aluminium powder is diffused into

Silicon. In this way, p-type semiconductor is formed on an n-type semiconductor. Such a formation of p-region on n region is called p-n junction.

Two important processes occur during the formation of p-n junction:

1. **Diffusion and**
2. **Drift**



p-n junction formation process

Electrons are majority charge carriers and holes are minority charge carriers in n-type. So, the concentration of electrons is more than the concentration of holes. Similarly, holes are majority charge carriers and electrons are minority charge carriers. So, concentration of holes is more as compared to electrons in p-type.

During the formation of p-n junction, and due to the concentration gradient across p- and n-sides, holes diffuse from p-side to n-side and electrons diffuse from n-side to p-side. This motion of charge carriers gives rise to diffusion current across the junction. When electrons diffuse from n-side to p-side, it leaves behind ionised donor on n-side. As the electrons continue to diffuse from n-side to p-side, a layer of positive charge on n-side of the junction is developed. Similarly, when holes diffuse from p-side to n-side, it leaves behind a layer of acceptor ion (negative charge) on p-side junction. This space charge region on either side of junction is known as depletion region.

Depletion layer, potential barrier, barrier electric field and diffusion/drift current:

Depletion layer: The region on either side of junction which becomes depleted (free) from mobile charge carriers has only immobile ions is called depletion region or depletion layer. The width of depletion layer is of the order of 10^{-6} m.

Potential barrier: The accumulation of negative charges in the p-region and the positive charges in the n-region, sets up a potential difference across the junction, is called **barrier potential** (V_B). On the average, potential barrier in p-n junction is 0.5 V and is given by

$E_b = \frac{V_B}{d}$

Where, E_b is the barrier electric field, d is the width of depletion layer. For Ge, V_B = 0.3 V and for Si, V_B = 0.7 V

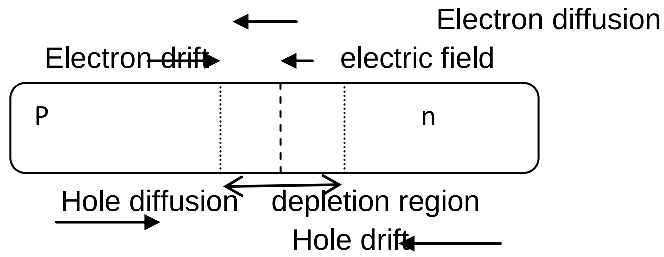
Barrier potential V_B depends on:

1. Nature of the semiconductor
2. Temperature and
3. Amount of doping

If barrier potential is 0.5 V and depletion width is 1 µm, the electric field $E = \frac{0.5}{10^{-6}} = 5\ x\ 10^5$ V/m.

Diffusion Current: Because of concentration difference, holes try to diffuse from p-side to n-side and electrons from n-side to p-side at the p-n junction. However, only those holes/electrons cross the junction which has high kinetic energy. The diffusion give rise to a current from p-side to n-side called diffusion current.

Drift current: Because of thermal collisions, electron-hole pairs are created at every part of a p-n junction. However, if an electron-hole pair is created in the depletion region, the electron is pushed by the electric field towards the n-side and the hole towards the p-side. This gives rise to a current from n-side to p-side called the drift current.
When diode is unbiased, $I_{diffusion} = I_{drift}$ *and* $I_{net} = 0$*, thai is no current flows in the diode.*
When diode is forward biased, $I_{diffusion} > I_{drift}$ *and* I_{net} *is from p-side to n side and*
When diode is reverse biased, $I_{diffusion} < I_{drift}$ *and* I_{net} *is from n-side to p-side.*
[On formation of p-n junction, immediately, due to differences in concentration of charge carriers (p-side of a junction has higher concentration of holes), holes from p-type diffuse to n side, leaving behind an ionised acceptor atom having negative charge in the p-region near the junction which is immobile and electrons from n-side diffuse to p-side, leaving behind an ionised donor atom in the n-region, having positive charge. The diffusion causes an excess positive charge in n region and excess negative charge in the p region near the junction. This double layer of charge creates an electric field which exerts a force on the electrons and holes, against their diffusion. In the equilibrium position, there is a barrier, for charge motion with the n-side at higher potential than p-side.]



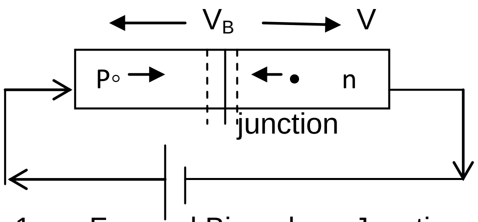
<u>p-n junction formation process</u>

Biasing of diodes:

Forward biasing: When p-type of p-n junction is at higher potential than n-side with respect to reference point (ground), that is, p-side is connected to the positive terminal and n-side is connected to the negative terminal of the DC source, the diode is said to be forward biased. In the forward bias, depletion layer is reduced (becomes thin) and current flows from p-side to n-side.

Reverse biasing: When n-side is at higher potential than p-side or when n-side is connected to positive terminal of battery and p-side is connected to negative terminal of battery, the diode is said to be in reverse biased. In reverse biasing, the depletion layer becomes wide.
For an ideal diode, forward resistance is zero (short circuited) and reverse resistance is infinite (open circuited).
In fig. 1, when a positive terminal of DC voltage source is connected to the p-type and negative terminal of this voltage source is connected to n-type, the electric field created due to this DC voltage is opposite to already present electric field due to barrier potential. The potential drop across the junction decreases and diffusion of electrons and holes thereby increased, resulting in a current in the circuit. The depletion layer effectively becomes smaller. This is called forward biasing.

In fig. 2, when the positive terminal to DC source is connected to n-side and negative to p-side, the direction of electric field due to this DC source will be in the same direction of present electric field due to the barrier potential, the barrier increases, the depletion region becomes larger. This is reverse biasing.



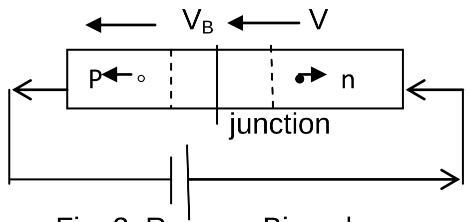
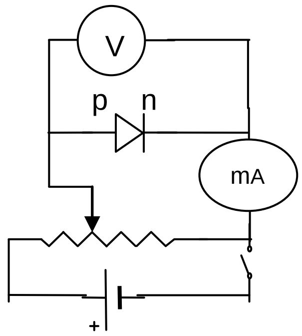
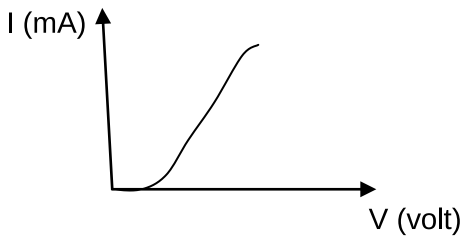


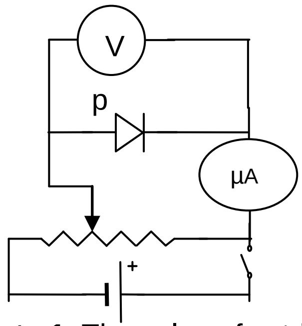
Fig. 1. Forward Biased p-n Junction Fig. 2. Reverse Biased p-n Junction

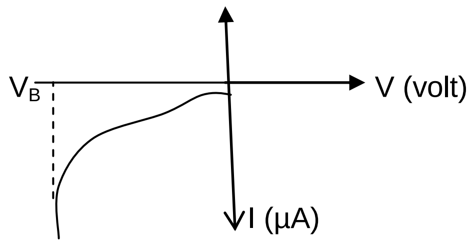
Characteristic Curve of a p-n junction diode and experimental circuit diagram:
Circuit diagram and graph between I versus V for forward biasing:



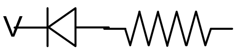
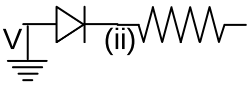


Circuit diagram and graph between I versus V for reverse biasing:

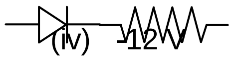




Note 1: The value of cut-in voltage for Ge is 0.2 V and for Si, it is 0.7 V.
Note 2: The reverse saturation current only depends on temperature. For every 10^0 rise, I_0 becomes nearly double.
Note 3: If the reverse bias voltage is too high, then p-n junction diode breaks.
Zener breakdown: When reverse bias voltage is increased, the electric field across the junction also increases (as E =V/d). At some stage, the electric field becomes so high, that it breaks the covalent bonds creating electron hole pairs. Thus a large number of carriers are generated. This causes large current to flow. This mechanism is known as Zener break down.
Avalanche breakdown: At high reverse voltage, due to high electric field, the minority charge carriers, while crossing the junction, acquires very high velocities. These by collisions breaks down the covalent bonds generating more carriers. A chain reaction is established, giving rise to high current. This mechanism is called Avalanche break down.
Note: Zener breakdown occurs in a highly doped p-n junction while Avalanche breakdown occurs in a lightly doped p-n junction.
Dynamic resistance: $r_d = \frac{\Delta V}{\Delta I}$
Q.5: What is ideal p-n junction diode? Indicate which of the following p-n diodes are forward biased and which are reverse biased? Ans. Ideal junction diode has forward resistance zero (short circuit) and reverse resistance infinite (open circuit) and barrier potential is also zero.

(i) +5 V  +7 V  (ii) 2 V

[Ans. Forward bias] [Ans. Reverse bias]

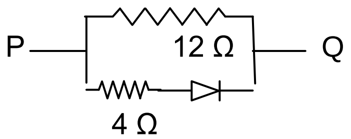
(iii) - 10 V  (iv) -12 V  - 5 V

[Ans. Forward bias] [Ans. Reverse bias]

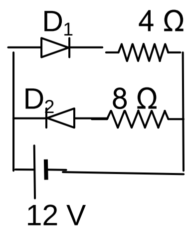
Important points regarding p-n junction diode:

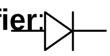
(i)In the depletion region of unbiased p-n junction diode, there are only fixed ions.
(ii)The cause of potential barrier in a p-n diode is concentration of positive and negative charges near the junction.
(iii)Barrier potential of a p-n junction diode depend on (a) temperature, (b) biasing, (c) doping density.
(iv)Majority carriers control the conduction of p-n junction.
(v)In the forward biasing, p-end is connected to the positive terminal and n-end with negative terminal of battery.
(vi)In forward biasing, the width of potential barrier in p-n diode decreases and in reverse biasing, it increases.
(vii)If two ends p and n of a p-n diode are joined by a wire, then there will not be a steady current in the circuit.
(viii)On increasing the reverse bias to a large values in a p-n junction diode, current suddenly increases.
(ix)The p-n junction diode is used as rectifier.

Q. 6: Find the net resistance of the network as shown between the points P and Q if $V_P > V_Q$ (ii) $V_P < V_Q$. [Ans. (i) 3 Ω and (ii) 12 Ω]



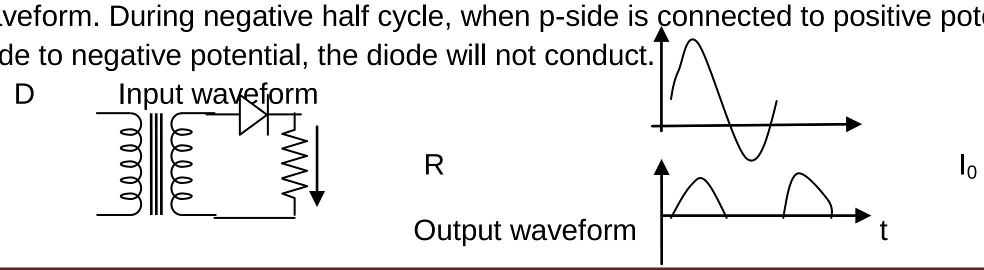
Q.7: Find the current passing through 4 Ω and 8 Ω resistance as shown in the below circuit. [Ans. 3 A, 0]



Symbol of diode as rectifier: 

Junction diode as rectifier: (a) Half wave, (b) Full wave rectifier

(a) Circuit diagram and Working of Half wave rectifier: During positive half cycle of input wave, when p-side is connected to the positive potential and n-side to the negative potential, diode will conduct (forward biasing) and output wave form will be same as positive half of the input waveform. During negative half cycle, when p-side is connected to positive potential and n-side to negative potential, the diode will not conduct.



Important points related to half wave rectifier:

Average output current in half cycle: $I_{dc} = \frac{I_0}{\pi}$

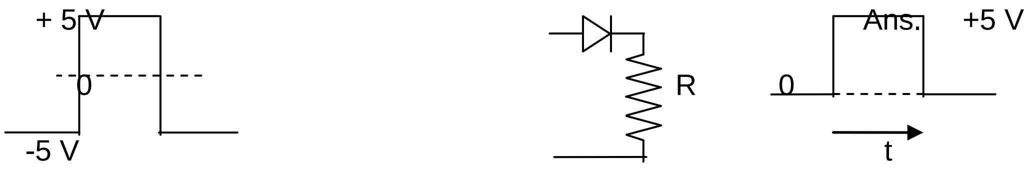
Average output voltage in half cycle: $V_{dc} = \frac{V_0}{\pi}$

RMS output: $I_{rms} = \frac{I_0}{\pi}$, $V_{rms} = \frac{V_0}{2}$

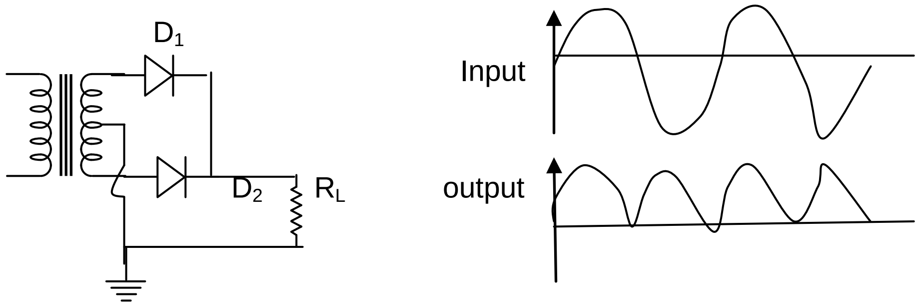
Ripple factor(r): $r = \frac{I_{AC}}{I_{DC}} = 1.21$

Note: The smaller the ripple factor, more effective will be rectifier.

Q.8: Draw the output waveform across resistor R if a square wave (-5 V to + 5 V) is applied to a p-n junction diode.



(b)(i) **Circuit diagram of Full wave rectifier**:



(ii)**Working of full wave rectifier**: During positive half cycle of input AC, the diode D_1 is forward biased and the diode D_2 is reversed biased. The forward current flows through diode D_1.

During the negative half cycle, the diode D_1 will be reversed biased and diode D_2 is forward biased. Thus current flows through diode D_2.

Important points related to full wave rectifier:

Average output

$V_{dc} = \frac{2V_0}{\pi}$ and $I_{dc} = \frac{2I_0}{\pi}$

RMS output:

$V_{rms} = \frac{V_0}{\sqrt{2}}$: and $I_{rms} = \frac{I_0}{\sqrt{2}}$

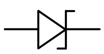
Ripple factor: r = 48%

Ripple frequency: = 2 (frequency of ac input)

Efficiency = 81%

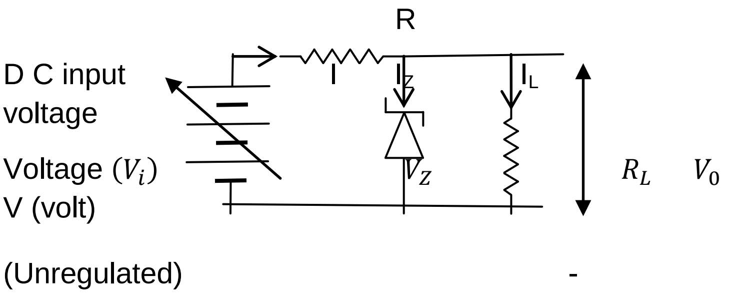
Application of p-n junction diode: (a) Zener diode, (b) Photo diode, (c) Light emitting diode, (iv) Solar cell

(a)**Zener Diode**: A diode meant to operate under reverse bias in the breakdown region, is called avalanche diode or Zener diode. Such diode is used as a voltage regulator.

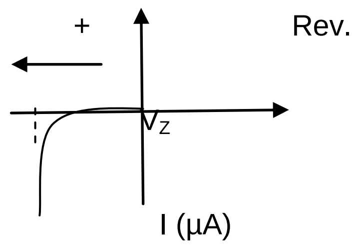
Symbol of Zener diode: 

Experimental circuit diagram and graph between I versus V:

As shown below, R is the series resistor, V_Z is the Zener voltage, R_L is the load resistance, V_0 is the DC output voltage.



Characteristics curve:



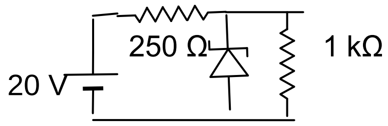
Zener breakdown occurs in junction which is heavily doped and narrow depletion layer. The avalanche breakdown occurs at higher reverse voltage

Zener diode as a voltage regulator: As the input voltage increases/decreases, the current through the R and Zener diode also increases/decreases. The voltage drop across the R increases/decreases without any change in the voltage across the Zener diode. So, there is no change in voltage across Zener diode, so it acts a voltage regulator. During voltage regulation, the current through the series resistance changes and resistance offered by Zener changes.

Principle: When a Zener diode is operated in the reverse breakdown region, the voltage across it remains practically constant (equals to breakdown voltage V_Z) for a large change in the reverse current. The use of Zener diode as a dc voltage regulator is based on this fact. Zener breakdown occurs in junction which is heavily doped and narrow depletion layer. The avalanche breakdown occurs at higher reverse voltage.

In the Zener diode circuit, total current $I = I_L + I_Z$

Q.9: The break down voltage of Zener diode is 12 V. It is used in a voltage regulator circuit as shown below. Find the current through the diode. [Ans. 20 mA]



Photonic p-n junction devices:

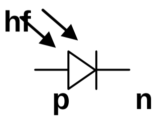
Photo detectors: It is used for detecting light signals (e. g. photodiodes, photo conducting cell)

Photovoltaic device: It converts light energy into electricity, e. g. solar cells

Devices for converting electrical energy into light, e.g. light emitting diodes and diodes lasers

(b)Photodiodes: It is a special type of junction diode used for detecting optical signals. It is reverse biased p-n junction fabricated from a photosensitive semiconductor and provided with a transparent window so as to allow light to fall on its junction. In photodiode, current carriers are generated by photons through photo excitation.

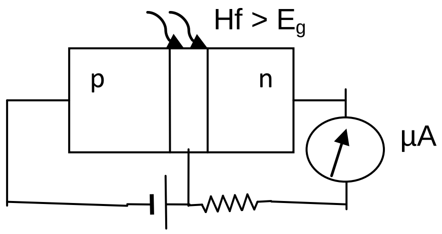
(i)Symbol:



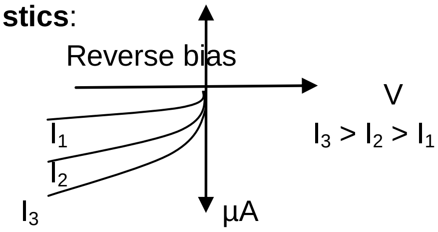
(ii)Working: When photodiode is illuminated with light (photons) having energy greater than energy gap of the semiconductor, then electron-hole pairs are generated due to the absorption of photons. These charge carriers contribute to the reverse current. They increase conductivity of the semiconductor.

Larger the intensity of incident light, larger will be conductivity of semiconductor. The value of reverse saturation current is increased with the increase in intensity.

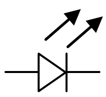
(iii)Construction:



(iv)I-V characteristics:



Q.10: Why photodiode is preferably operated in reverse condition?
Answer: In n-type semiconductor, majority carriers are electrons which have electron density much larger than minority hole density. That n >> p. When illuminated with light, both types of carriers increase equally in number. So, $n' = n + \Delta n \; and \; p' = p + \Delta p$ and now, n >> p and $\Delta n = \Delta p$, therefore, $\frac{\Delta n}{n} \ll \frac{\Delta p}{p}$, that is, fractional increase in majority carriers is much less than fractional increase in minority carriers. So, fractional change due to photo effects on the minority carrier dominated reverse bias current is more easily measurable than fractional change in majority carrier dominated forward bias current.
(v)Uses of photodiodes:
(i)In detection of optical signals
(ii)In demodulation of optical signals
(iii)In high operated switches
(iv)In electronic counters
(v)In speed reading of computer punched cards.
Q. 11: A p-n photodiode is made of a material with a band gap of 1.5 eV. What is the minimum wavelength of radiation that can be observed by the material? [Ans. λ=830 nm, f = 1.2 X 10^6 Hz]
Q. 12: (NCERT 14.11): A p-n photodiode is fabricated from a semiconductor with band gap of 2.8 eV. Can it detect a wavelength of 600 nm? [Ans. To detect light, E > E_g, here E = 2.06 eV for λ=600nm, while E_g = 2.8 eV, so, it will not detect 600 nm wavelength.
(c)Light emitting diodes: It is a heavily doped forward biased p-n junction which spontaneously converts the electrical energy into light energy (like infrared and visible light)..
Two important features of LED:
(a)The colour of light emitted by an LED depends on its band gap energy.
(b)The intensity of light emitted is determined by the forward current conducted by the p-n junction.
The compound semiconductor Gallium-Arsenide-Phosphide ($GaAs_{1-x} P_X$) is used for making LEDs for different colours. For a semiconductor to emit visible light (wavelength 400 nm t0 700 nm), the minimum band gap must be 1.8 eV.
Symbol:



Advantages of LEDs over conventional incandescent lamps:
(i)Low operational voltage and less power consumption
(ii)Fast OFF/On switching capability

(iii)The bandwidth of emitted light is 100 Ǎ to 500 Ǎ, i.e. light is nearly monochromatic.
(iv)Long life and ruggedness

Uses of LEDs:
(i)Infrared LEds are used in burglar alarm system.
(ii)In optical communication
(iii)In image scanning circuits for picture phones
(iv)These are used as indicator lamps in radio receivers and other electronic equipments
(v)Hand calculators, cash registers, digital clocks

Q.13:Why photo-diode is used in reverse bias condition? Distinguish between light emitting diode and photodiode. (b) Give reason why the Zener diode is fabricated by heavily doping both the p- and n-side of junctions

Answer (a)Because the change in reverse current through the photodiode due to change in light flux or light intensity can be measured easily as the reverse saturation current is directly proportional to the light flux or light intensity.

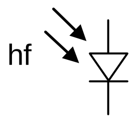
Difference between LED and Photodiode:

1.Light Emitting diode (LED)	Photodiode
It is forward biased.	It is reverse biased
2.Recombination of holes and electrons takes place at the junction and emits e. m. radiation.	Energy (hc/λ) is supplied by the light to take an electron from valence band to conduction band.

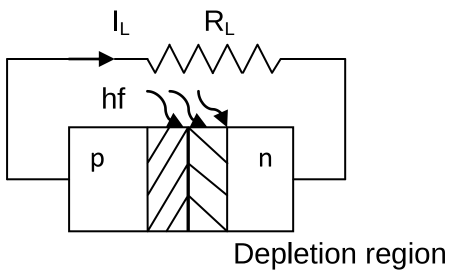
(b) Heavy doping makes the depletion layer very thin. This makes the electric field of the junction very high, even for a small reverse bias voltage. This, in turn, helps the Zener diode to act as a voltage regulator.

(d)(i)**Solar cells**: It is a junction diodes which converts solar energy into electricity and is based on photovoltaic effect (generation of voltage due to bombardment of light photons).The p-n Junction is made of Si or GaAs.

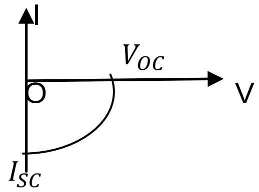
(ii)Symbol:



(iii)Working: When photon of light of energy $hf > E_g$ falls at the junction, electron- hole pair are generated near the junction and they move in opposite directions due to junction field. They will be collected at the two sides of the junction, giving rise to a photovoltage between the top and bottom metal electrodes. The top metal contact acts as a positive electrode and bottom metal contact acts as a negative electrode. When an external load is connected across metal electrodes, a photocurrent flows.

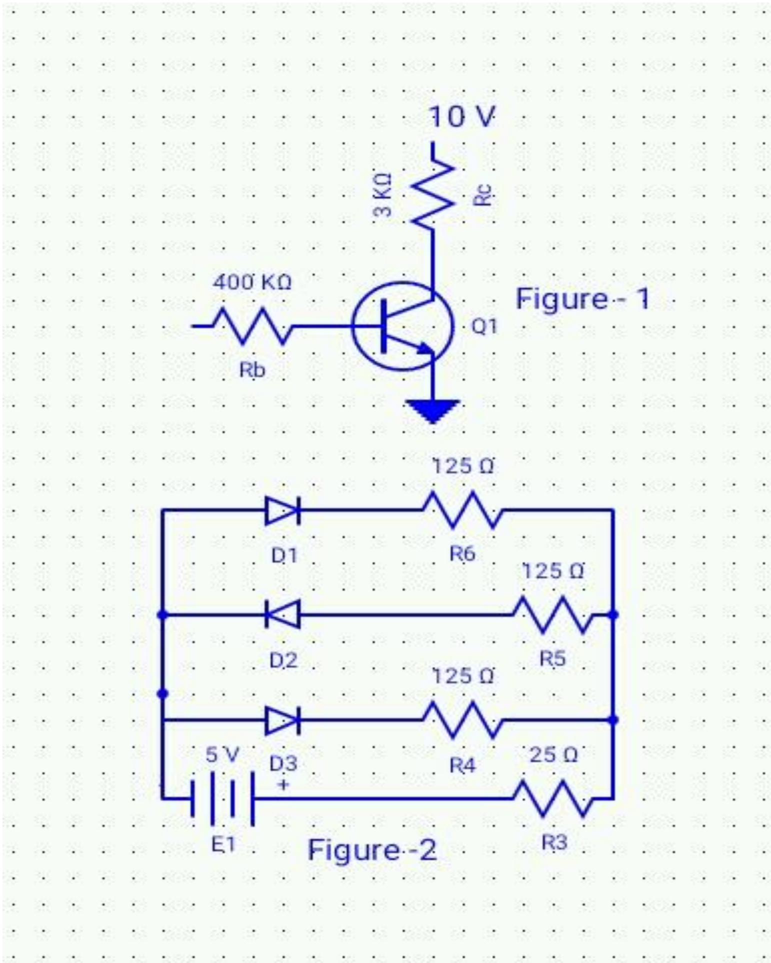


(iv) I-V characteristics: It is drawn in the forth quadrant of the co-ordinate axis, because a solar cell does not draw current but supplies the current to the load. Here, V_{OC} is open circuit voltage and I_{SC} is the short circuit current.



(v)Uses: (i) Solar cells are used in providing domestic light (ii) It is used in space vehicle for charging batteries in day time and then taking electrical power from them during night.

1. As shown in the figure -1, when input voltage of base resistance is 10 V, V_{bc} is zero and V_{ce} is also zero, find the value of I_b , I_c and β
2. If each diode in figure-2 has a forward bias resistance of 25 Ω and infinite resistance in reverse bias, what will be the value of the current I_1 , I_2 and I_3 ?



3. Make the output waveform Y of the NAND gate for the following inputs A and B.

Time	A	B
For $t < t_1$	1	1
From t_1 to t_2	0	0
From t_2 to t_3	0	1
From t_3 to t_4	1	0
From t_4 to t_5	1	1
From t_5 to t_6	0	0
For $t > t_6$	0	1

4. A transistor is connected in C-E configuration. The collector supply is 8 V and the voltage drop across a resistor of 800 Ω in the collector circuit is 0.5 V. If the current gain factor (α) is 0.96, find the base current. [Ans. 26 μ]