2nd sem. B.sc Physics

UNIT-(I)

"SEMICONDUCTOR DIODES"

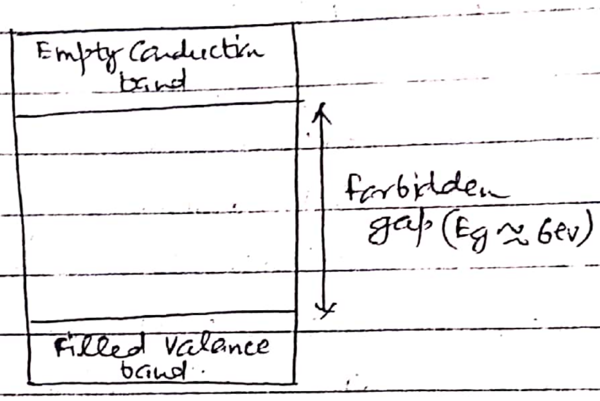
Energy band in Solids: →

In an atom, electron revolves around the nucleus in circular orbits (Bohr's theory). Energy of electron in each subshell is definite. These definite energy values are called energy levels of the atoms. If large no. of atoms are brought close to one another to form a solid crystal, they begin to influence each other. Due to this interatomic interaction, there is no appreciable modifications in energy levels of electrons in inner shells, but there is a considerable modification in the energy levels of electrons in the outer shells. Thus the maximum effect of interaction is on the valance electrons ($\bar{e}$'s in outer shells) and energy E of these electrons becomes $E \pm \Delta E$. Thus each energy level becomes broad. This broadening of energy level is called energy band. The bands of filled energy levels and empty energy level are seperated by an energy gap called forbidden gap or forbidden band. The lower band which is completely filled up is called as valance band and upper band which is normally empty at (0K) is called as conduction band. The gap between valance band and conduction band is a measure of energy (E_g). For insulators, $E_g \approx 6$ eV; for semiconductor like Si, $E_g \approx 1.1$ eV.

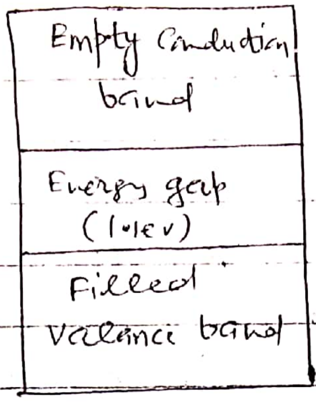
Now we will discuss energy bands in terms of band gap for insulators, semiconductors and conductors.

(I) Insulators: → In these, valance band is completely filled, conduction band is empty and forbidden gap is quite large.

e.g in case of diamond band gap $E_g \simeq$ 6ev. Due to such a large forbidden band gap, no electron is able to go from valance band to conduction band even if electric field is applied. Hence material behaves as insulator.



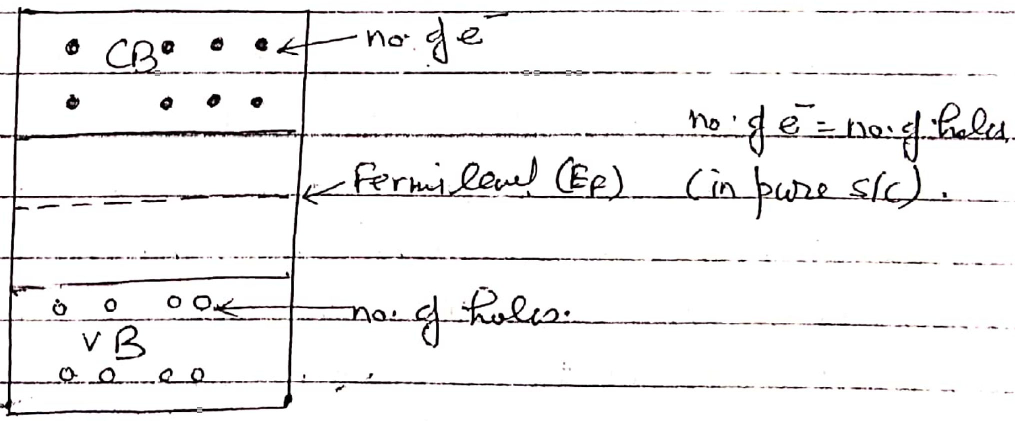
(II) Semiconductors :- In semiconductors, valance band is completely filled and conduction band is empty, but forbidden gap between valance and conduction band is quite small e.g for Si band gap is 1.1 ev. So at zero kelvin, electrons are not able to cross even this small forbidden gap and hence conduction band remains empty. However at room temperature some electrons in valance band acquire thermal energy and becomes free if absorbed thermal energy is greater than band gap energy (E_g). And such electrons jump over to conduction band, where they are free to move under the influence of small electric field. As a result of it, semiconductor conducts at room temperature. So we can say that S/C behaves as an insulator at zero kelvin, but conducts at temp. higher than zero kelvin. The no. of valance electrons which excite from valance band to conduction band leave behind a deficiency of electron (called a hole) in the valance band of a pure semiconductor.



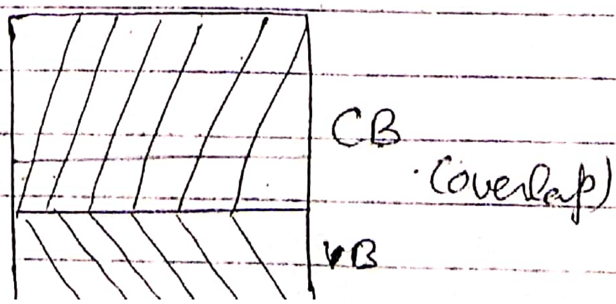
Fermi energy :- It is the maximum possible energy possessed by free electrons at absolute 0K.

Fermi level :→ It is that energy level in energy band diagram, for which probability of occupying energy state by e^- becomes half.

In an intrinsic (Pure) s/c, Fermi level lies midway between valance band and Conduction band as no. of e^- in CB is equal to no. holes in V.B.

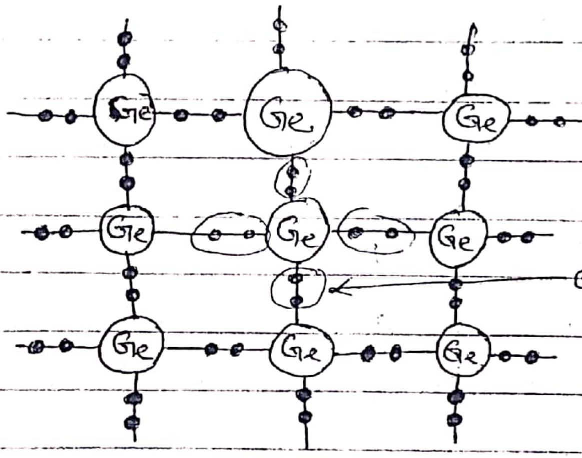


(III) Conductors :→ In it valance band and Conduction band overlap each other. Large no. of electrons from VB can move to CB by acquiring energy from even a small electric field. So Conductivity becomes high.



Intrinsic and Extrinsic Semiconductors →

A pure semiconductor which is free from every impurity is called intrinsic s/c. Ge and Si are intrinsic s/c. The electronic configuration of Si is at. no. 14 (2, 8, 4) and Germanium at. no. 32 (2, 8, 18, 4). Both the atoms have four valance electrons. Fig below shows crystal structure of Germanium.



The four valance electrons of Germanium atom forms covalent bonds by sharing the valance e's of four neighbouring atoms of Ge. So there is now no free electron in Ge-structure. Since no electron is available for conduction, Ge acts as an insulator at 0K. The conduction is possible, if covalent bond is broken and an e^- becomes free. The minimum energy required to break a covalent bond is $E_g \approx 1.1$ ev for Si and 0.72 ev for Ge. So Even at room temperature some e's gets this much energy from thermal vibrations of atoms. And these e's move from VB to CB and results in some conductivity of s/c. For every e^- going from VB to CB, there exists a hole in VB. So. no. of e^- = no. of holes in an intrinsic s/c.

In an intrinsic s/c, e^- and holes are always produced due to thermal vibrations of atoms. So it is difficult to control their no. in a pure s/c. Hence Extrinsic s/c are prepared.

Extrinsic Semiconductors:-

These are the impure s/c. If an impurity of IIIrd or Vth group is added to a pure s/c so as to enhance (increase) its conductivity, then Extrinsic s/c are formed.

The process of deliberately adding a suitable amount of impurity to a pure s/c so as to increase its electrical conductivity is called doping. The impurity atoms added are called dopants. The concentration of dopant atoms should not be more than 1% of crystal atoms.

Extrinsic s/c are of two types:-

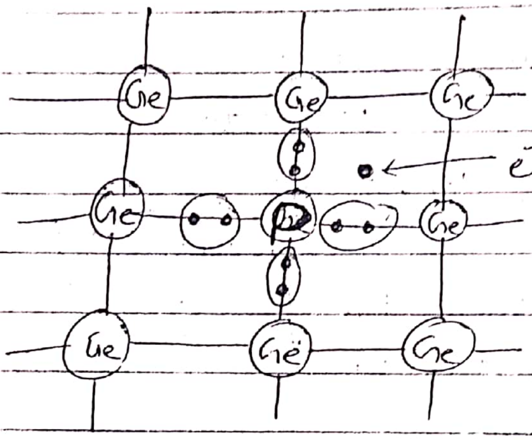
(i) P-type semiconductors

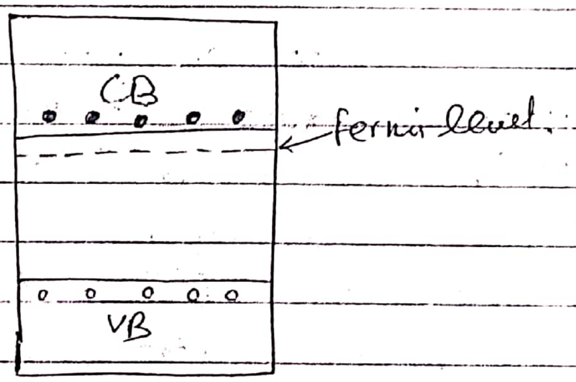
(ii) n-type "

(I) n-type semiconductors:- When an impurity of Vth group i.e. a pentavalent impurity is added in a controlled manner to pure Si or Ge, the new s/c formed is called n type s/c. Pure Si or Ge has four valance electrons and an impurity of Vth group has five valance electrons. Let Phosphorus Z=15 (2,8,5) from Vth group is added as an impurity atom. This impurity atom replaces Si atom and four of valance electrons of Phosphorus make covalent bonds with four valance e's of Si. So one e^- of Phosphourus remains free i.e. loosely bound with parent impurity atom. Thus each impurity atom added to a pure s/c donates one electron for conduction. So these impurity atoms are also called donor atoms. Since the conduction is now mainly due to e's i.e. negative charge, hence the name is n-type s/c.

At room temperature, some of covalent bonds get broken, producing free e^- & holes in equal no. in the n-type s/c., but overall no. of holes in n-type are small. So in n-type s/c, electrons are majority charge carriers and holes are minority charge carriers.

When we add pentavalent impurity to a pure s/c, of Ge or Si, fermi level in forbidden energy gap shifts very close to Conduction band.





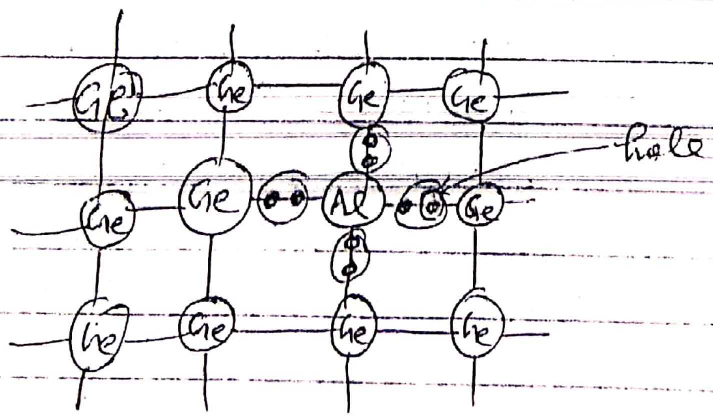
(II) P type semiconductor :- When an impurity of IIIrd group i.e. trivalent impurity is added in a controlled manner to pure Si or Ge, the new semiconductor formed is called P type semiconductor. Pure Si or Ge has four valance electrons and an impurity of IIIrd group has three valance electrons. Let Al (Z=13) 2, 8, 3 is from III group is added as an impurity atom to pure Si or Ge. This impurity atom replaces Si atom and three of ~~four~~ valance electrons of Al make covalent bonds with three Ge/Si atoms. So there will be One incomplete covalent bond with a neighbouring Ge atom, due to deficiency of an electron from impurity atom.

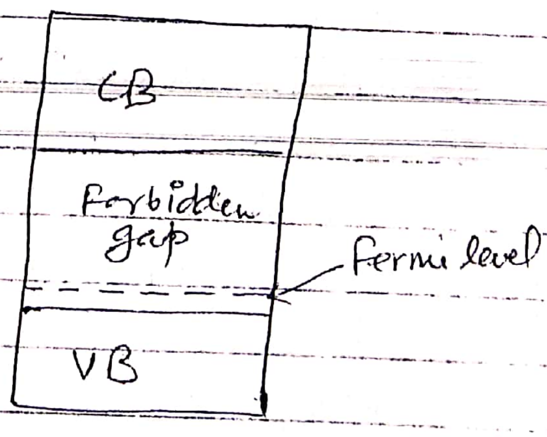
This deficiency of an electron is completed by taking an electron from Ge-Ge bond. Thus a hole is created in Ge-Ge lattice at the site, where one e^- was taken to make covalent bond by Ge-Al atom. That's is how movement of holes takes place. Actually e^- moves, but it appears as if hole is moving. Hole is another aspect of electron.

The trivalent atoms are called acceptor atoms because it can accept one electron from the lattice bond. Since the conduction is due to +ve charge i.e Positive charge, so called P-type s/c.

Also at ordinary temperature some of covalent bonds gets broken and releases equal no of e^- and holes. But overall no. of holes is large in P-type s/c, so they acts as majority charge carriers and electrons acts as minority charge carriers.

When we add a trivalent impurity to Pure Ge/Si, Fermi level in Forbidden gap shifts near to valance band.

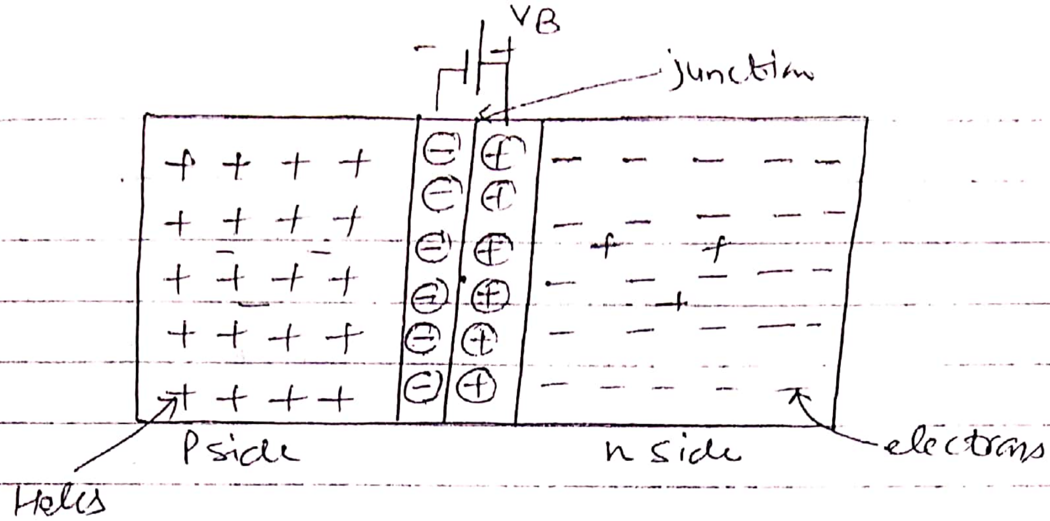




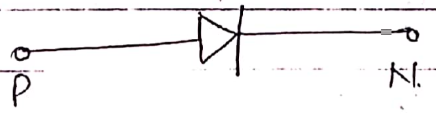
P-N junction diode: →

When a ptype s/c is brought into close contact with a n-type s/c, resulting arrangement is called P-N junction. There are three main techniques for the formation of a PN junction 1. Diffusion 2. Growing and 3. Alloying. Out of these three techniques, Diffusion technique is mostly used. In this technique, after the formation of PN junction, electrical connections are made from P and n-regions.

When PN junction is formed, then due to concentration gradient i.e difference of concentrations in P and n regions, electrons in n-region diffuse through the junction into p-region and holes from p-region diffuse into n-region. When an electron diffuses from n into P region, it leaves behind near the junction the +ve ions which are immobile. Similarly when a hole moves from P side to n side, a -ve ion is created on P region near the junction. So accumulation of electric charges of opposite polarity in two regions of junction give rise to an electric field between these regions as if a fictitious battery is connected across the junction with it +ve terminal connected in n-region and -ve terminal connected in P-region. This electric field opposes the further flow of ēs from n-region to P region and holes from P to n-region. This electric field sets a potential barrier at junction called knee voltage or barrier potential (V_0). The value of V_0 is 0.7 V for Si and 0.3 V for Ge. The region which has only +ve and -ve immobile ions is called depletion region.

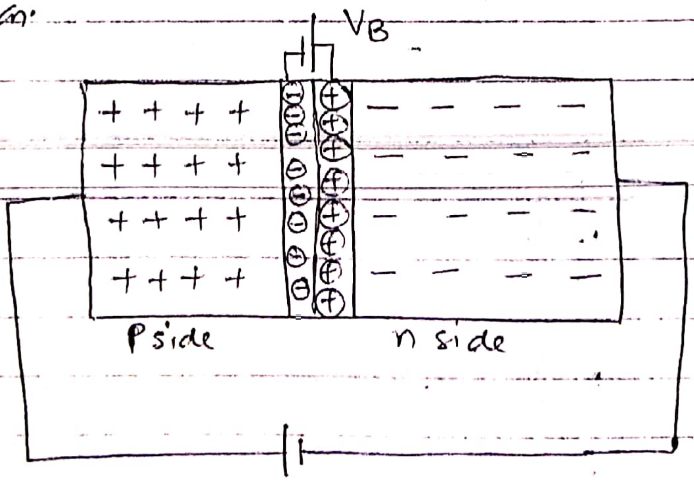


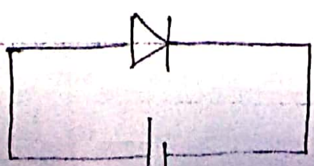
The width of depletion layer and magnitude of barrier potential depend upon the nature of s/c, doping concentration. The symbol of P-N junction diode is as shown.



biasing of P-N junction:→

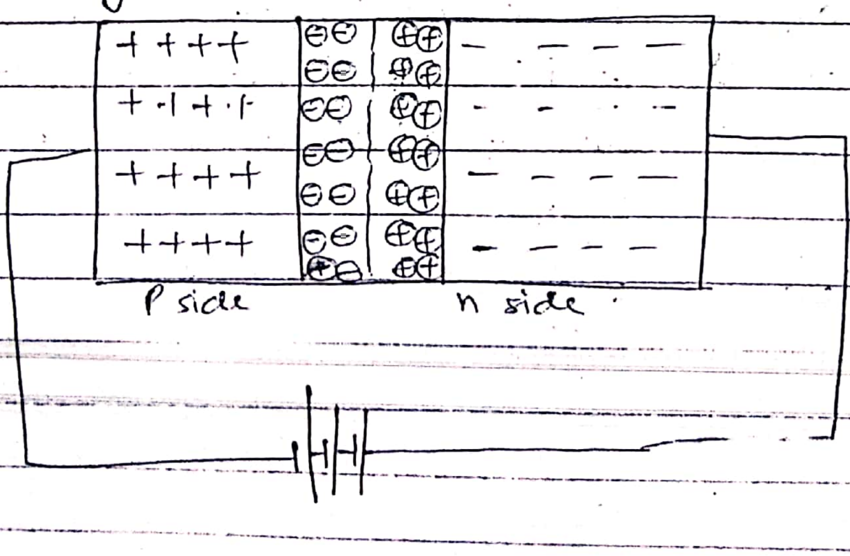
There are two methods of biasing of P-N junction
(I) forward biasing:→ A P-N junction is said to be forward biased, if +ve terminal of external battery is connected to P side and -ve terminal to n side of PN junction.

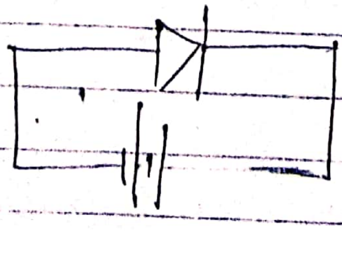




The barrier potential at junction offers a resistance to the flow of majority carriers from moving across the depletion region. If the external voltage is sufficient to overcome the junction barrier, the holes from P side and electrons from n-side penetrate the junction and recombine with each other. For every e^- hole recombination, e^- from -ve terminal of battery enters the n-region and drift towards junction. Also a covalent bond in the crystal near the +ve terminal, breaks down to create a free e^- and hole. The e^- enters +ve terminal of battery and hole drift towards n region. This process continues so long as the external battery is connected to P-n junction.

(II) Reverse biasing: → A PN junction is said to be reverse biased, if P side is connected to -ve terminal and n side is connected to +ve terminal of battery.





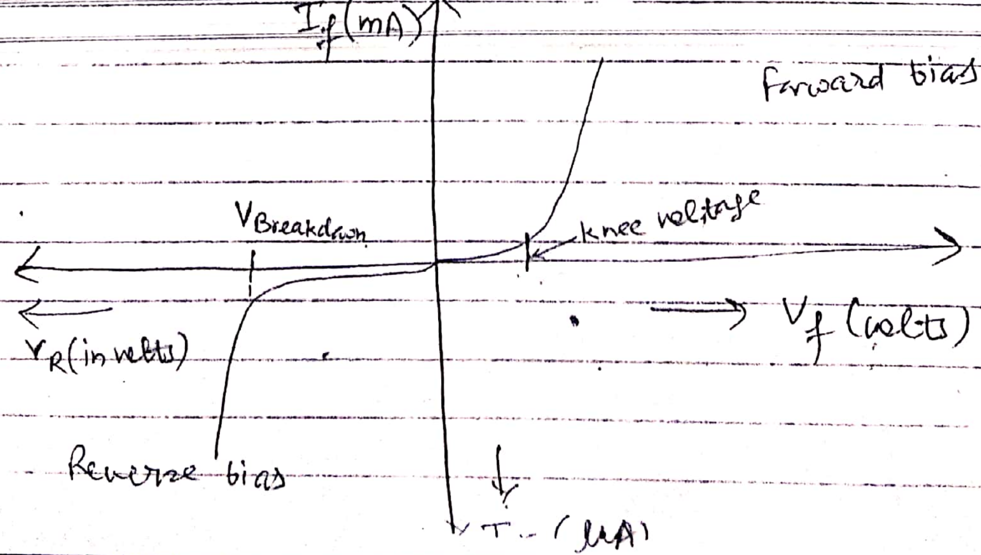
The majority carriers i.e holes in P-region are attracted to -ve terminal of battery and electrons in n-region are attracted to +ve terminal of battery. So depletion region increases. Due to this increased depletion region, holes in P side and e^- in side n are not able to cross the barrier pottential. But minority carriers i.e electrons in P-side and holes in n side have a tedency to move towards opposite sides of P-N junction. If reverse voltage is increased, then current through P-N junction increases abruptly. The reverse voltage at which it occurs is called breakdown voltage.

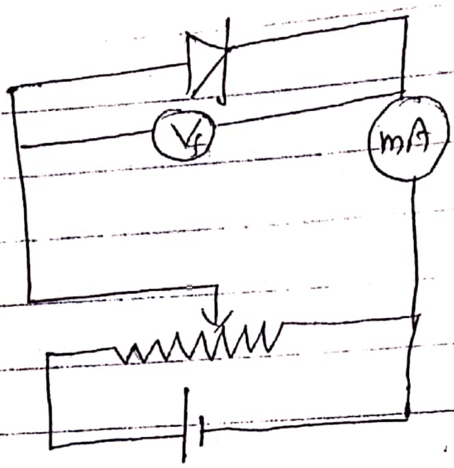
The maximum reverse voltage which can be applied to a PN junction diode safely is called Peak inverse voltage (PIV).

V-I charateristics of PN diode :-

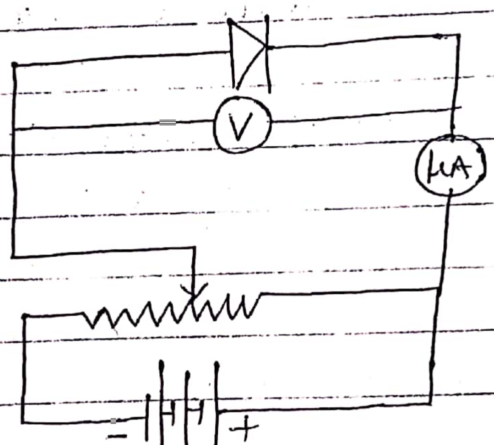
A graph between voltage applied across terminals of PN junction and current flowing through it is called VI charateristics of PN diode.

VI characteristics can be drawn in two modes
(I) Forward biasing (II) Reverse biasing





(forward biasing)



(Reverse biasing)

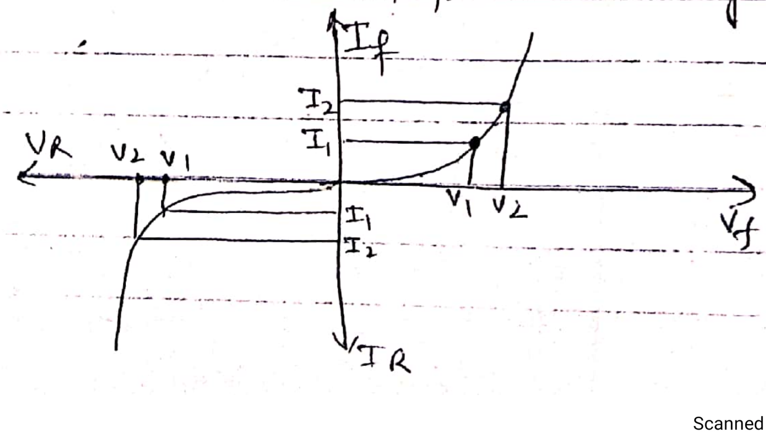
Resistance of PN junction :→

A PN junction offers resistance in both forward and reverse bias modes but forward resistance is quite small as compared to its reverse resistance.

dynamic forward resistance $= \frac{\Delta V_f}{\Delta I_f} = \frac{V_2 - V_1}{I_2 - I_1}$

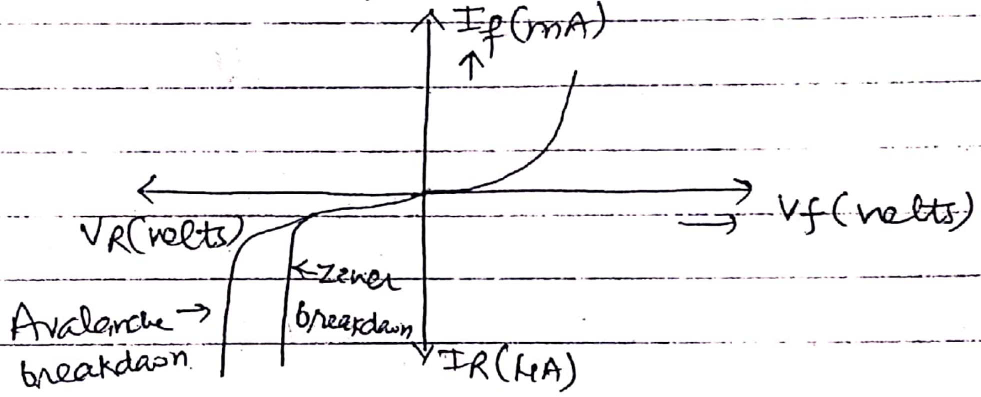
dynamic reverse resistance $= \frac{\Delta V_r}{\Delta I_r} = \frac{V_2 - V_1}{I_2 - I_1}$

These can be determined from VI cha. of P-N diode.



ZENER DIODE: →

Zener diode is a reverse biased heavily doped PN junction diode which operates in the breakdown region. The reverse breakdown of PN junction may occur due to either Zener effect or avalanche effect.



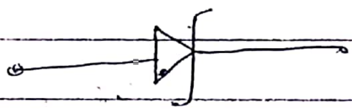
Breakdown mechanism: →

Two mechanisms are responsible for breakdown of PN junction

(i) Zener breakdown (ii) Avalanche breakdown

(i) Zener breakdown: → This form of breakdown occurs in the junctions that are heavily doped. due to heavy doping, depletion layer is narrow. When reverse bias voltage is increased, electric field also increases across the narrow depletion layer. Due to this strong electric field covalent bonds gets broken. This causes a generation of large no. of carriers and hence large current to flow.

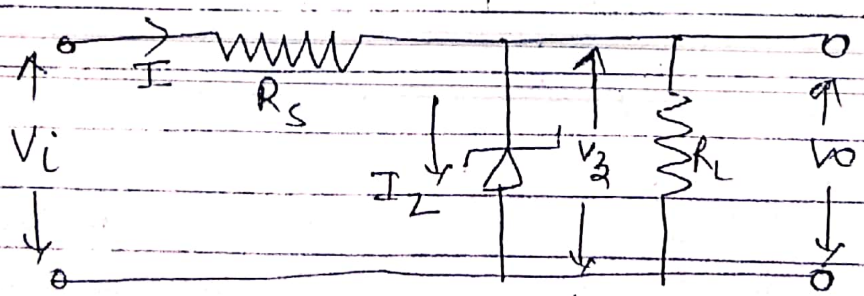
(ii) Avalanche breakdown: → This form of breakdown occurs in junctions, which are lightly doped. Due to light doping, PN junctions have wide depletion layers, so increased applied electric field is not enough to cause zener breakdown. Due to increased electric field velocity and hence energy of minority carriers increases. These high energy carriers breaks covalent bonds in crystal and generate more carriers. These generated carriers are again accelerated by electric field and break more covalent bonds by collision. This produces a very high reverse current.



Symbol of zener diode.

Zener diode as voltage regulator:→

In many application, it becomes necessary that output voltage should remain constant inspite of variations in input or load. For this Zener diode is used as voltage regulator. Zener diode has a special characteristic that whatever current is drawn, the voltage across the zener diode remains constant equal to breakdown voltage. This characteristic makes zener diode a voltage regulator.



If input voltage V_i increases, current increases, but zener diode keeps the voltage fixed equal to breakdown voltage (V_Z).

On the other hand, if I/P voltage is kept fixed and Load resistance R_L is decreased, current across the load increases but Zener keeps voltage $V_0 = V_Z$ constant.

LED: → It is a forward biased P-N junction diode which emits light when recombination of electrons and holes takes place at the junction. When P-N junction is forward biased, electron moves from n side to P side and holes moves from P side to n side. So there is a recombination of electrons and holes. During recombination of electrons and holes, some of this energy difference is given out in the form of light and heat. For a PN junction of Ge and Si, larger %age of this energy is given out in the form of heat. But in some special material PN junctions like gallium Arsenide (GaAs), gallium phosphide (GaP), Gallium Arsenide phosphide (GaAsP) a greater percentage of energy difference is emmited in the form of visible light. Such a PN junction diode is called LED OR LED PN junction diode. The colour of light emmited depends upon the type of material used in making LED.

1. GaAs — Infrared radⁿ.
2. GaP — red or green
3. GaAsP — Red or yellow

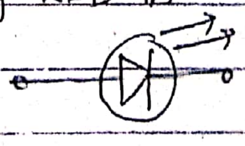
The emmited wavelength $\lambda = \frac{hc}{E_g}$

h = Planck's constant

$c = 3 \times 10^8$ m/sec.

E_g = band gap energy which is different for different material.

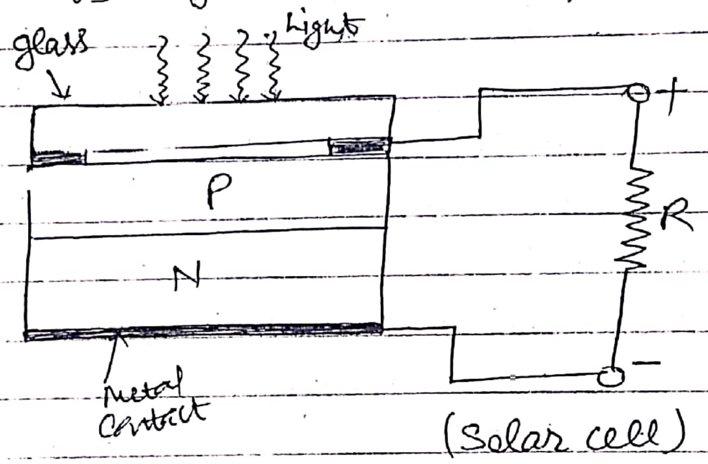
The symbol of LED is



Applications of LED:

1. Infrared LED can be used for burglar alarm system.
2. LED are used in digital watches, panel indicators, calculators, multimeters etc.
3. In field of optical communications.

Solar cell: Solar cell is basically a solar energy converter. It is a PN junction which converts solar energy into electrical energy. Fig below shows its construction.



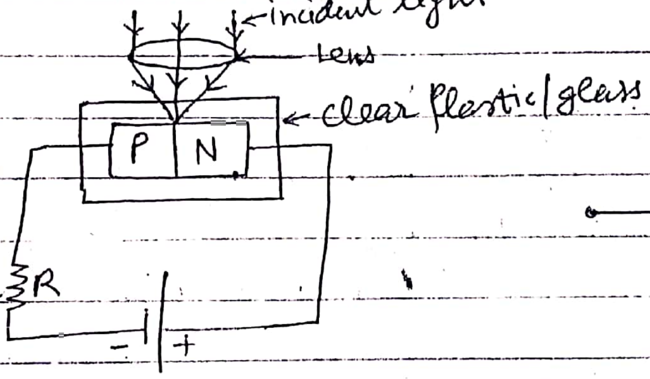
(Solar cell)

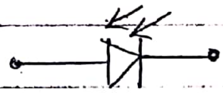
A solar cell consists of a silicon or gallium arsenide PN jun. diode packed in a can with glass window on top. The upper layer is of P type material. This layer is very thin so that the incident light photons may easily reach the PN junction.

When photon of energy $h\nu > E_g$ falls at the junction, electron hole pairs are generated near the junction, which move in opposite direction due to junction field. The photo generated electron move towards n side of PN side junction and holes moves towards P sides of jun. They will be collected at two sides of junction which gives rise to open ckt voltage between top and bottom metal electrodes. When external load is connected across metal electrodes a photo current flows. Solar cells are used in charging of storage batteries during day time & in artificial

Photo-diode :→

It is a reverse biased P-N junction embedded in a transparent plastic case. All sides of plastic case are painted black except one. Metallic/glass case can also be used for enclosing the PN junction. Light is allowed to fall on PN junction only through the clear region. Since the size of Photo-diode is very small, a convex lens is used to focus the light on the PN junction. Fig below shows a photo diode.





When light of suitable wavelength is incident on the junction, additional electron hole pairs are generated. Concentration of newly generated electron-hole pairs is proportional to intensity of incident light. In this process a small change in majority carrier concentration and large change in minority carrier concentration take place. Thus reverse current increased to a large value due to additional minority carriers.

A photodiode can be turned ON and OFF in nanoseconds, Hence it is one of fastest photodetector.

Applications of Photodiode :→

(I) Reading of sound track on films
(II) Street light automatic ON/OFF.
(III) Counting of objects.

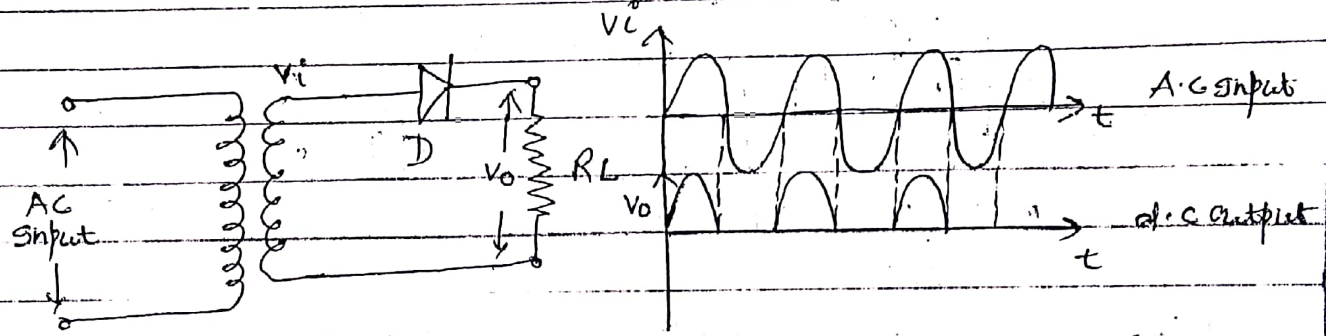
Rectifier → Rectifier is a device which converts a.c to d.c. PN junction diode can act as a rectifier because PN junction diode allows the current to flow, when diode is forward biased and no current flows, when diode is reverse biased.

Rectifier can be of two types:-

(I) Half wave rectifier

(II) full wave rectifier

(I) Half wave Rectifier → fig below shows PN junction diode as a half wave rectifier.



During positive half of a.c input at secondary of transformer, diode D becomes forward biased, and hence conducts and current flows through the diode and hence develops a voltage across load R_L.

During -ve half of a.c input at secondary of transformer, diode D becomes reverse biased and hence donot conducts so no voltage is developed across R_L during -ve half cycle.

So output across R_L is unidirectional, but its amplitude varies, hence it is called pulsating d.c. since only half cycle is rectified it is called Half wave Rectifier.

Efficiency of half wave rectifier → It is the ratio of output d.c power (P_{dc}) to input a.c power at secondary to transformer (P_{ac}).

$$\boxed{\text{efficiency }(\eta) = \frac{P_{dc}}{P_{ac}} = \frac{40.6}{1+\frac{R_f}{R_L}}}$$

$\boxed{\eta = 40.6\%}$; (*) Derivations at next pages.

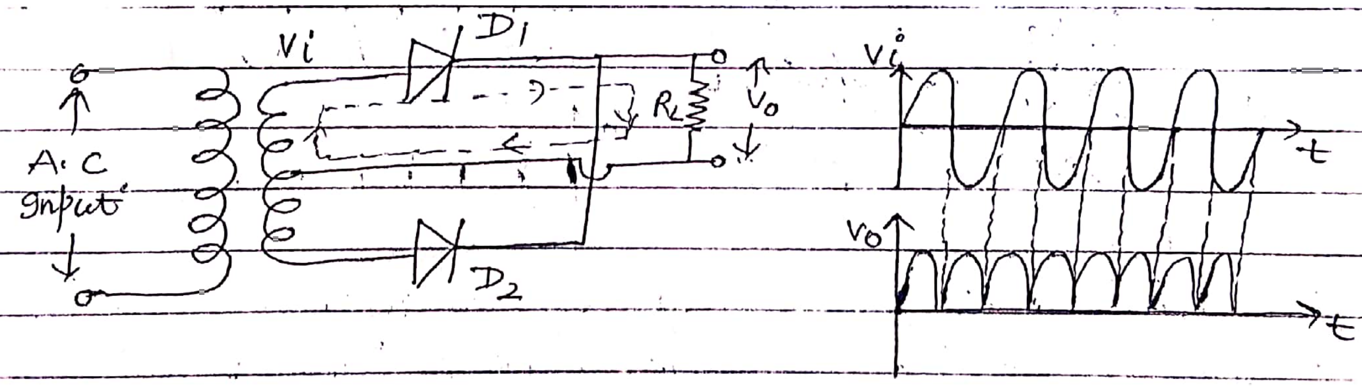
Ripple factor → It is the ratio of rms value of ac component to average value of output across the load.

$$\boxed{r = \frac{V_{rms}}{V_{dc}}} \Rightarrow \boxed{r = \frac{I_{rms}}{I_{dc}}}$$

or $$\boxed{r = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}} \Rightarrow \boxed{r = 1.21}$$

(II) Full wave rectifier →

fig below shows full wave rectifier using a centre tap transformer.



During +ve half cycle at secondary of transformer, diode D_1 becomes forward biased and diode D_2 becomes reverse biased and conducts as shown and thus current flowing through D_1 develops a voltage across R_L.

During -ve half cycle at secondary of transformer, diode D_1 becomes reverse biased and diode D_2 becomes forward biased and D_1 donot conducts and D_2 conducts and therefore current flowing through D_2 develops a voltage across R_L.

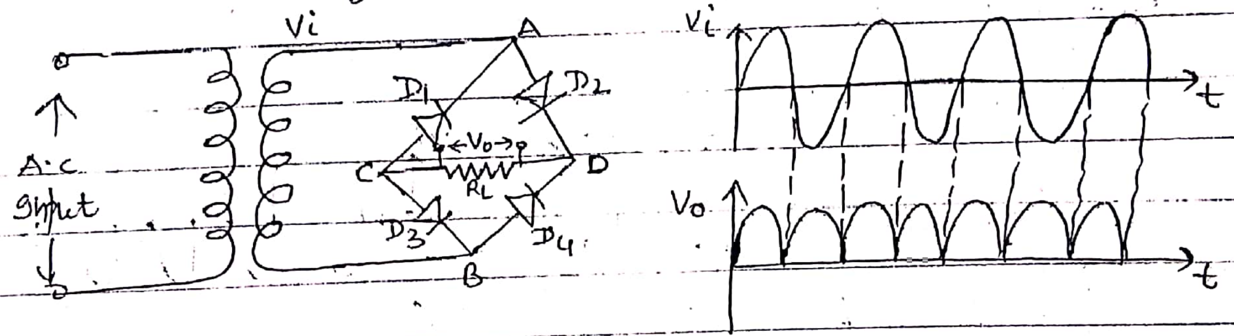
since both positive and -ve half of a.c input are rectified, so it is called full wave rectifier.

rectifier efficiency: → $\boxed{\eta = \frac{P_{dc}}{P_{ac}} = 81.2\%}$

ripple factor: → $\boxed{r = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1} = 0.46}$

In centre tapped transformer based full wave rectifier, It is difficult to locate centre tap on secondary winding. So to avoid using centre tap transformer for full wave rectification, bridge rectifier is used. (*) Derivations at Next pages.

Bridge rectifier: → It is a full wave rectifier and does not require centre tapped transformer. Fig below shows a bridge rectifier as full wave rectifier.



During +ve half of a.c input at secondary of transformer, diodes D_2 and D_3 are forward biased and D_1 and D_4 are reverse biased and donot conduct. So D_2 & D_3 conducts.

During -ve half of a.c input at secondary of transformer, diodes D_1 and D_4 are forward biased and D_2 and D_3 are reverse biased and donot conduct. only D_1 and D_4 conducts.

disadvantages: → (I) It is uneconomical as it requires four diodes.

(II) Efficiency of bridge rectifier is very low.

(I) Mathematical Treatment of Half wave Rectifier :→

In a half wave rectifier, the input a.c voltage at the secondary of transformer is

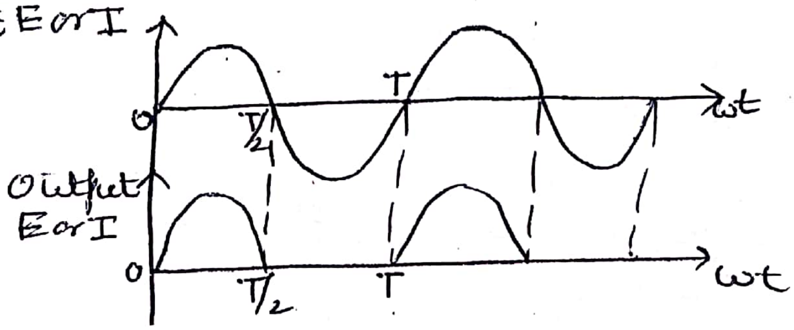
$$V = V_0 \sin\omega t \quad \text{—— (I)}$$

and output unidirectional current at the load resistance R_L is given by

$$I = \frac{V_0 \sin\omega t}{R_f + R_L} = I_0 \sin\omega t \quad \text{—— (II)}$$

Following parameters judges the performance of a rectifier :-

① **Average value of DC current :→**



for $0 \le t \le T/2$, DC output is unidirection & pulsating

and for $T/2 \le t \le T$, DC o/p is zero.

∴ Average value of D.C over complete cycle is

$$I_{dc} = \frac{1}{T}\left[\int_0^{T/2} I_0 \sin\omega t\,dt + \int_{T/2}^{T} 0\,dt\right]$$

$$I_{dc} = \frac{-1}{T}\frac{I_0}{\omega}\left[\cos\omega t\right]_0^{T/2} = -\frac{I_0 \cdot \cancel{T}}{\cancel{T} \cdot 2\pi}\left[\cos\omega\frac{T}{2} - \cos 0\right]$$

$$I_{dc} = -\frac{I_0}{\cancel{2}\pi}\left[\cos\frac{\cancel{2}\pi}{\cancel{T}}\cdot\frac{\cancel{T}}{\cancel{2}} - \cos 0\right] = +\frac{I_0}{\cancel{2}\pi}\left[+\cancel{2}\right]$$

$$\boxed{I_{dc} = \frac{I_0}{\pi}} \quad \text{—— (III)} \qquad \text{similarly} \qquad \boxed{V_{dc} = \frac{V_0}{\pi}}$$

② RMS value of current :→

If I_{rms} be root mean square value of input A.C ripple current, Then

$$I_{rms} = \left[\frac{1}{T}\left[\int_0^{T/2} (I_0)^2 \sin^2 \omega t\,dt\right]\right]^{1/2}$$

$$= \left[\frac{I_0^2}{2T}\int_0^{T/2}(1-\cos 2\omega t)dt\right]^{1/2}$$

$$= \left[\left[\frac{I_0^2}{2T}\right]^{1/2}\left[\left[dt\right]_0^{T/2}\right]^{1/2} - \left(\frac{I_0^2}{2T}\right)^{1/2}\left[\left[\frac{\sin 2\omega t}{2\omega}\right]_0^{T/2}\right]\right]^{1/2}$$

$$= \left(\frac{I_0^2}{2\cancel{T}}\cdot\frac{\cancel{T}}{2}\right)^{1/2} - 0$$

$$\boxed{I_{rms} = \frac{I_0}{2}} \quad \text{—— (IV)}$$

③ Power supplied to rectifier :→

$$P_{ac} = (I_{rms})^2 (R_f + R_L) \qquad [\because P = I^2 R]$$

R_f = forward resistance of diode

$$P_{ac} = \frac{I_0^2}{4}(R_f + R_L) \text{ —— (V)}$$

④ Average output power :→

$$P_{dc} = (I_{dc})^2 R_L = \frac{I_0^2}{\pi^2} R_L \text{ —— (VI)}$$

⑤ Rectifier Efficiency :→ It is defined as ratio of dc power delivered to load to A.C. input power from secondary of transformer.

$$\eta = \frac{P_{dc}}{P_{ac}} \times 100\,\%$$

$$\eta = \frac{\frac{I_0^2}{\pi^2} R_L \times 100\%}{\frac{I_0^2}{4}(R_f+R_L)} = \frac{\frac{\cancel{I_0^2}}{\pi^2} R_L \times 4}{\cancel{I_0^2}(R_f+R_L)} \times 100\,\%$$

$$\boxed{\eta = \frac{R_L}{R_f+R_L} \times 40.6\,\%}$$

It means only 40.6% of A.C input power is converted into d.c in load. Rest exists as A.C in load.

(6) Ripple factor :→

Ripple factor is given by

$$r = \left[\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1\right]^{1/2}$$

$$r = \left[\frac{(I_0/2)^2}{(I_0/\pi)^2} - 1\right]^{1/2} = 1.21$$

$$\boxed{r = 1.21}$$

So It means rms ripple voltage exceeds o/p d.c.

(7) Peak inverse voltage :→ It is defined as maximum voltage appearing across the rectifier diode, when the diode is not conducting.
In half wave rectifier, Max. voltage across the diode is equal to Max. transformer voltage V_0 across secondary of transformer.

$\therefore$ $\boxed{PIV = V_0}$

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Mathematical Treatment of Full wave Rectifier

RMS

In a full wave rectifier, current through the diodes during first half cycle is,

$$\left.\begin{aligned} I_{D_1} &= I_0 \sin\omega t \\ I_{D_2} &= 0 \end{aligned}\right] \text{ for } 0 \le t \le T/2 \quad \text{— (I)}$$

For second half

$$\left.\begin{aligned} I_{D_1} &= 0 \\ I_{D_2} &= -I_0 \sin\omega t \end{aligned}\right] \text{ for } T/2 \le t \le T \quad \text{— (II)}$$

(1) Average or DC value of current :→

$$I_{dc} = \frac{1}{T}\left[\int_0^{T/2} I_{D_1}\,dt + \int_{T/2}^{T} I_{D_2}\,dt\right]$$

$$= \frac{1}{T}\left[\int_0^{T/2} I_0 \sin\omega t\,dt + \int_{T/2}^{T} -I_0 \sin\omega t\,dt\right]$$

$$= \frac{I_0}{T}\left[\left[\frac{-\cos\omega t}{\omega}\right]_0^{T/2} + \left[\frac{\cos\omega t}{\omega}\right]_{T/2}^{T}\right]$$

$$= \frac{I_0}{T}\left[\frac{-1}{\omega}\left[\cos\omega\frac{T}{2} - \cos 0\right] + \frac{1}{\omega}\left[\cos\omega T - \cos\omega T/2\right]\right]$$

$$= \frac{I_0}{T}\left[-\frac{1}{\omega}\left[\cos\frac{\cancel{2}\pi}{\cancel{T}}\cdot\frac{\cancel{T}}{\cancel{2}} - 1\right] + \frac{1}{\omega}\left[\cos\frac{2\pi}{\cancel{T}}\cdot\cancel{T} - \cos\frac{\cancel{2}\pi}{\cancel{T}}\cdot\frac{\cancel{T}}{\cancel{2}}\right]\right]$$

$$= \frac{I_0}{T}\left[-\frac{1}{\omega}\left[-1-1\right] + \frac{1}{\omega}\left[1+1\right]\right]$$

$$= \frac{I_0}{T}\left[-\frac{1}{\omega}\left[-2\right] + \frac{2}{\omega}\right] = \frac{I_0}{T}\frac{4}{\omega} = \frac{I_0}{\cancel{T}}\cdot\frac{\cancel{4}^{2}\cdot\cancel{T}}{\cancel{2}\pi}$$

$$\boxed{I_{dc} = \frac{2I_0}{\pi}} \text{ — (III) Also, } \boxed{V_{dc} = \frac{2V_0}{\pi}}$$

② RMS value of current: →

$$I_{rms} = \left[\frac{1}{T}\left[\int_0^{T/2} (I_{D1})^2 dt + \int_{T/2}^{T} (I_{D2})^2 dt\right]\right]^{1/2}$$

$$= \left[\frac{1}{T}\left[\int_0^{T/2} I_0^2 \sin^2\omega t\, dt + \int_{T/2}^{T} I_0^2 \sin^2\omega t\, dt\right]\right]^{1/2}$$

$$= \left[\frac{I_0^2}{T}\left[\int_0^{T/2} \sin^2\omega t\, dt + \int_{T/2}^{T} \sin^2\omega t\, dt\right]\right]^{1/2}$$

$$= \left[\frac{I_0^2}{T}\left[\int_0^{T/2} \left(\frac{1-\cos 2\omega t}{2}\right) dt + \int_{T/2}^{T} \left(\frac{1-\cos 2\omega t}{2}\right) dt\right]\right]^{1/2}$$

$$= \left[\frac{I_0^2}{2T}\left[[dt]_0^{T/2} + (dt]_{T/2}^{T}\right]\right]^{1/2}$$

$$= \left[\frac{I_0^2}{2T}\left[\frac{T}{2} + \frac{T}{2}\right]\right]^{1/2} = \left[\frac{I_0^2}{2\cancel{T}} \cdot \cancel{T}\right]^{1/2}$$

$$\boxed{I_{rms} = \frac{I_0}{\sqrt{2}}} \quad \text{— IV}$$

③ Power supplied to Rectifier: –

$$P_{ac} = (I_{rms})^2 (R_f + R_L) = \left(\frac{I_0}{\sqrt{2}}\right)^2 (R_f + R_L) \quad \text{— V}$$

④ Average output power: →

$$P_{dc} = I_{dc}^2 \times R_L = \left(\frac{2 I_0}{\pi}\right)^2 \times R_L \quad \text{— VI}$$

⑤ Rectifier Efficiency: → It is defined as ratio of dc power delivered to load to the A.C power i/p from secondary of transformer.

i.e $$\eta = \frac{P_{dc}}{P_{ac}} = \frac{\left(\frac{2I_0}{\pi}\right)^2 \cdot R_L}{\left(\frac{I_0}{\sqrt{2}}\right)^2 (R_f + R_L)}$$

$$\boxed{\eta = 81.2 \cdot \frac{R_L}{R_f + R_L} \%}$$

So 81.2 % of A.c input power is converted into dc in load. The rest exists as A.c power in load.

(6) Ripple factor :→

$$\gamma = \left[\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1\right]^{1/2} = \left[\left(\frac{I_0}{\sqrt{2}}\right)^2 \Big/ \left(\frac{2I_0}{\pi}\right)^2 - 1\right]^{1/2}$$

$$\boxed{\gamma = 0.48}$$

Which means ripples are less than that in half wave rectifier.

(7) Peak Inverse voltage :→

It is maximum voltage appearing across the diodes in reverse bias.

In full wave rectifier,

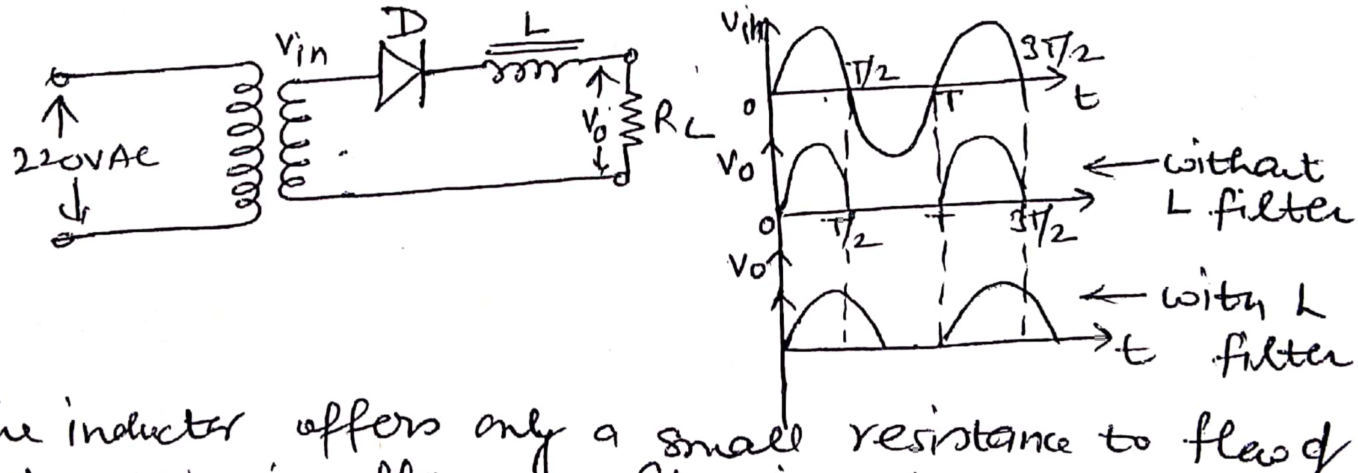
$$\boxed{PIV = 2V_0}$$

Filters: → The function of a rectifier is to convert a.c into d.c. However in both half wave and full wave rectifier output, variations or ripples exists. So output of rectifier is smoothened by using electronic circuits called filters.

Following types of filters are generally used:-

1. Induction (L) filter
2. Shunt capacitance filter
3. L section or Choke
4. π filter
5. RC filter circuit

1. Induction filter: → Fig below shows circuit of a half wave rectifier with induction (L) filter



The inductor offers only a small resistance to flow of dc, while it offers a high impedance (ωL) to flow of AC.

For dc $\omega \to 0$ so Impedance offered by inductor $(X_L) = \omega L \to 0$

For AC ω is large, so $X_L = \omega L$ is large

Hence, AC components of rectifier voltage are largely reduced by inductor, while dc passes through it without any resistance.

This is how induction filter works. Its working can

also be viewed from another aspect explained below.
The inductor stores up energy in the magnetic field when the current is above its average value and gives back the energy to load when the current tends to fall below the average value.

In a half wave rectifier without filter, the current in load resistance flows from time $t = 0$ to $T/2$ and time $t = T/2$ to T, it remains zero. It again flows from $t = T$ to $3T/2$ and remains zero for next half cycle.
When inductor filter is introduced in series, growth of current is opposed by inductor in first quarter cycle and during the next quarter cycle from $t = T/4$ to $T/2$, when current tends to fall, the period of current conduction is increased. Thus the gap of Non conduction from $T/2$ to T is filled to some extent.

Ripple factor with induction filter: → (For full wave Rectifier)

According to fourier Analysis, the output voltage for full wave rectifier is,

$$V = \frac{2V_o}{\pi}\left[1 - \frac{2}{3}\cos 2\omega t - \frac{2}{15}\cos 4\omega t \text{ ——— }\right] \quad \text{— I}$$

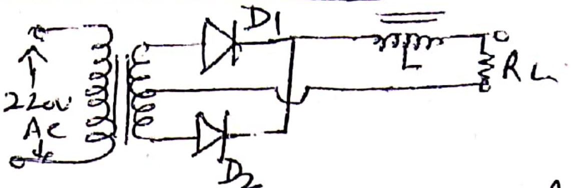
Let us consider only first two terms,

$$V = \frac{2V_o}{\pi} - \frac{4V_o}{3\pi}\cos 2\omega t \quad \text{— II}$$

So $$I_{dc} = \frac{2V_o}{\pi R_L} \quad \text{— III} \qquad \left[\because I = \frac{V}{R}\right]$$

Also from II Peak value of A.C voltage $= \frac{4V_o}{3\pi}$

$$\therefore \quad V_{rms} = \frac{1}{\sqrt{2}}\,\frac{4V_o}{3\pi} \quad \text{— IV} \qquad \left[\because V_{rms} = \frac{\text{Peak value}}{\sqrt{2}}\right]$$



Full wave Rectifier with L filter

$$\therefore I_{rms} = \frac{\frac{4V_0}{3\sqrt{2}\pi}}{\sqrt{R_L^2 + (2\omega L)^2}}$$

$$\therefore \text{Ripple factor } (r) = \frac{I_{rms}}{I_{dc}} = \frac{4V_0/3\sqrt{2}\pi}{\sqrt{R_L^2+(2\omega L)^2}} \Big/ \frac{2V_0}{\pi R_L}$$

$$r = \frac{\frac{4V_0}{3\sqrt{2}\pi}}{\sqrt{R_L^2+(2\omega L)^2}} \times \frac{\pi R_L}{2V_0}$$

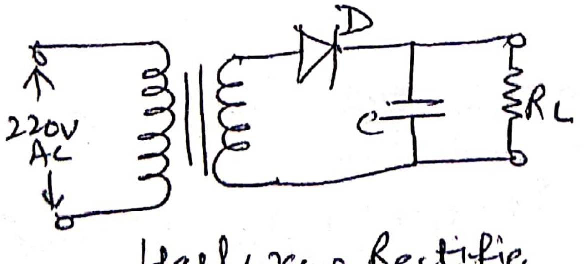
$$r = \frac{\overset{2}{\cancel{4}}\cancel{V_0}}{3\sqrt{2}\cancel{\pi}\sqrt{R_L^2+(2\omega L)^2}} \times \frac{\cancel{\pi}R_L}{\cancel{2V_0}}$$

$$r = \frac{2R_L}{3\sqrt{2}\sqrt{R_L^2+4\omega^2L^2}}$$

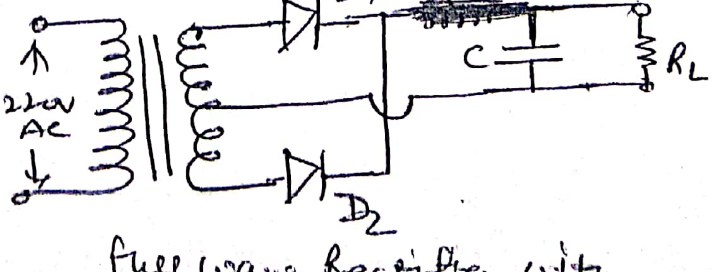
If $\frac{4\omega^2L^2}{R_L^2} >> 1 \Rightarrow r = \frac{2R_L}{3\sqrt{2}\sqrt{4\omega^2L^2}} = \frac{\cancel{2}R_L}{3\sqrt{2}\cancel{2}\omega L}$

$$\boxed{r = \frac{R_L}{3\sqrt{2}\,\omega L}}$$

2) Shunt Capacitance filter: → Fig below shows a half wave Rectifier with shunt C filter and a full wave rectifier with shunt C filter.



Half wave Rectifier with Shunt Cap. filter



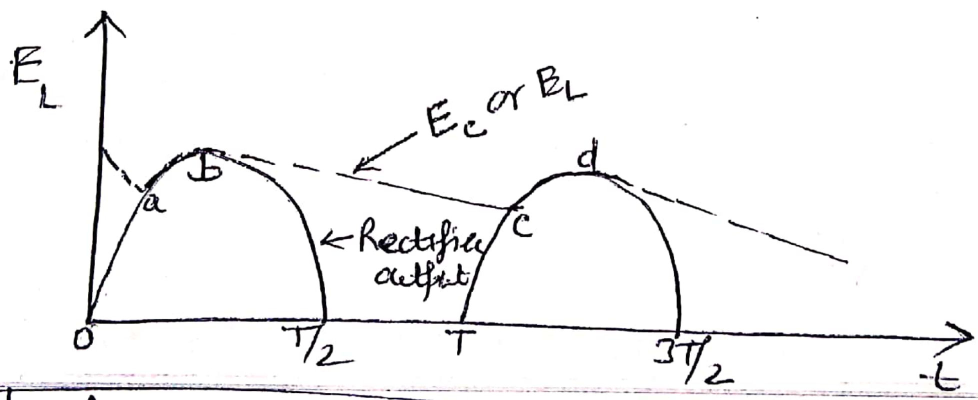
Full wave Rectifier with Shunt Cap. filter

The capacitive Reactance $X_C = \frac{1}{\omega C}$

for dc components, $\omega \to 0$, $X_C \to \infty$

for AC components, $\omega \to$ High, $X_C \to$ low

So AC components can pass through the capacitor. The dc component is almost blocked by the capacitor. During the +ve half cycle of input, diode conducts and capacitor C charges to peak value of supply voltage. This is shown by point b in fig. The capacitor holds the charge till the input ac supply to the rectifier goes negative. During -ve half cycle, diode stops conducting. Now condenser discharges through load resistance R_L and loses charge. The voltage E_L across R_L decreases exponentially along curve bc as shown. The process of charging and discharging of capacitor repeats for each cycle of input supply voltage.

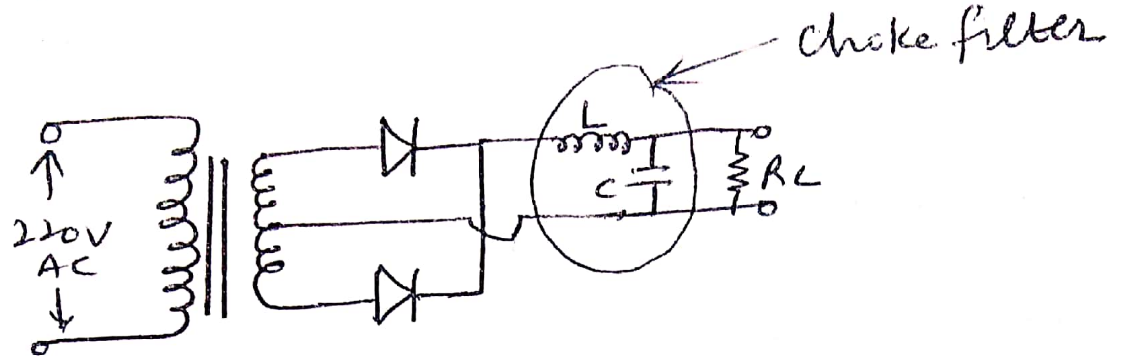


$$\boxed{\text{Ripple factor} = \frac{1}{4\sqrt{3}\,\nu C R_L}}$$

(3) L section or choke input type filter →

It is a combination of series inductor and shunt capacitance.

Fig below shows full wave rectifier with a choke input filter.



Inductor offers a high impedance $X_L = \omega L$ to a.c and thus reduces a.c components, while it offers negligible resistance to d.c components. The shunt capacitor bye pass a.c components and does not allow them to flow across Load. Thus ripples in output are considerably reduced by combination of these two L and C jointly called as choke filter.

From fourier analysis, $(V_{Peak})_{inductor} = \frac{4V_0}{3\pi}$

$$\therefore (V_{rms})_{indu} = \frac{4V_0}{\sqrt{2}\,3\pi} \qquad \left[V_{rms} = \frac{1}{\sqrt{2}} V_{peak}\right]$$

$$\therefore (I_{rms})_{inductor} = \frac{4V_0}{\sqrt{2}\,3\pi} \Big/ X_L \qquad X_L = 2\omega L$$

The same current flows through capacitor and therefore rms value of A.C voltage across it is,

$$(V_{rms})_{cap} = (I_{rms})_{indu} \cdot X_C$$

$$= \frac{4V_0}{3\sqrt{2}\pi \cdot X_L} \cdot X_C = \frac{4V_0}{3\sqrt{2}\pi} \frac{1}{2\omega C \cdot 2\omega L}$$

$$(V_{rms})_{cap.} = \frac{V_0}{3\sqrt{2}\,\pi\omega^2 LC}$$

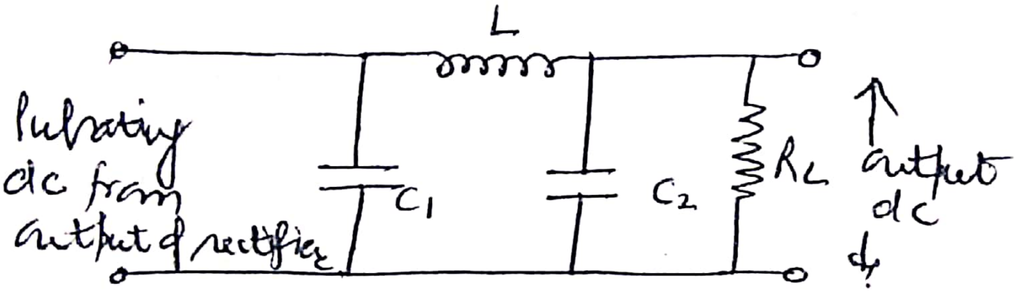
The value of $V_{dc} = \frac{2V_0}{\pi}$

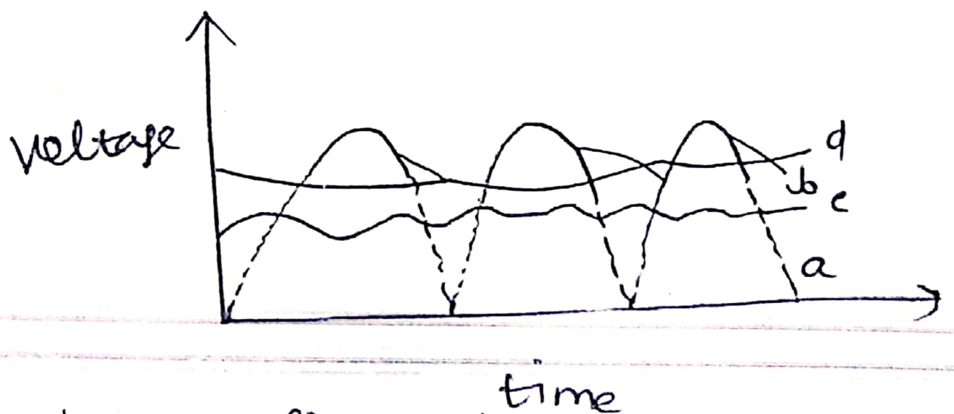
$\therefore$ ripple factor $r = \frac{V_{rms}}{V_{dc}} = \frac{V_0}{3\sqrt{2}\cancel{\pi}\omega^2 LC} \times \frac{\cancel{\pi}}{2\cancel{V_0}}$

$$\boxed{r = \frac{1}{6\sqrt{2}\omega^2 LC}}$$

(4) π- filter →

As the name indicates, the shape of this filter resembles with π. Fig below shows π filter section.





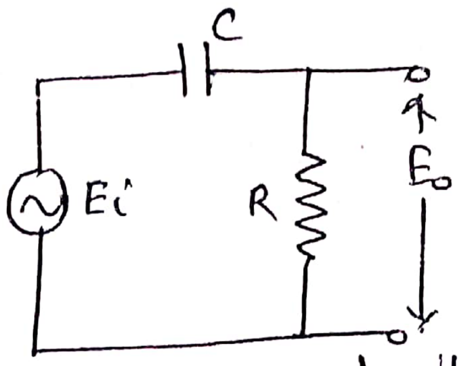
It consists of first capacitor C_1 to smooth and support the output voltage as in shunt capacitor filter. The action of 2nd part $L-C_2$ filter is that of choke filter. The choke filter reduces the ripple contained in output of shunt cap. filter C_1.

The curve 'a' shows d.c output from full wave rectifier without filter. The curve 'b' shows the output of shunt capacitor filter, The curve 'c' shows the smooth output from choke input filter. Thus the resultant waveform with π-filter is shown by 'd' curve.

(5) RC filter circuit :-

RC circuit filter consist of a resistor and a capacitor. These are of two types
(i) High pass R-C circuit
(ii) Low pass R-C circuit

(i) High pass R-C circuit :-



The reactance of a capacitor c is

$$X_C = \frac{1}{\omega C}$$

Since at high frequencies, X_C is small, almost all the high frequency input a.c appears at the output, the low freq. A.c is almost rejected. Therefore this acts as high pass filter.

Let $E_i = (E_i)_m \sin\omega t$ — (I)

$(E_i)_m$ is peak value of input voltage.

Then current $(I) = \dfrac{E_i}{\left(R^2 + \frac{1}{\omega^2 C^2}\right)^{1/2}}$ — (II)

In a CR circuit current I leads the emf by angle θ, so that

$$I = I_m \sin(\omega t + \theta) \quad \text{— (III)}$$

Now output voltage

$$E_o = IR = I_m R \sin(\omega t + \theta) \quad \text{— (IV)}$$

Max. peak value of o/p emf $= (E_o)_m = I_m R$ — (V)

$\therefore$ from (IV) & (V)

$$E_o = (E_o)_m \sin(\omega t + \theta) \quad \text{— (VI)}$$

Comparing eqn (VI) with (I) we find that output voltage lead the input voltage by angle θ.

Now using (II) and (I),

$$E_o = IR$$

$$\Rightarrow E_o = \frac{E_i}{(R^2 + 1/\omega^2 C^2)^{1/2}} \cdot R = \frac{(E_i)_m R \sin\omega t}{\left(R^2 + \frac{1}{\omega^2 C^2}\right)^{1/2}} \quad \text{— (VII)}$$

Max. value of $\sin\omega t = 1$

$\therefore$ Max. value of output voltage $(E_o)_m$ is

$$(E_o)_m = \frac{(E_i)_m R}{\left(R^2 + \frac{1}{\omega^2 C^2}\right)^{1/2}}$$

$$\Rightarrow \frac{(E_o)_m}{(E_i)_m} = \frac{R}{\left(R^2 + \frac{1}{\omega^2 C^2}\right)^{1/2}} = \frac{1}{\left[1 + \frac{1}{\omega^2 C^2 R^2}\right]^{1/2}} \quad \text{— VIII}$$

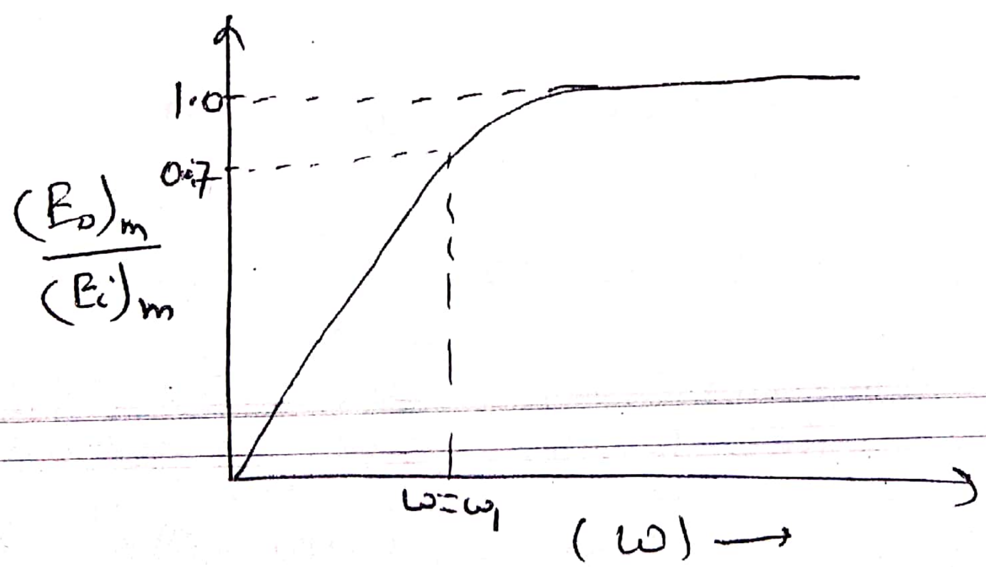
At $\omega = 0$, $\frac{(E_o)_m}{(E_i)_m} = 0$

at $\omega \to \infty$ $\frac{(E_o)_m}{(E_i)_m} = 1$

$\therefore$ Eq VIII can also be written as

$$\frac{(E_o)_m}{(E_i)_m} = \frac{1}{\left[1 + \frac{\omega_1^2}{\omega^2}\right]^{1/2}}$$

where $\omega_1 = \frac{1}{RC}$

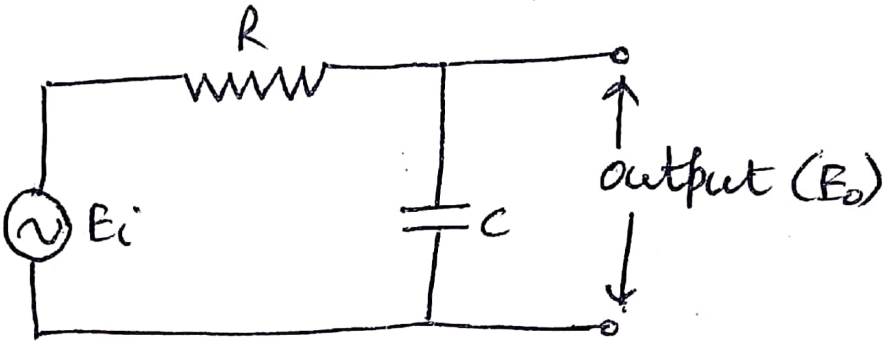


$\omega_1 = \frac{1}{RC}$ is lower cutoff frequency.

So At high freq. voltage gain approaches unity.

Low pass RC circuit:

Fig below shows a low pass RC circuit. The diff between High pass and low pass RC circuit is that in low pass RC circuit, output voltage is obtained across capacitor.



The reactance of capacitor $X_C = \frac{1}{\omega C}$ is very small for high frequencies. Therefore almost all the low input appears across capacitor. So ckt acts as low pass filter and reject high frequencies.

Let

$$E_i = (E_i)_m \sin\omega t \quad \text{——— (I)}$$

is input voltage.

The current through ckt is

$$I = \frac{E_i}{\left(R^2 + \frac{1}{\omega^2 C^2}\right)^{1/2}} \quad \text{——— (II)}$$

$$E_0 = (E_0)_m \sin(\omega t - \theta) \quad \text{——— (III)}$$

Output voltage is

$$E_0 = \frac{I}{\omega C} \quad \text{——— (IV)}$$

from I, II and IV

$$E_0 = \frac{E_i'}{\left(R^2 + \frac{1}{\omega^2 C^2}\right)^{1/2} \cdot \omega C}$$

$$E_0 = \frac{(E_i')_m \sin\omega t}{\omega C\left(R^2 + \frac{1}{\omega^2 C^2}\right)^{1/2}}$$

Max. value of $\sin\omega t = 1$

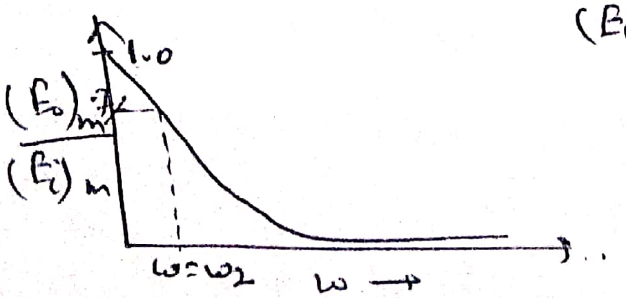
$$\therefore (E_0)_m = \frac{(E_i')_m}{\omega C\left(R^2 + \frac{1}{\omega^2 C^2}\right)^{1/2}}$$

$$\frac{(E_0)_m}{(E_i')_m} = \frac{1}{(1 + \omega^2 C^2 R^2)^{1/2}}$$

Let $\omega_2 = \frac{1}{CR}$

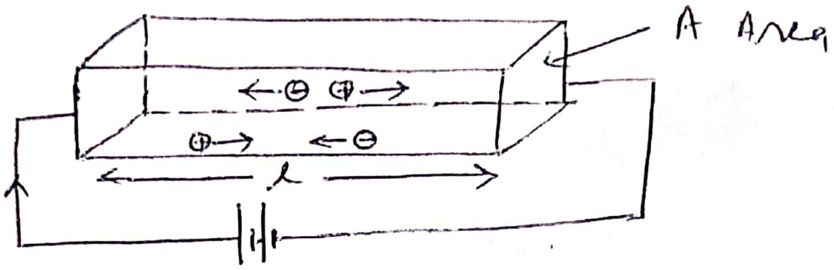
$$\therefore \frac{(E_0)_m}{(E_i')_m} = \frac{1}{\left[1 + \left(\frac{\omega}{\omega_2}\right)^2\right]^{1/2}}$$

At $\omega = \omega_2$ $\frac{(E_0)_m}{(E_i)_m} = .707$



3. Carrier Mobilities and Electrical Resistivity of semiconductor

Consider a block of semiconductor of length l and area of cross section A.



Let n_e and n_h be no. densities of free electrons & holes. Let current I flows through the semiconductor block, when a potential diff. is V is applied across it. Since flow of current in a semiconductor is due to motion of both electrons and holes, so

$$I = I_e + I_h \quad \text{—— (I)}$$

where I_e and I_h are current due to motion of electrons and current due to motion of holes respectively.

Eq^n (I) can be rewritten as,

$$I = n_e A e v_e + n_h A e v_h \qquad [\because I = neAv_d]$$

where v_e, v_h are drift velocity of electrons & holes.

$$\Rightarrow I = eA(n_e v_e + n_h v_h) \quad \text{—— (II)}$$

$$\Rightarrow \frac{V}{R} = eA(n_e v_e + n_h v_h)$$

$$\Rightarrow \frac{El}{R} = eA(n_e v_e + n_h v_h) \qquad \left[\because \frac{V}{l} = E\right]$$

$$\Rightarrow \frac{E}{RA/l} = e(n_e v_e + n_h v_h)$$

$$\Rightarrow \frac{E}{\rho} = e(n_e v_e + n_h v_h) \quad \text{—— (III)}$$

Now Mobility (μ) of electrons or holes is defined as drift velocity per unit electric field. i.e.

$$\left.\mu_e = \frac{v_e}{E} \qquad \mu_h = \frac{v_h}{E}\right] \quad \text{—— (IV)}$$

using III and IV, we get

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$$\frac{1}{\rho} = \frac{e(n_e v_e + n_h v_h)}{E}$$

$$\frac{1}{\rho} = e(n_e \mu_e + n_h \mu_h)$$

$$\Rightarrow \boxed{\sigma = e(n_e \mu_e + n_h \mu_h)}$$

where σ is conductivity.

~~Hall Effect~~: →