

**NCERT-XII / Unit- 14 / Semiconductor**

**Semi conductor**

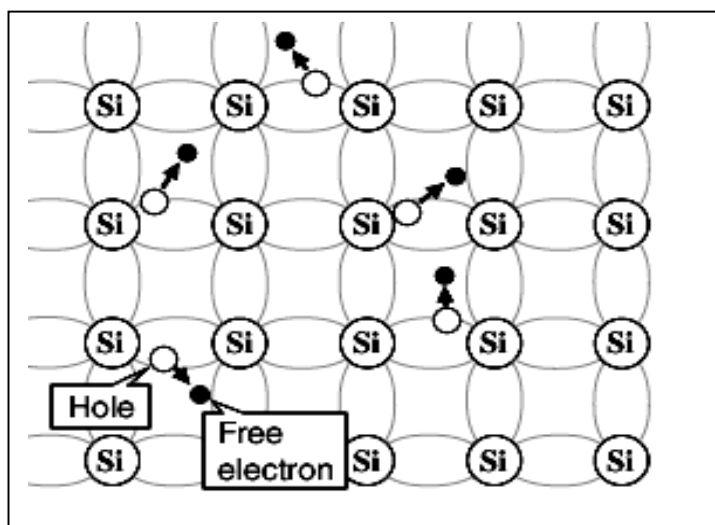
It is a class of material having its conductor band separated from the valance band by a narrow band of forbidden energy gab of 0.2ev to 2.5ev.

At absolute zero, its conductor band is totally empty, it behaves like an insulator . At higher temp, some electrons move from valance band to conduction band under the action of an electric field.

Semi conductors are divided into two categories -

1) **Intrinsic semi conductor :-**

A pure semi conductor like Ge or Si in which conduction possible due to equal no. of thermally generated holes and electrons is known as intrinsic semiconductor At zero Kelvin, all valance electrons of Ge or Si atoms are attached to their respective atoms, so they behave like an insulator. It temp increases, due to thermal agitation, one of the electron of the outer shell may dislodged, breaking



the covalent bond and thus leaving behind a hole. An adjacent with sufficient energy may jump into the hole position and reconstructing the bond, thereby a hole at another position. Another electron from any of the neighboring atom may come to complete the bond. In this way equal no. of holes and electrons move in the crystal randomly.

**Limitation of intrinsic semi conductor**

- i) The no of intrinsic charge carriers is very small of about  $10^{16} \text{ m}^{-3}$ , resulting low conductivity.
- ii) Intrinsic charge carriers are thermally generated .so it is not possible to control their number.
- iii) As the no. of hole is equal to no of electron  $n_e = n_h$ , it does not have dominant holes or electrons.

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**To overcome the drawback of Intrinsic semi conductor**

**Doping** :- It is process of deliberate addition of a desirable impurity atom to a pure semiconductor to increase its conductivity.

**Dopants** :- The impurity atoms added to a pure semiconductor is known as dopant .

**They are of two types**

- i) Trivalent atoms like Al, B, Ga, In etc. acceptor impurities.
- ii) Pentavalent atoms like As, Sb, P etc. donor impurities.

**Method of doping** :-

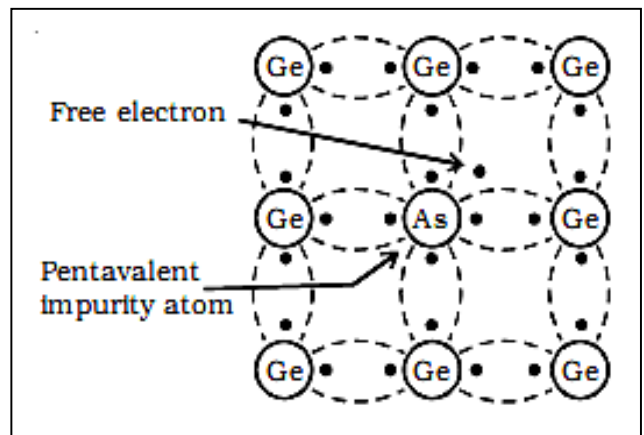
- 1) It is achieved by adding impurity atom to a pure sample of a molten semiconductor.
- 2) By heating the semi conductor in an atom sphere containing dopant atoms so that it diffuses into it.
- 3) By bombarding the semiconductor with dopant atoms.

**Extrinsic semiconductor**

Depending on the types impurity, it is of two types

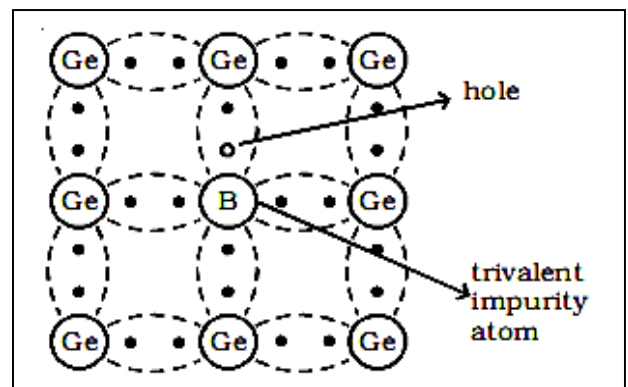
1. **N-types semiconductor**

The extrinsic semi conductor which is obtained due to addition of pentavalent impurity atoms like Sb, As to pure semi conductor crystal, of which four balance electrons have the covalent bonding with semiconductor atom and the free fifth electron makes the electrons, the majority charge carrier is known as N-type semi conductor.



2. **P-type semiconductor**

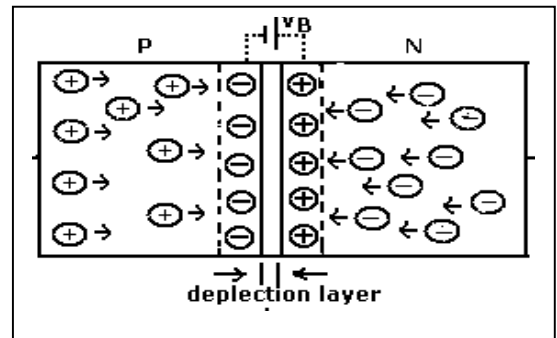
The extrinsic semi conductor which is obtained due to addition of trivalent impurity atoms like B, Al to pure semiconductor crystal, in which each impurity atom produces a hole in the crystal by extracting an electron to share co-valent bonding with the semiconductor atom and making hole, the majority charge carriers is known as p-type extrinsic.



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**P.N junction Diode**

When a p-type semi conductor is placed in contact with an N-type semiconductor, forming layer of immobile charge carriers across the junction, the combination is known as P-N junction diode.



**Depletion layer** :- When a p-type semiconductor is placed in

contact with an N-type semiconductor, diffusion of electrons from N-type and holes from p-type take place across the junction, forming a layer of immobile charge carriers across the junction, which oppose further diffusion of holes and electron is known as depletion layer.

**Barrier field** :The electric field set up across the junction due to the immobile charge carrier is known as Barrier field.

The potential diff. developed across the junction is known as **barrier potential**.

**Biasing of a pn junction diode**:- The process by which a PN junction diode is connected to a battery is called biasing.

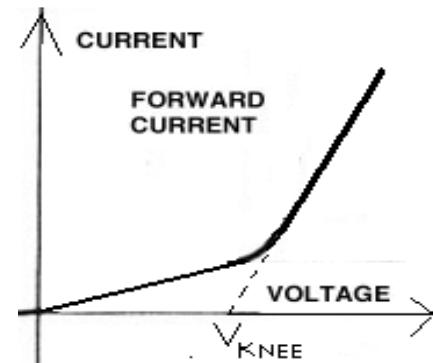
Forward Biasing	Reverse Biasing
2. When +ve terminal of the battery is connected to the p section and -ve terminal of the battery is connected to N-section of the junction diode, then it is said to be forward biased.	2. When -ve terminal of the battery is connected to p section and -ve terminal is connected to the N-section of the junction diode , then it is reverse biased
3. The positive terminal of the battery repels the holes in p section and -ve terminal of the battery repels the electron in N- section towards the junction , so conduction takes place across the junction.	3. During reverse biasing holes in p-section and election in N-section are attracted by the connecting terminals of the battery, so they move away from the junction making conduction impossible.
4. Thickness of depletion layer decreases .	4. Thickness of depletion layer increases.
5. The junction offer low resistance during foreword biasing	5. The junction offer high resistance during foreword biasing

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**Characteristic of junction Diode :-**

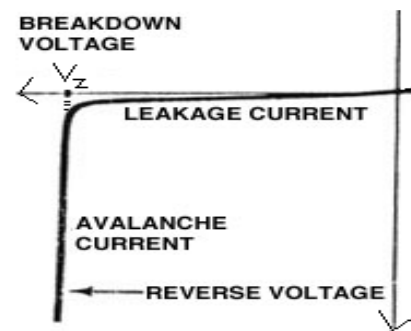
**1. Forward bias characteristic**

At zero battery voltage, diode current is zero, As battery voltage increases, current increases slowly, but after a certain voltage called knee voltage, current increases rapidly. After knee voltage, junction diode behaves like an insulator.

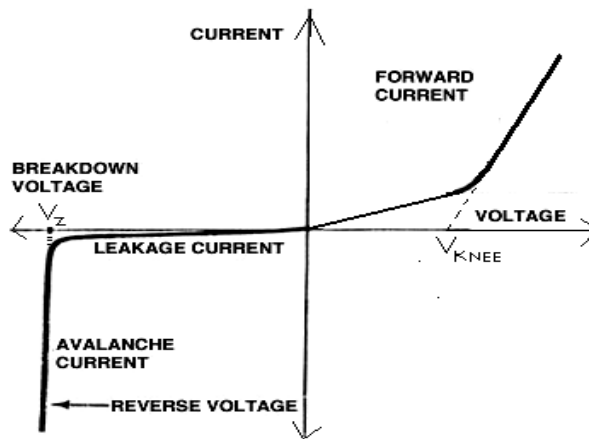


**2. Reverse bias characteristic**

During reverse biasing, a small current flows due to minority charge carrier, which depends on temperature of junction diode. As the reverse voltage is increased, there is a abrupt rise in the reverse current at a certain value of reverse voltage known as **Zener voltage or break down voltage**



. At zener voltage a large no of covalent bonds are broken, as a result, a large electron hole pair are produced which diffuses through the junction giving a sudden false in reverse current.



**Dynamic resistance**

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

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

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**Rectification**

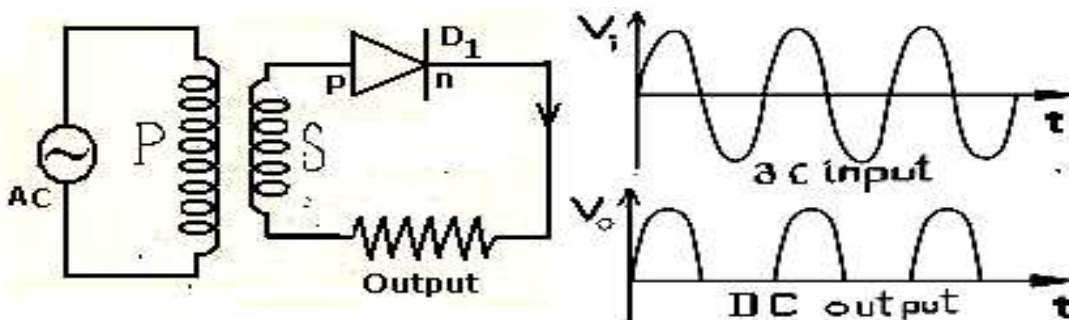
The process by which alternating current or voltage can be converted into direct current or voltage is known as rectification.

The device which can convert A.C into D.C. is known as rectifier.

PN junction diode is a rectifier which works as -

- i) Half wave rectifier.
- ii) Full wave rectifier.

**Half wave Rectifier :**



The above circuit diagram is showing the electrical arrangement of a half wave rectifier.

The alternating voltage to be rectified is connected across the primary coil of a step down transformer, whose one end of the secondary is connected to the p section of the junction diode, while other end is connected to N section through a load resistance  $R_L$ .

During the +ve half cycle of a.c. input, junction diode is forward biased and conduction will take place through it giving an out put of same shape as of +ve half cycle of a.c. input.

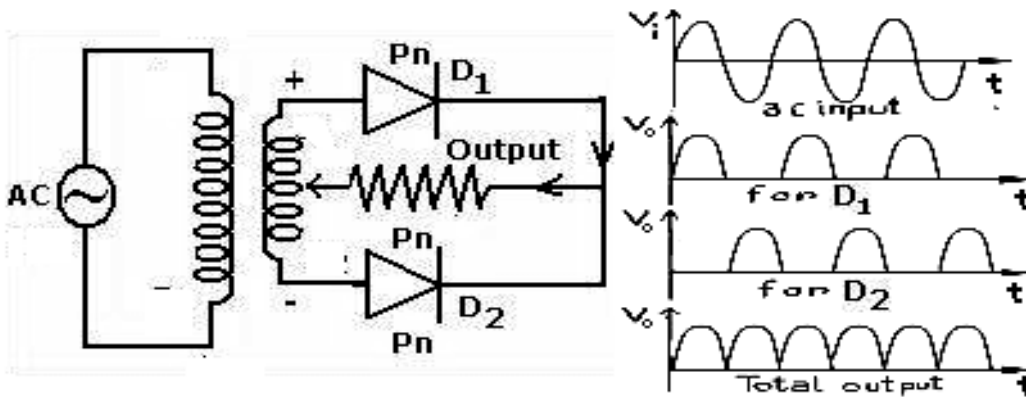
During the next -ve half cycle junction diode is reverse biased giving no output across  $R_L$ .

Thus only for the +ve half cycle of the a.c. input, we are getting d.c. out put across  $R_L$  which is unidirectional, discontinuous and pulsating in nature as seen from the variation of out-put and input.

This is known as half wave rectifier.

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Full wave Rectifier :



The diagram is showing the circuit arrangement of a full wave rectifier.

The alternating voltage to be rectified is connected across the primary of a step down centre tapped transformer whose two ends of the secondary is connected to the p section of two junction diodes  $D_1$  and  $D_2$ . The N sections are connected to the centre tapping key through a load resistance  $R_L$ , across which D.C. out put voltage is taken.

Since the transformer is centre tapping in nature, it divides the potential across secondary into two equal and opposite halves, Let for the +ve half cycle of a.c. input, upper half be +ve and lower half be -ve. So  $D_1$  will be forward biased and  $D_2$  will be reversed biased. so we will get d.c. out put across  $R_L$  due to conduction through  $D_1$ .

For the next -ve half cycle of input a.c., upper half will be -ve and lower half will be +ve. so  $D_2$  is forward biased while  $D_1$  is reversed biased. so we will get d.c. out put across  $R_L$  in the same direction due to conduction through  $D_2$ .

Thus for both the half of a.c. input we are getting d.c. out put across  $R_L$ , which is pulsating, continuous and unidirectional known as, full wave rectifier.

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**1. Zener diode**

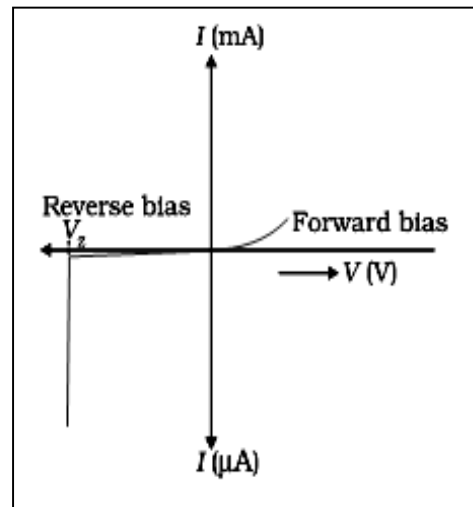
It is a semiconductor diode, operating under reverse bias in the breakdown region and used as a voltage regulator.

Zener diode is heavily doped p-side and n-sides. Due to this, depletion region formed is very thin ( $<10^{-6}$  m) and the electric field of the junction is extremely high ( $\sim 5 \times 10^6$  V/m) even for a small reverse bias voltage of about 5V.

**I-V characteristics of a Zener diode**

It is seen that when the applied reverse bias voltage(V) reaches the breakdown voltage ( $V_z$ ) of the Zener diode, there is a large change in the current. After the breakdown voltage  $V_z$ , a large change in the current can be produced by almost insignificant

change in the reverse bias voltage. In other words, Zener voltage remains constant, even though current through the Zener diode varies over a wide range.



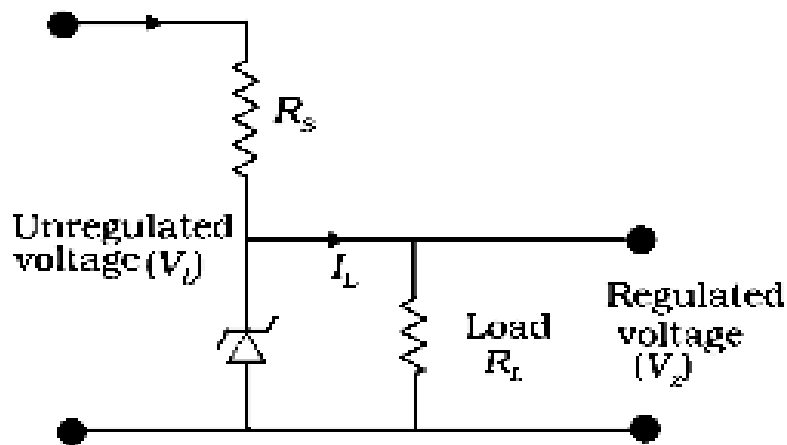
**Why and how reverse current suddenly increases at the breakdown voltage ?**

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

**What is internal field emission or field ionisation.** The emission of electrons from the host atoms due to the high electric field is known as internal field emission or field ionisation. The electric field required for field ionisation is of the order of  $10^6$  V/m.

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Zener diode as a voltage regulator



To get a constant dc voltage from the dc unregulated output of a rectifier, we use a Zener diode.

The unregulated dc voltage (filtered output of a rectifier) is connected to the reverse biased Zener diode through a series resistance  $R_s$ .

If the input voltage increases, the current through  $R_s$  and Zener diode also increases, increasing the voltage drop across  $R_s$  without changing the voltage across the Zener diode. Similarly, if the input voltage decreases, the current through  $R_s$  and Zener diode also decreases. The voltage drop across  $R_s$  decreases without changing the voltage across the Zener diode. This is because in the breakdown region, Zener voltage remains constant even though the current through the Zener diode changes.

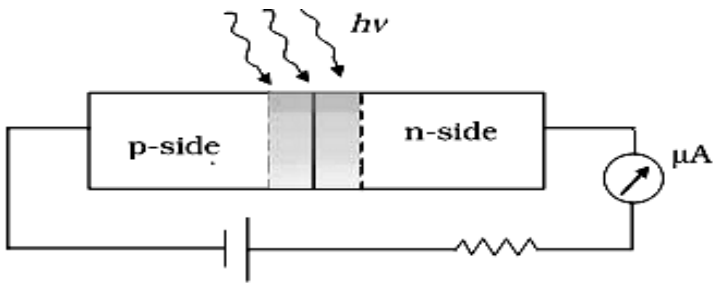
Thus the Zener diode acts as a voltage regulator.

We have to select the Zener diode according to the required output voltage and accordingly the series resistance  $R_s$ .



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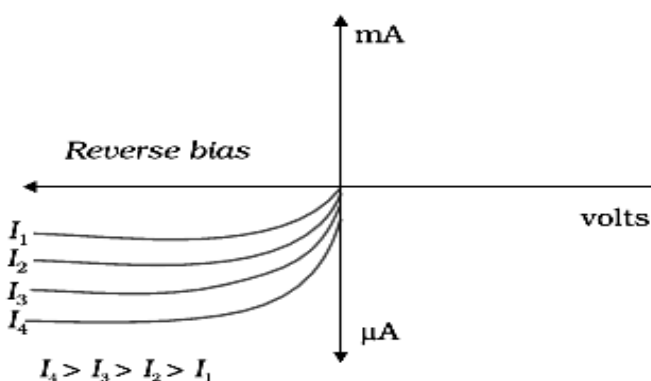
2. Photodiode



A Photodiode is reverse biased p-n junction diode fabricated with a transparent window to allow light to fall on the diode.

When the photodiode is illuminated with light (photons) with energy ( $h\nu$ ) greater than the energy gap ( $E_g$ ) of the semiconductor, then electron-hole pairs are generated due to the absorption of photons, in or near the depletion region. Due to electric field of the junction, electrons and holes are separated before they recombine, electrons reach n-side and holes reach p-side. Electrons are collected on n-side and holes are collected on p-side giving rise to an emf. When connected to an external load is, current flows, whose magnitude depends on the intensity of incident light.

The photodiode can be used as a photo detector to detect optical signals. The I-V characteristics of a photodiode is shown below



**NCERT-XII / Unit- 14 / Semiconductor****3. Light emitting diode**

It is a heavily doped p-n junction which under forward bias emits spontaneous radiation, having a transparent cover so that emitted light can come out. When the diode is forward biased, electrons are sent from  $n \rightarrow p$  (where they are minority carriers) and holes are sent from  $p \rightarrow n$  (where they are minority carriers). At the junction boundary the concentration of minority carriers increases as compared to the no bias state. Thus at the junction boundary on either side of the junction, excess minority carriers recombine with majority carriers, releasing energy in the form of photons. Photons with energy equal to the band gap are emitted.

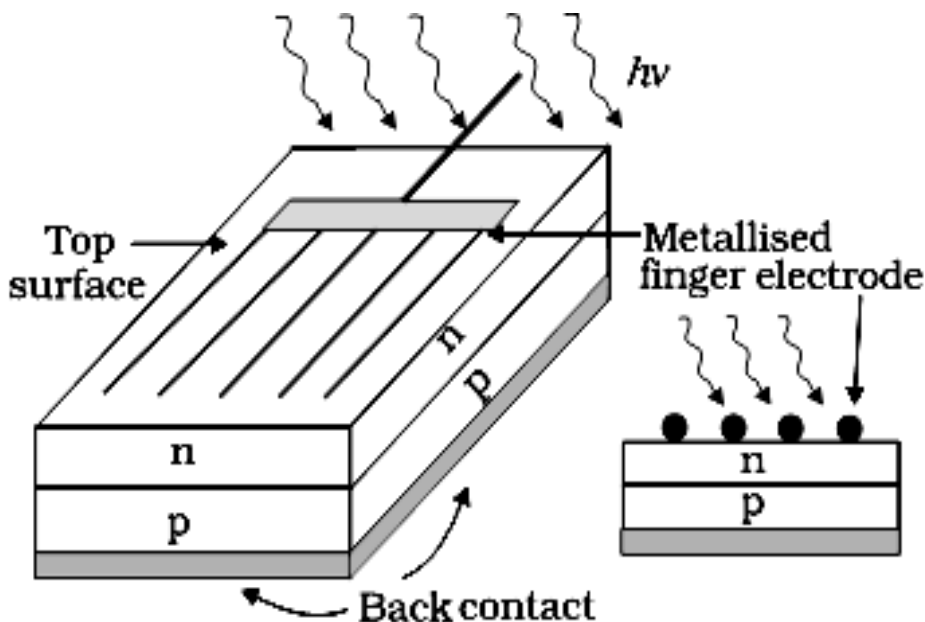
**Important points of LED**

1. Intensity of light increases as the forward current increases and reaches a maximum, with further increase in the forward current, light intensity decreases.
2. LEDs that can emit **red, yellow, orange, green and blue** light are commercially available.
3. The semiconductor with band gap from 1.8 eV to 3.0 eV used for visible LED.
4. Compound semiconductor **Gallium Arsenide- Phosphide** ( $\text{GaAs}_{1-x}\text{P}_x$ ) is used for making LEDs of different colours.  
**GaAs<sub>0.6</sub>P<sub>0.4</sub>** ( $E_g \sim 1.9$  eV) is used for red LED.  
**GaAs** ( $E_g \sim 1.4$  eV) is used for making infrared LED.
5. LEDs find extensive use in remote controls, burglar alarm systems, optical communication, etc.
6. Advantages of LED over incandescent low power lamps :
  - (i) Low operational voltage and less power.
  - (ii) Fast action and no warm-up time required.
  - (iii) The bandwidth of emitted light is monochromatic.
  - (iv) Long life and ruggedness.
  - (v) Fast on-off switching capability.

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**4. Solar cell**

A solar cell is a unbiased p-n junction which generates emf when solar radiation falls on the p-n junction.

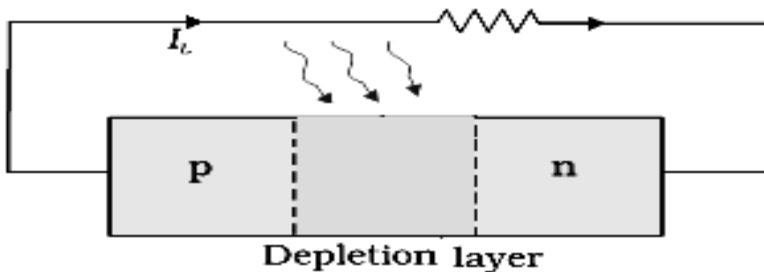


**Construction:-**

It works on the principle of photovoltaic effect, with much larger junction area. A p-Si wafer of about 300  $\mu\text{m}$  is taken over which a thin layer ( $\sim 0.3 \mu\text{m}$ ) of n-Si is grown on one-side by diffusion process. The other side of p-Si is coated with a metal (back contact). On the top of n-Si layer, metal finger electrode (or metallic grid) is deposited. This acts as a front contact. The metallic grid occupies only a very small cell area so that light can be incident on the cell from the top.

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**Generation of emf by a solar cell**



The generation of emf by a solar cell, when light falls on, it is due to the following three basic processes:

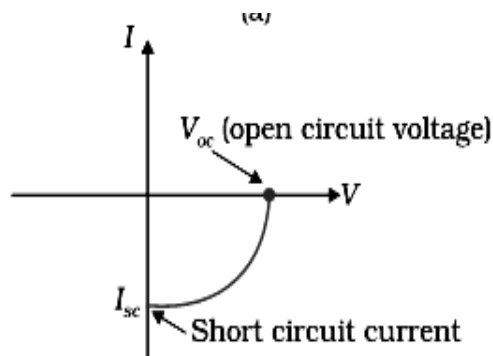
**generation, separation** and **collection** . They are —

- (i) generation of e-h pairs due to light (with  $h\nu > E_g$ ) close to the junction;
- (ii) separation of electrons and holes due to electric field of the depletion region .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 becomes negative giving rise to photo-voltage. When an external load is connected as shown in the above figure , a photocurrent  $I_L$  flows through the load.

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**The I-V characteristics of a solar cell is shown below**



The I – V characteristics of solar cell is drawn in the fourth quadrant of the coordinate axes.

This is because a solar cell does not draw current but supplies the same to the load.

Material for solar cell :- Semiconductors with band gap close to 1.5 eV are ideal materials for solar cell. Solar cells are made with semiconductors like Si ( $E_g = 1.1$  eV), GaAs ( $E_g = 1.43$  eV), CdTe ( $E_g = 1.45$  eV), CuInSe<sub>2</sub> ( $E_g = 1.04$  eV)

Important criteria for selection of material for solar cell

- (i) band gap ( $\sim 1.0$  to  $1.8$  eV), (ii) high optical absorption ( $\sim 10^4$  cm<sup>-1</sup>),  
(iii) electrical conductivity, (iv) availability of the raw material, (v) cost.

Uses :-

Solar cells are used to power electronic devices in satellites and space vehicles and also as power supply to some calculators. Production of low-cost photovoltaic cells for large-scale solar energy is a topic for research.

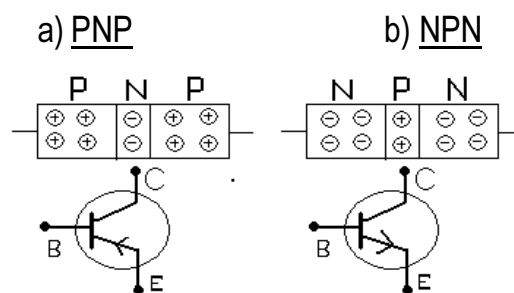
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**TRANSISTOR**

Whenever a definite type of semiconductor is sandwiched between the two other type, the combination is known as transistor. It is a three terminal device, which are known as

- (i) Emitter (E) :- To emit a definite type of charge carrier.
- ii) Base(B) :- To provide a connectivity between E and C.
- iii) Collector(C) :- To collect the charge carrier from E through B e.

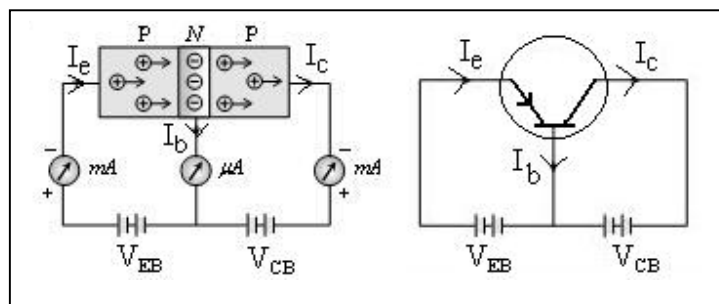
There are two types of semi-conductor -



The arrow in E indicates the flow of hole from emitter to base.

**WORKING OF PNP TRANSISTOR**

The above diagram showing the circuital arrangement for the working of out PNP transistor. Here the input circuit should be forward biased while the out put

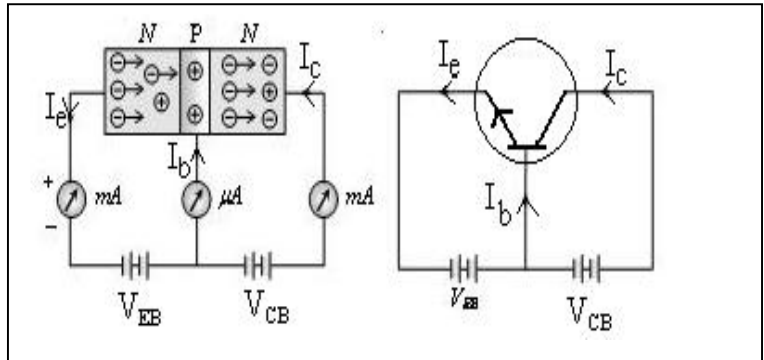


circuit should be reverse biased. Due to forward biasing voltage holes in the p-type emitter will be repelled towards the base which is N-type. In case 5% hole and electron recombination will take place. Out of the remaining 95% hole of the emitter, every hole reaching the collector, increase concentration of the holes. Every extra hole reaching the collector will be neutralised by the reverse biasing battery by sending an electron to the collection. In the mean time a covalent bond is break down in the emitter releasing an electron and creating a hole is it. This hole will make up the lose of hole in the emitter while the electron will be swept away by the +ve terminal of forward biasing battery. In this away, is the external circuit electrons flow while inside the semiconductor holes flow constituting  $I_e, I_b, I_c$  as emitter current, base current & collector current  $I_e = I_b + I_c$

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**Working of PNP Transistor**

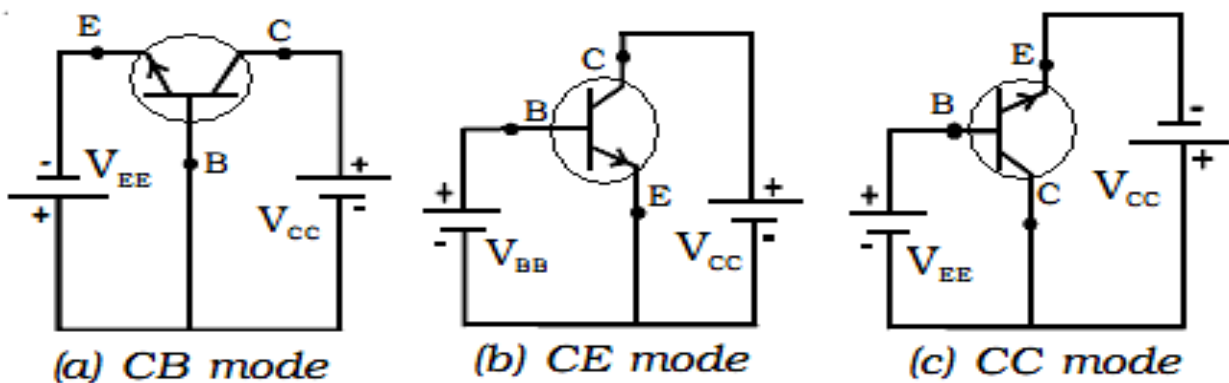
The above diagram is showing the circuitual arrangement for the working of NPN transistor. Here the input circuit is forward biased while the out put circuit is reversed biased. Due to the reverse biasing battery electrons is the emitter



will be repelled towards the base where 5% hole and electrons recombination will take place. Out of the remaining 95% electrons in the emitter, every electron reaching the collection through the base increases the electron concentration in the collector. Every extra electron reaching the collector will be swept away by the +ve terminal of the reverse biasing battery. The loss of electron in the emitter will be made up by supplying an electron by the forward biasing battery.

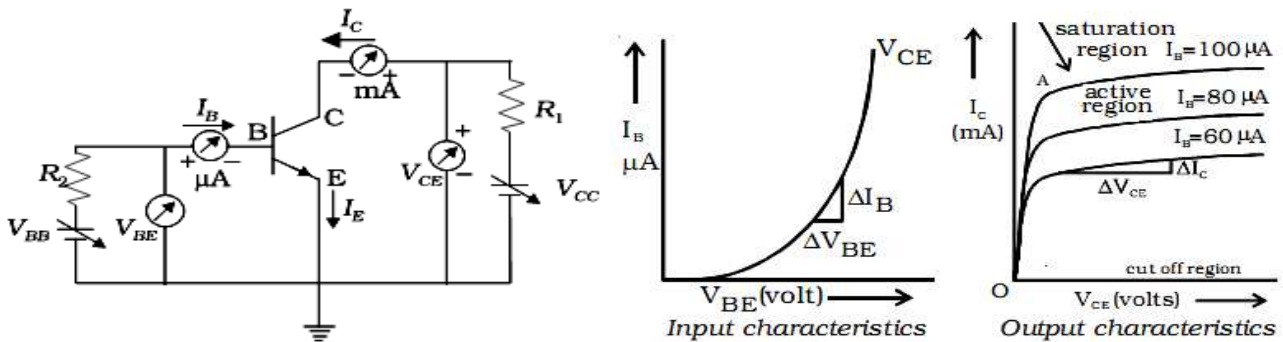
In this away in the external circuit and through the transistor, electrons flow constituting  $I_e, I_b, I_c$  as emitter current, base current and collector current, so that  $I_e = I_b + I_c$

**Three configuration of transistor**



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**Common emitter transistor characteristics**



**(i) Input characteristic:-** The variation of the base current \$I\_B\$ with the base-emitter voltage \$V\_{BE}\$ is called the input characteristic.

**Input resistance:-** (\$r\_i\$): This is defined as the ratio of change in base-emitter voltage (\$\Delta V\_{BE}\$) to the resulting change in base current (\$\Delta I\_B\$) at constant collector-emitter voltage (\$V\_{CE}\$).

$$r_i = \left( \frac{\Delta V_{BE}}{\Delta I_B} \right)_{V_{CE}}$$

**(ii) Output characteristic:-** The variation of the collector current \$I\_C\$ with the collector-emitter voltage \$V\_{CE}\$ is called the output characteristic.

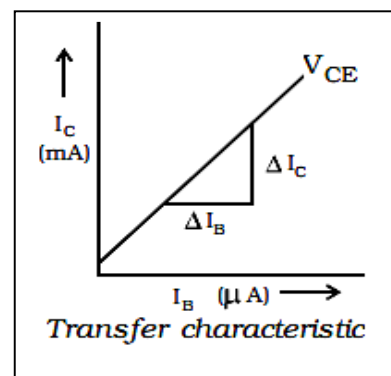
**Output resistance (\$r\_o\$):** This is defined as the ratio of change in collector-emitter voltage (\$\Delta V\_{CE}\$) to the change in collector current (\$\Delta I\_C\$) at a constant base current \$I\_B\$.

$$r_o = \left( \frac{\Delta V_{CE}}{\Delta I_C} \right)_{I_B}$$

**(iii) Transfer characteristic -** The transfer characteristic curve is drawn between \$I\_C\$ and \$I\_B\$, when \$V\_{CE}\$ is kept constant.

**Current amplification factor (\$\beta\$):** This is defined as the ratio of the change in collector current to the change in base current at a constant collector-emitter voltage (\$V\_{CE}\$) when the transistor is in active state.

$$\beta_{ac} = \left( \frac{\Delta I_C}{\Delta I_B} \right)_{V_{CE}}$$





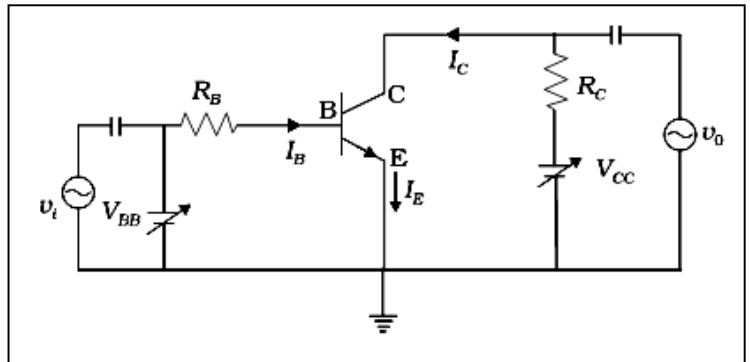
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**Transistor as an Amplifier (CE-Configuration)**

Let us consider a base-biased transistor in CE configuration as shown in above figure ,in which , voltage equation of the input and output circuit are

$$V_{BB} = I_B R_B + V_{BE} \dots\dots\dots(1)$$

$$V_{CC} = V_{CE} + I_C R_L \dots\dots\dots(2)$$



Let a small sinusoidal voltage with

amplitude  $v_i$  is superposed on the dc base bias  $V_{BB}$  , then the base current(  $I_B$  ) will have sinusoidal variations. As a result the collector current (  $I_C$  ) also will have sinusoidal variations, producing in turn corresponding change in the value of  $v_o$ . We can measure the ac variations across the input and output terminals by blocking the dc voltages by large capacitors and the output is taken between the collector and the ground.

So (1) =>  $v_i = R_B \Delta I_B + \Delta V_{BE}$  , since  $\Delta V_{BE}$  is very small ,so neglecting it

$$\text{So we have } , v_i = R_B \Delta I_B \dots\dots\dots(3)$$

The change in  $I_B$  causes a change in  $I_C$  .So we define a parameter  $\beta_{ac}$  , known as ac current

gain as follows 
$$\beta_{ac} = \frac{\Delta I_c}{\Delta I_B} = \frac{i_c}{i_b} \dots\dots\dots(4)$$

The change in  $I_C$  due to a change in  $I_B$  causes a change in  $V_{CE}$  and the voltage drop across the resistor  $R_L$  because  $V_{CC}$  is fixed.

$$\text{so from ( 2 ) , } \Delta V_{CC} = \Delta V_{CE} + R_L \Delta I_C = 0 \Rightarrow \Delta V_{CE} = - R_L \Delta I_C \dots\dots\dots(5)$$

The change in  $V_{CE}$  is the output voltage  $v_o$ ,

$$\text{So, } v_o = \Delta V_{CE} = - \beta_{ac} R_L \Delta I_C \dots\dots\dots(6)$$

$$A_v = \frac{v_o}{v_i} = \frac{\Delta V_{CE}}{r \Delta I_B} = - \frac{\beta_{ac} R_L}{r} \dots\dots\dots(7)$$

The voltage gain of the amplifier is-

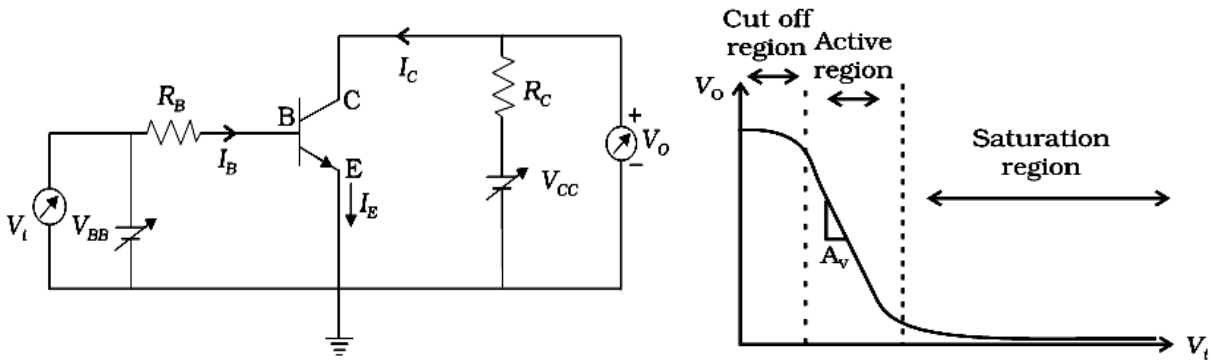
The negative sign represents that output voltage is opposite with phase with the input voltage.

$$\text{So, the power gain can be expressed as } A_p = \beta_{ac} \times A_v \dots\dots\dots(8)$$

Since  $\beta_{ac}$  and  $A_v$  are greater than 1, we get ac power gain. **The transistor is not a power generating device. The energy for the higher ac power at the output is supplied by the battery**

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**Transistor as switch**



The device which makes an electrical circuit on & off is called a switch .

When a transistor is driven back and forth between cut-off and the saturation , it can be used as a switch .

**Working:-** When the input voltage is very much low , the base –emitter junction of the transistor is not sufficiently forward biased and so current flowing through the output circuit is zero .This region is called cut off region and is regarded as the “off” state of the switch .

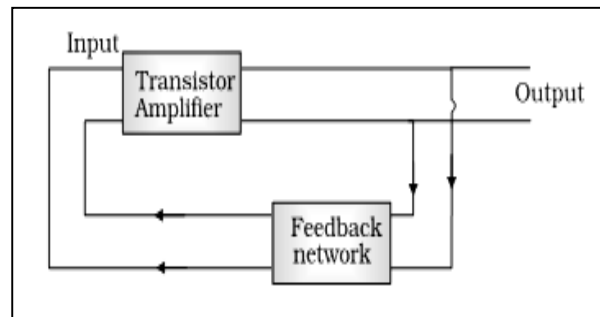
When the input voltage is very much higher , the base- emitter junction is heavily forward biased and so a large collector current starts to flow through the output circuit . This region is called saturation region and is regarded as the “on” state of the switch .

Thus , we can say that a low input switches the transistor off and a high input switches it on. The switching circuits are designed in such a way that the transistor does not remain in active state.

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**Oscillator:-** An oscillator is a device in which with help of an amplifier , we get self-sustained ac output without any external input.

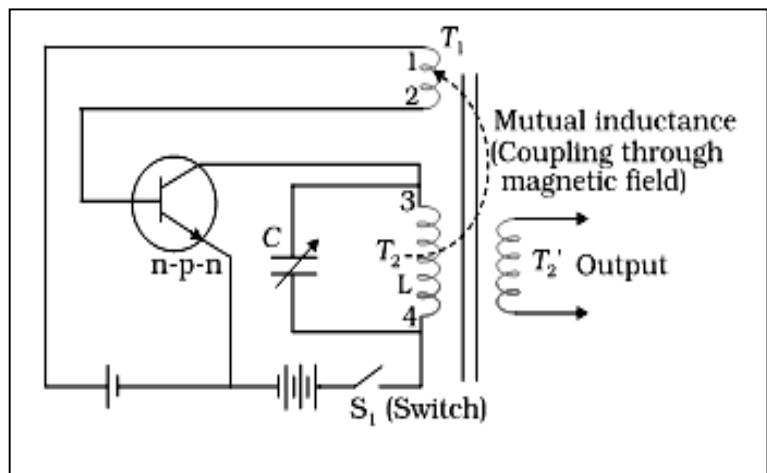
**Feedback amplifier** The process by which , a portion of the output power is returned back (feedback) to the input in phase with the starting power ,is termed positive feedback .



The feedback can be achieved by inductive coupling (through mutual inductance) or LC or RC networks . Different types of oscillators essentially use different methods of coupling the output to the input (feedback network) . It uses the resonant circuit for obtaining oscillation at a particular frequency.

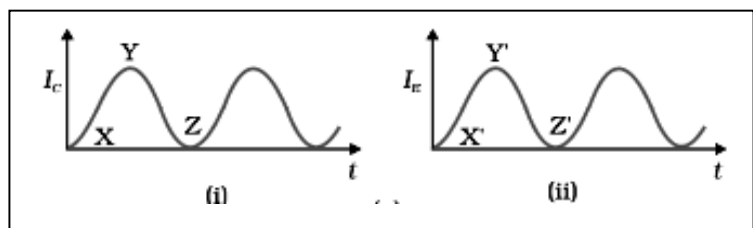
**Transistor as an oscillator :-**

Here positive feedback is obtained by inductive coupling from the coil ( $T_1$ ) to another coil ( $T_2$ ) , wound on the same core , through their mutual inductance. The base-emitter junction of the n-p-n transistor used , is forward biased while the base-collector junction is reverse biased.



Let the switch  $S_1$  is put on to apply proper bias for the first time , due to which , a surge of collector current ( $I_C$ ) flows in the transistor and also through  $T_2$  , where terminals are numbered 3 and 4 .

[ Rise and fall of current  $I_C$  and  $I_E$  due to the inductive coupling ]  $I_C$  does not reach full amplitude instantaneously but increases from X to Y, as shown in fig. (i).



The inductive coupling between coil  $T_2$

and coil  $T_1$  now causes a current to flow in the emitter circuit. As a result of this positive feedback, the

current in  $T_1$  ( emitter current ,  $I_E$  ) also increases from  $X'$  to  $Y'$  as shown in fig.(ii).  $I_C$  connected in the collector circuit acquires the value Y when the transistor becomes saturated. Since there is no further

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change in  $I_C$ , the magnetic field around  $T_2$  ceases to grow. As soon as the field becomes static, there will be no further feedback from  $T_2$  to  $T_1$ . Without continued feedback, the  $I_E$  begins to fall. Consequently,  $I_C$  decreases from Y towards Z [ fig.(i)]. However, a decrease of  $I_C$  causes the magnetic field to decay around the coil  $T_2$ . Thus,  $T_1$  is now seeing a decaying field in  $T_2$ . This causes a further decrease in  $I_E$  till it reaches Z' when the transistor is cut-off. This means that both  $I_E$  and  $I_C$  cease to flow. Therefore, the transistor has reverted back to its original state.

The whole process now repeats itself. That is, the transistor is driven to saturation, then to cut-off, and then back to saturation. The time for change from saturation to cut-off and back is determined by the constants of the tank circuit or tuned circuit that is inductance L of coil  $T_2$  and C connected in parallel to it . The resonance frequency ( $\nu$ ) of this tuned circuit determines the frequency at which the oscillator will oscillate.

$$\nu = \left( \frac{1}{2\pi\sqrt{LC}} \right) .$$

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Tuned collector oscillator:- It is an oscillator in which the tank or tuned circuit is connected in the collector side.

Tuned base oscillator :- It is an oscillator in which the tank or tuned circuit is connected in the base .

Types of oscillator ( using RC circuit as tanked circuit )

Colpitt's oscillator , Hartley oscillator, RC-oscillator.