SEMICONDUCTOR ELECTRONICS

NEET AND JEE Syllabus

KEY CONCEPT

1. Energy Bands in Solids

(i) Overlapped energy levels are termed as energy bands

(ii) The energy band formed by teh overlapping of valency electrons is known as volency energy band.

(iii) The energy band formed by the overlapping of conduction electrons is known as conduction energy band.

(iv) Electrical conduction in solid can take place only when electron remains present in its conduction energy band.

(v) The minimum energy required for excitting an electrond from valency energy band to conduction energy band is known as forbidden energy gap (ΔEg)

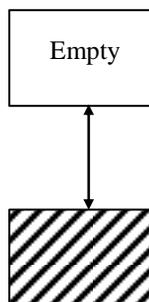$$\Delta Eg = CEB_{min} - VEB_{max}$$

2. Types of solid materials on the basis of forbidden energy gap

2.1 Conductors
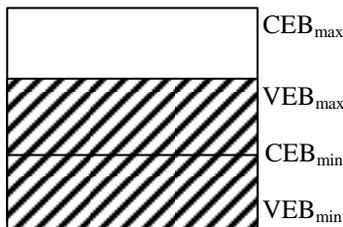
Those solid substances in which forbidden energy gap is zero are known as conductors

2.2 Insulators

These are solids in which the energy band formation occurs in such a manner, that valence band is completely filled while the conduction band is completely empty. Furthermore the valence band and the conduction band are separated by a large forbidden energy gap $\Delta Eg \geq 6eV$.

The energy band in diamond is shown is Fig. There occurs a forbidden band of width 6 eV between conduction and valence band. No electron can have energy corresponding to the forbidden band. Thus an electron needs at least 6 eV to reach the empty conduction band. Such an energy can not be supplied by heat or electric fields that are generally used in laboratories. Therefore diamond is an **insulator.**

2.3 Semiconductors

These are solids in which the forbidden energy gap between the valence band an dthe conduction band is small, of the order of 1eV . At 0 kelvin temperature, the valence band is completely filled and the conduction band is completely empty. At OK, it behaves lie an insulator (electron can not absorb infinitesimal energy because there is a forbidden gap just above the top of the valence band). At a finitude temperature, (room temperature), some electrons gain energy due to thermal motion and jump from the tope of the valence band to the conduction band. These electrons contribute to the conductions to the conduction of electricity in a semiconductor.
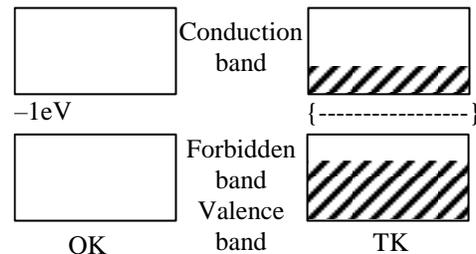
The forbidden gap in semiconductor is small ~ 1eV . At finite temperature, some balance electron goes to conduction band. Then the formlessly is in the middle of the gap

The energy gap is some semiconductors is as follows :

E_g (Silicon) = 1.12 eV

E_g (Germanium) = 0.7 eV

E_g (Indium antimonide) 0.17 eV

E_g (Gallium arsenide) = 1.43 eV

E_g (Tellurium) = 0.33 eV

The energy gap decreases slightly with increases in temperature.

3. Comparison Between Conductors, Insulators and Semiconductors

S.No.	Conductors	Insulators	Semiconductors
1.	Valence band is partially filled or valence band andconduction band overlap	Completely empty conduction band separated from completely filled valence	At OK, the conductive band is empty while valence band is full Separated by small energy gap
2.	There is no forbidden energy gap	The forbidden gap is large Eg (diamond) ~ 6 eV Eg (diamond) ~ 6 eV	Separated by small energy gap Eg (si)
3.	At room temperature , all electrons remains in the partially , filled valence band or over lapped band	At room temperatue, electrons do not get sufficient thermal energy to cross over the forbidden energy band remains empty	At room temperature, may electrons have sufficient energy to go to conduction band. (see Fig 46)
4.	Conducts electric current. Very small resistivity ρ (ohm. meter) ρ (Cu) $= 1.7 \times 10^{-8}$ Ω m ρ (Ag) $= 1.6 \times 10^{-8}$ Ωm The conductively is high σ 10^7 to 10^8 ohm/m (or siemen /m)	Does not conduct electric current (negligible conduction) Very large resistively (ohm meter) ρ (glass) $\sim 10^{11} - 10^{12}$ Ωm ρ (diamond) $\sim 10^{14}$ Ω m Very low conductivity $\sigma \sim 10^{-10}$ to 10^{-14} Ωm Verylow conductivity $\sigma \sim 10^{-10}$ to 10^{-15} ohm /m (or siemen/m)	May conduct electric current but conducton is small. Medium resistivity and medium conductivity ρ (Si) $= 2100$ Ωm ρ (Ge) $= 0.47$ Ωm σ (Ge) ~ 2.13 σ (Si) $\sim 4.7 \times 10^{-4}$ (ohm/m).
5.	Only electrons are the current carriers Number of free electrons (in Cu) $\sim 10^{28}$ per m	No current carriers (the electric conduction is almost zero for all practical purposes, see σ mentioned before)	Both electrons and holes contribute to current conduction. Numner of free electrons (at room temperature) is in Ge $\sim 10^{19}$ per m^3 in Si $\sim 10^{16}$ per m^3
6.	Conductivity decreases with temperature.	Conductivity negligibly small however increases slightly at very high temperatures	Conductivily increases with temperature (the resistivity/ resistance decreases with temperature).

| | | | |
| | | conductivity | p(resistivity) |

The temperature coefficient of resistance of a semiconductor is negative
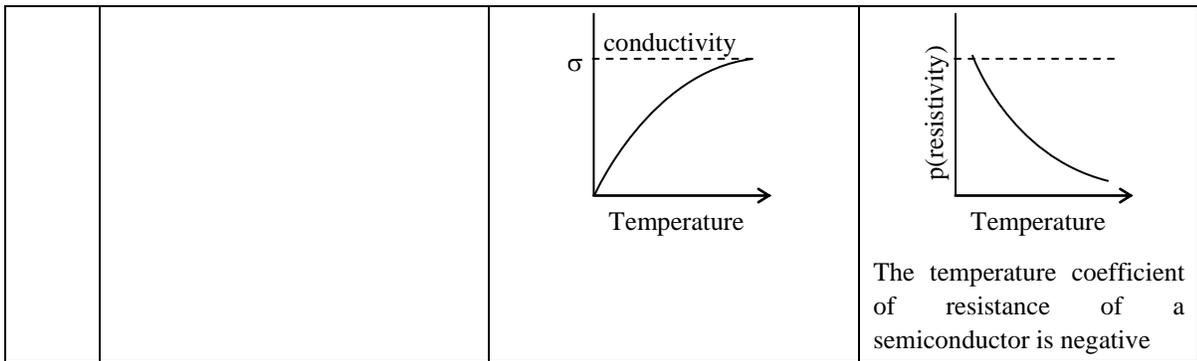
4. Comment : Band Structure and Optical Properties

The optical properties of a solid are closely related with their energy band structure. The photons of visible light have energies between about 1eV and 3 eV , as sin the case of insulators like mica, diamond, then visible light from valence band can not go to conduction band. The such solids are transparent to visible light.

In case of semiconductors, since band gap is ~ 1 eV , the visible light is readily absorbed and these are usually opaque, to visible light,. Infrared photons have energies less than 1eV and therefore infrared light is not absorbed by Si or Ge.

The metals are usually opaque, because electrons in the partially filled band can readily absorbs visible light photon without leaving the valence band.

The ultraviolet photons energies are large and if they are more than the Eg of insulators, then those insulators will absorb UV radiation. Thus some special glasses are although transparent for visible light are opaque for UV light.

5. Types of Semiconductors

The semiconductor are of two type

(1) A semiconductor in a pure form is called intrinsic semiconductor. The imputity must be less than 0.01 ppm (parts per million), i.e., less than 1 in 10^8 parts of semiconductor. At low temperature, the electrons are present in valence bonds of the semiconductor.As the tem perature is increased a few electrons are raised to conduction bond .

◆ In intrinsic semiconductors:-

$$n_e{}^{(0)} = n_n{}^{(0)} = n_i = AT^{3/2} e^{-\Delta Eg/2KT}$$

Where $n_e{}^{(0)}$ is electron density in conduction band, $n_e{}^{(0)}$ is hole density in valance band and n_i is the density of intrinsic carriers.

conduction

Empty

Eg(gap)

Filled
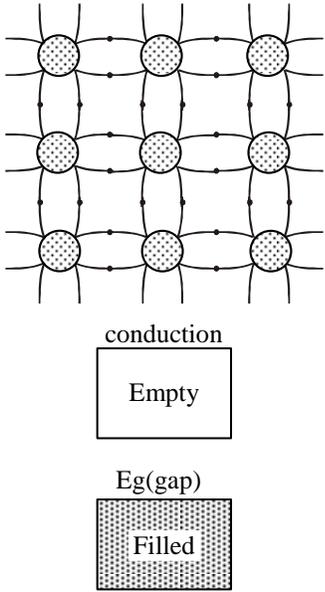
At absolute zero all the valence electrons are tightly bound and no free electron is available for electrical condition. In the band picture, at absolute zero temperature. The conduction band is completely empty while, the the valence band **a perfect insulator at absolute zero.**

At room temperature (~ 300K), some of the electrons may gain sufficient thermal energy and move away from the influence of the nucleus, i.e., the covalent bond may be broken. The electron, so obtained is free to move in the crystal and conduct electricity (see Fig). The vacancy created in the covalent bond is called a **hole.**

Free electrons

conduction

conduction
band

gap Eg

Valence band
with holes
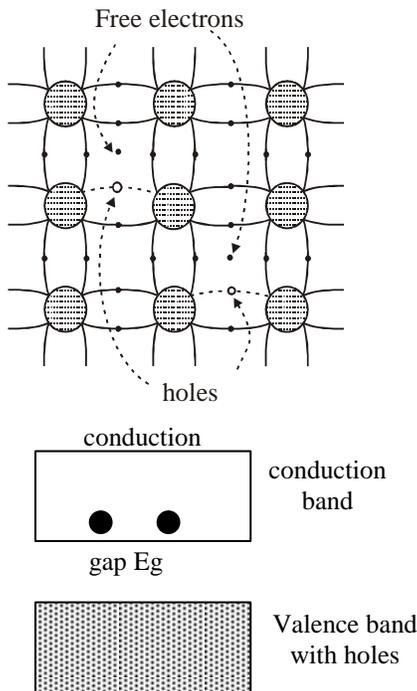
When a covalent band is broken, the electron hole pair is created. Thus in intrinsic semiconductor

Number of holes = number of free electrons

$$n_h = n_e$$

6. Conduction in Intrinsic semiconductors

In intrinsic semiconductor , the number of free electrons and holes are equal. Both electrons and holes contribute in current conduction. For the purpose of flow of current , a hole , behaves like a positively charged particle having some effective mass. Therefore while the electron moves from negative electrode a of the battery to the positive electrode though the semiconductor, the hole moves in opposite side .

The holes exist only inside a semiconductor. There are no holes in a metal. There , electric conduction through holes takes place inside the semiconductor only. Outside, in the metal wires, the electric current flow is due to electrons only. (In cell current flow is due to the motion of positive and negative ions).
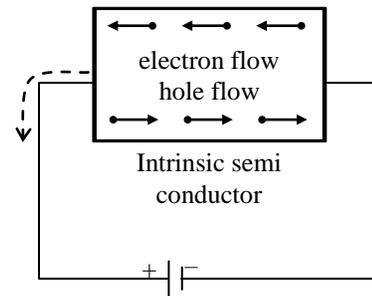
In an instrinsic semiconductor the current flow occurs due to the motion of both, the electrons and the holes,. Let e = magnitude of charge on the electrons, n_h= number density of holes, μ_e = mobility of electrons an μ_b = mobility of holes , then the conductivity of intrinsic semiconductor is $\sigma = e (n_e\mu_e + n_h \mu_h)$onsider a block of semiconductor of length ℓ, area of cross section A and having density of electron and holes as n_e and n_h respeicively when a potential difference say V is applied across it, current I flows through it as shown in fig. The current I is made of electron current I_e and hople current I_h.
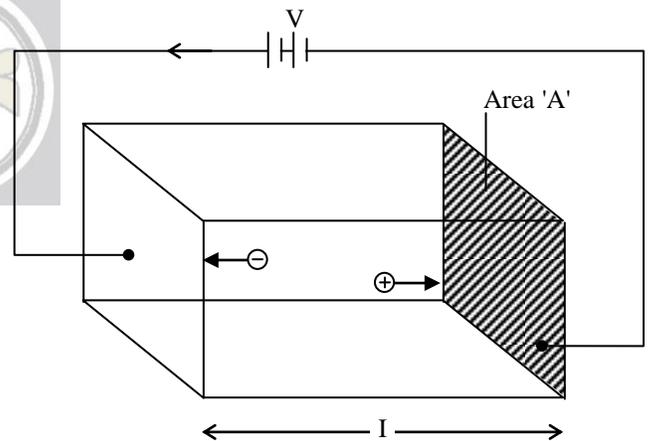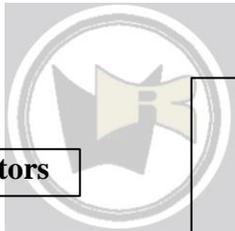
Thus, $I = I_e + I_h$ ....(i)

If v_e is drift velocity of electrons,

then $I_e = en_e Av_e$ ....(ii)

Similarly , the hole current is given by

$$I_h = en_e Av_h$$ ....(iii)

Using equations (ii) and (iii), the equation (i) becomes

$$I = eA (n_e v_e + n_h v_h)$$ ....(iv)

if R is the resistance offered by the simiconductor to the flow of current, then

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$$I = \frac{V}{R} \quad \text{or} \quad \frac{V}{R} = eA \ (n_e \ v_e + n_h \ v_h) \quad \text{.......(v)}$$

The electric field set up across the semiconductor is given by

$$E = \frac{V}{\ell} \qquad \text{or} \qquad V = E\ell$$

Therefore, equation (v) becomes

$$\frac{E\ell}{R} = eA \ (n_e \ v_e + n_h \ v_h)$$

$$\text{or} - \frac{E\ell}{R\frac{A}{\ell}} = e \ (n_e \ v_e + n_h \ v_h)$$

But $R \ \dfrac{A}{\ell} = \ \rho = $ resistivity of the material of semiconductor

Therefore, $\dfrac{E}{\rho} = e \ (n_e \ n_e + n_h \ v_h)$ ......(vi)

Mobnility of electrons or holes is defined as the frigt velocity acquired per unit electric field. Therefore, mobility of electrons and holes is given by

$$\mu_e = \frac{v_e}{E} \qquad \text{and} \quad \mu_h = \frac{v_h}{E}$$

From equation (vi) ,we have

$$\frac{1}{\rho} = e \ \left\{ n_e . \frac{ve}{E} + n_h . \frac{v_h}{E} \right\} \quad \text{or}$$

$$\sigma = e \ (n_e \ \mu_e + n_h \ \mu_h) \qquad \text{.........(vii)}$$

where $\sigma = \dfrac{1}{\rho}$ is called conductivity of the material of

semiconductor and μ_e and μ_h are electron and hole mobilities respectively.

Comment

(i) In pure semiconductors, at any temperature t, the carrier concentration $n_e = n_h = n$ and the conductivity σ is determined by the value of E_g (width of the forbidden band) (see relations given above).

(ii) In metal , however , the value of n is almost the same at different temperatures. The resistance arises due to interaction of free (conduction) electrons with the lattice vibrations (see, chapter 3, 3-5 also).

(iii) At absolute zero, $n = 0$, $\sigma = 0$ i.e., the pure semiconductor behaves like a perfect insulator.

However , as temperature increases both n and s increses.In germanium at T 300 K, $n_e = n_h = 2.5 \times 10^{19}$ per m^3.The higher is the temperature , higher is the conductivity and lower is the resistivity.

(iv) The temperature coefficient of the resistance of a semiconductor is negative .

(v) Pure semiconductors are of little use (may be used as heat or light sensitive resistance).
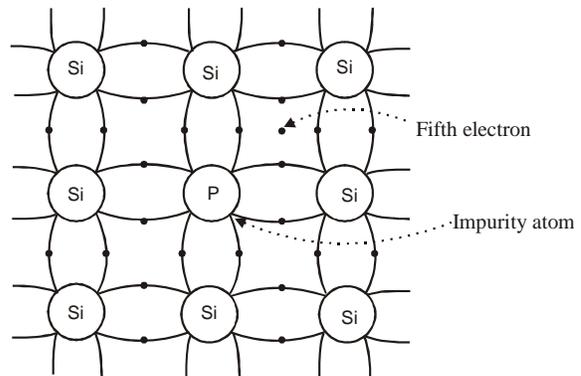
7. Extrinsic Semiconductors

A semiconductor in which impurities have been added in a controlled manner is called extrinsic semiconductor . The process of deliberately adding impurities to a semiconductor is called doping. The impurity atoms are either from V group (such as arsinic (as), antimony (Sb), phosphorus (P) etc. or from III group (such as Aluminium (AI) , gallium (Ga) , indium (In) etc. There are two types of extrinsic semiconductors,

(i) N-type (extrinsic) semiconductor and
(ii) P-type (extrinsic) semiconductor.

The conductivity of extrinsic semiconductor is controlled by the amont of doping, I part of a donor impurityper 10^9 parts of germanium increases its conductivity by a factor of neraly10^3.

The compounds of trivalent and penta valent elements also behave like semiconductors, (indium antimonide), In P, GaP.
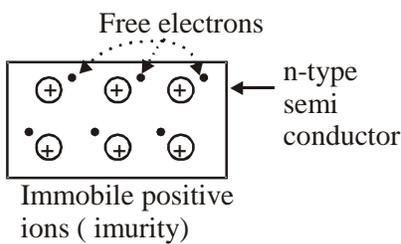
7.1 N-Type Semiconductor

N- Type (n- type) semiconductor is obtained by adding a small amount of pentavent (V group) impurity to a sample of intrinsic semiconductor. The pentavalent impurities are P (phophorus $Z + 15$), As ($Z = 3$), Sb ($Z = 51$), Bi ($Z = 83$).
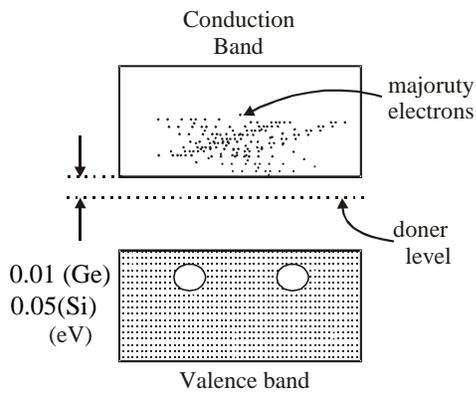
In the energy band pricture we say that impurity atoms, produce donor energy levels just below the conduction band . Ther electrons from these levels jump to the conduction band easily by gaining thermal energies (at room temperature). There may also break some covalent bonds producing electron hole paire, but their number is small. So in this type of extrinisc semiconductor, there are a large number of free electrons (donated by impurity atoms) and a negligible number of holes from cavalent cond breaking.

The impurity atom on donating electrons becomes positive ions. However the over all charge on the semiconductor is zero. The negative charge of the immobile positive charge of the immobile positive ions.

The majority charge carriers are electrons (negative charge) . Therefore, this type of extrinsic semiconductor is called n - type .

The Fermi level does not lie in the middle of band gap, but it shifts towards the conduction band.

The few hole s formed by covalent bond breaking are called minority charrge carriers.

The conductivity of th n-type semiconductors is controoled by the amoutn of impurity atoms added in it. Since

7.2 P-Type Semiconductor
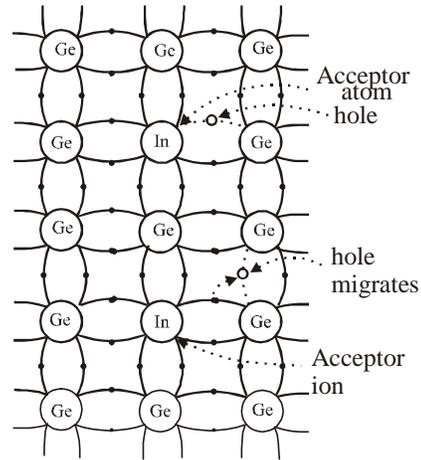
P-type (pype) semiconductor is obtained by adding a small amount of trivalent (III groupe) impurity to intrinsic semiconductor. The impurities may be Boron (Z = 5), AI (Z = 13, Ga (Z – 31) In (Z = 49), TI (Z = 81). For each acceptor ion there exist a hole in this type of semiconductor , there are a large number of holes present. The majority charge carriers are holes. Therefore it is called a p-type semicondutor.
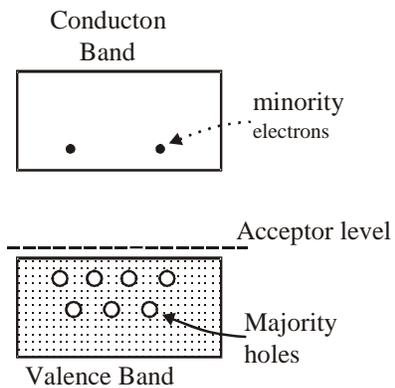

In the band picture, we say that acceptor energy levels lie just above the valence band. These levels accepts electrons from the valence band and creates holes. The breaking of covalent bonds may create electron-hole pairs but their number is very little. The majority carriers are holes. The minority carriers are electron.

The conduction takes place mainly through the motion of holes

$$n_h \gg n_e$$

$$\sigma_p \approx e\mu_h \, n_h$$

The overall charge on p-type semiconductor is zero. It is represented as shown in Fig. The positive charge of free holes is balanced by the negative charge of immobile impurity ions.

Free holes

p-type semi conductor
Immobile negative
ions (imurity)
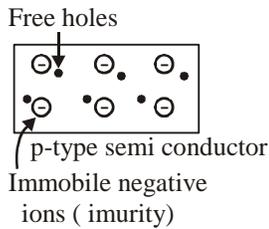
COMMENT

When temprature is increased, covalent bonds break. This increases minority charge carriers. At very high temperature, it may happen that electron-hole numbers obtained from bond breadking , far excceds the cahrge carrirers from impurities . Then the semiconductor behaves like intrinsic semiconductor . The critical temperature at which this happens is 85°C for germanium and 200°C for silicon.

8. PN Junction

When a piece of p-type material and piece of n-type matrial are joined in such a manner that cyrstal structure remains continuous at the boundary, then a pn junction is formed.It is also called a pn junction (PN junction) diode.

A PN junction can not be made by simply pushing the two pieces together as it would not lead to a single crystal structure .There are special fabricaton techniques to form a PN junction.

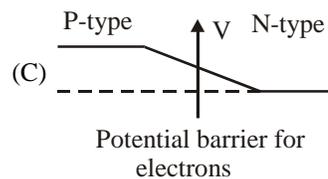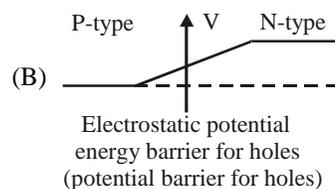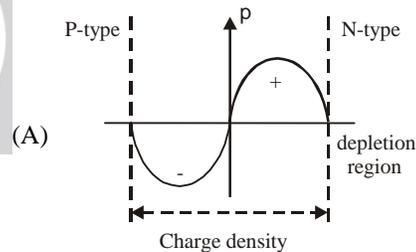Immediately after a PN junction is formed, the following process are initiated :
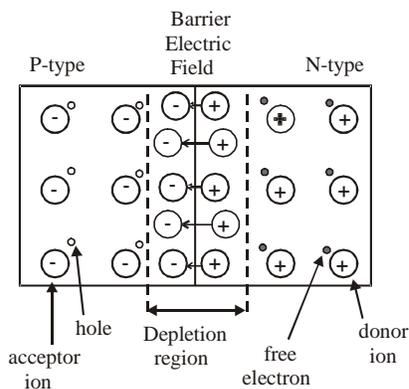
(i) The negative ions on P-sides and positive ions on N-sides are immobile.The majority holes from P region diffuse into N region, and the majority electrons from N region diffuse into P region.

(ii) Due to the above, the electrons and holes at the juction region recombine and disappear (i.e., cavalent bonds are completed).

(iii) As a result, a layer of negative ions on P-side and a layer of positive ions on N-side is formed at the junction. In this region, due to recombination of electrons and holes, depletion of free charge carriers occurs. So this region is called depletion region. The charge density on the two sides of the junction (due to ion layers) is shown in Fig.

(iv) The uncompensated ion layers in the depletion region generates an electric field in this region. The electric field points from N side to P side. This electric field prevents further tdiffusion of holes from P-sides. It also prevents further diffusion of electrons from the N side to P side . The electric field is called barrier electric field.

(v) The barrier electric field gives rise to a difference of potentail from one side to the other side. This is called barrier potential (or potential barrier). For silicon PN junction the barrier potential is about 0.7 V while for germanium PN junction, it is about 0.3V.

(A)

Charge density

(B)

Electrostatic potential energy barrier for holes (potential barrier for holes)

(C)

Potential barrier for electrons

(vi) For holes the potential on the N-sides is higher . Holes can not cross the deplection region because of this barrier potential . Fig 60 (B). For electrons the potential barrier is shown in Fig. 60(C)

(vii) On the average the potential barrier height in PN junction is ~ 0.5 V and the width of the depletion region ~1 µm or 10–6 m. The barrier electric field is thus

$$E = \frac{V}{d} = \frac{0.5}{10^{-6}}$$

$$= 5 \times 10^5 \text{ volt /m}$$

9. PN Junction with Forward Bias

(i) When the positive terminal of a battery is connected to the P-side and the negative terminal to the N-side of a PN-junction, then it is said to be forward biased (Fig).
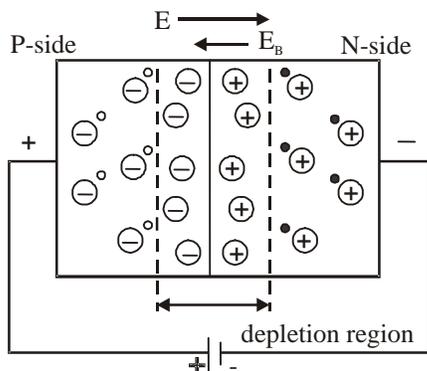
depletion region

(ii) The holes are repelled from the positive terminal and compelled to move towards the junction. The electrons are also repelled from the negative terminal and move towards the junction . This **reduces the depletion region** for a forward biased PN-junction

(iii) **The potential barrier is reduced . More charge carries diffuse across the junction.**

(iv) In the P-type material, near the positive terminal , an electron breaks the covalent bond and goes to battery. As a result a hole is created in P-sides . At the same time an electron enters the N-sides from the negative terminal. The currrent in the P - region airses due to flow of the holes while the currrent in the N-regioon is due to electrons.

(v) The electric field at the barrier, due to the battery is from P side to N side (forward bias). This is in opposition to the barrier electric field.

(vi) If battery potential is increased, the potential barrier is further reduced. More majority carriers diffuse across the junction. The current increases

10. PN Junction with Reverse Bias

(i) When the positive terminal of a battery is connected to the N-side and the negative termanl is connected to the P-side of thePN junction , then it is said to be reverse biased.

(ii) The holes in the P-region are attracted towards the negative terminal and the electrons in the N-region are attracted twowards the positive termanl . Thus the majority carriers move away from the juction. The depletion region increases for a reverse biased PN- junction,


depletion region
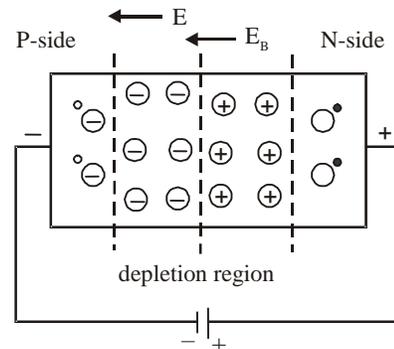
(iii) The barrier potential increases , This makes it more difficult for the majority carriers to diffuse across the junction .

(iv) A very little current called reverse saturation current flows due to minority carrier flow.It is of the order of nanoamperes (10^{-9}A)for silicon and microamperes (10^{-6} A) for germanium PN - diodes.

(v) In reverse bias situation , the junction behaves like a highresistivity material sanwiched in between two regions.

(vi) The effective capacitance of PN junction in the reverse bias condition is of the order of few pico farads.

11. PN Junction Diode Characteristics

Forward bias characteristics

The circuit diagram for studying the V-I characteristics of a PN junction diode in forward bias is shown in Fig.

In forward bias the depletion region decreases, the barrier potentail decreases, and current folws due to diffusion of charge carriers across the junction . Majority holes from P side cross over to N side, and majority electrons from N side cross over to P side, The current voltage chracteristics is shown in Fig.
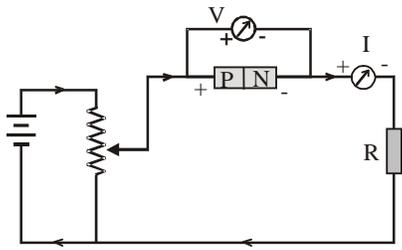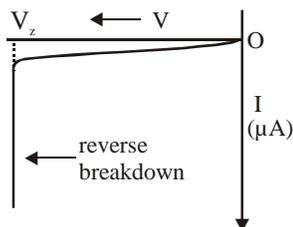
The diode current is negligibly small for first few tenths of a volt. The reason is that the diode does not conduct will till the external voltageV, overcomes the barrier potential . The voltage at which the current starts to increse repidly is called cut-in or Knee voltage (V_o) of the diode. For a silicon diode V_o ~7volt and for germanium V_o junction diode in reverse bias is shown in Fig.
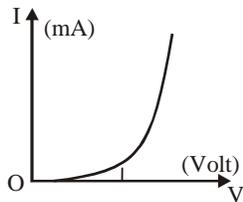
In reverse bias state, the depletion region increases and potential barrier also increases. The majority holes in P region and majority electrons in N region , now do not cross the junction . They donot give rise to any current.
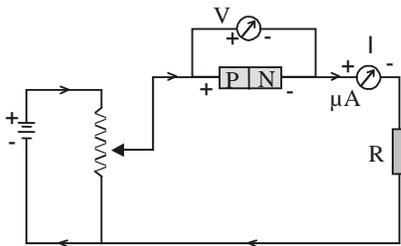

In reverse bias a very smal current flows. This arises due to the flow of minority charge carriers across the junction . The reverse current is only few μ A for germanium diodes and only a few nA for silicon diodes. It remains small and almost constant for all reverse bias voltages less than the break down voltage V_Z. At breakdown, the current increses rapidly for small increase in voltage

The full charactaristics, forward and reverse bias are shown in Fig. The PN junction diode thus is a unidirectional device. Large current (mA) flows in one direction, but neglible current flows in the reverse direction.

The symbol used for PN junction diode is shown in Fig.
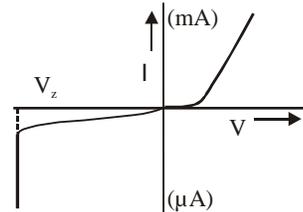
The equation for diode current is

Easy direction for conventional current

$$I = I_o (e^{eV/kT} - 1)$$

Where I_o is called saturation current, V is positive for forward and negative for reverse bias, k is Boltzmann constant,   T   is   temperature   and $e = 1.6 \times 10^{-19}$ C.

12. Reverse Breakdown

If the reverse bias voltage is made too high, the current through the PN junction increases rapidly at V_Z(seefig). The voltage at which this happens is called **breakdown voltage** or **Zener voltage.**

There two mechnism which causes this breakdown . One is called avalanche breakdown

Zener breakdown and the other is called avalanche breakdown

Zener breakdown . When reverse bias is increased the electric field at then junction also increases. 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 a large current to flow. This machanism is know as Zener breakdown.
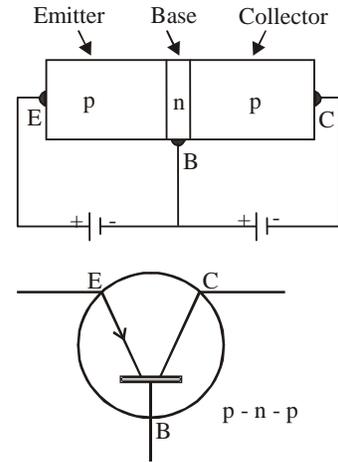
Avalanche breakdown. At high reverse voltage, due to high electric field, the miniority charge carriers, while crossing the junction acquires very high velocities .

These by collision breaks down the covalent bonds , generating more carriers. A chain reaction is established , giving rise to high current. This mechanism is called **avalanche breakdown .**

Avalanche break down:-

The covalent bonds where the junction break down liberating a large number of electron hole pairs.Then the reverse current increases abruptly to high value .This is called avalanche break down and may damage the junction.This phenomenon is used to Zener diode and used in voltage regulator.

Important Points

S.No.	Half wave rectifier	Full wave rectifier
1.	$I_{av} = I_{dC} = \dfrac{I_0}{\pi}$	$I_{av} = \dfrac{2I_0}{\pi}$
2.	$E_{av} = E_{dc} = \dfrac{V_0}{\pi}$	$E_{av} = \dfrac{2V_0}{\pi}$
3.	$r = 1.21 \therefore I_{ac} > I_{dc}$	$r = 0.48 , \therefore I_{ac} < I_{dc}$
4.	$\eta = \dfrac{0.406}{1 + \dfrac{r_p}{R_L}}$	$\eta = \dfrac{0.812}{1 + \dfrac{r_p}{R_L}}$
5.	From factor = 1.57	1.11
6.	Ripple frequency = ω	2ω
7.	Pulse frequency = $\dfrac{\text{input pulse frequency}}{2}$	pulse frequency = Input pulse frequency

13.   Transistor

A transistor is an electronic device formed by p and n type of semiconductor which is used in place of a triode valve. It was discovered in 1948 by American scientists Bardeen, shockley   and Barattain . Transistors are of two types: p-n-p transistor and n-p-n transistor.

13.1 p-n-p Transistor :

 It consists of a very thin slice of n-type semiconductor sandwiched between two small crystals of p-type semiconductor (fig). The central slice is called the 'base' while the left and right crystals are called the 'emitter' and the 'collector' respectively. The emitter is given a positive potential negative potential with respect to the base. Thus ,

the emitter -base (p-n) junction on the left is under forward-bias (high resistance). The symbol for this transistor   is   shown   in Fig. 12(b) in which the direction of the arrow indicates the direction of current (direction of flow of holes).
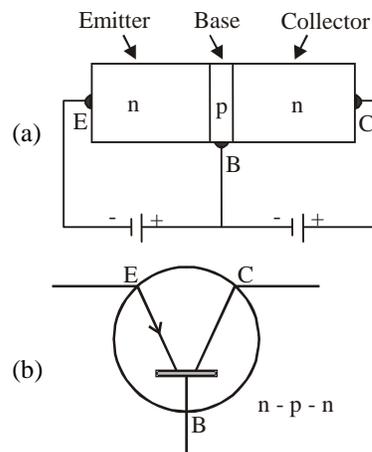

13.2 n-p-n Transistor :

It consists of a very thin slice of p-type semiconductor (fig). In this transistor the meter is given a negative potential while the collector is given a positive potential with respect to the base. Again, the emitter - base (n-p) junction on the left is under forward-bias, while the base collector (p-n) junction on the right is denser   reverse-   bias   .
*The symbol for the n-p-n transistor is shown in Fig. (b) in which the direction of the arrow indicates the direction of current (opposite of the direction of flow of electrons).
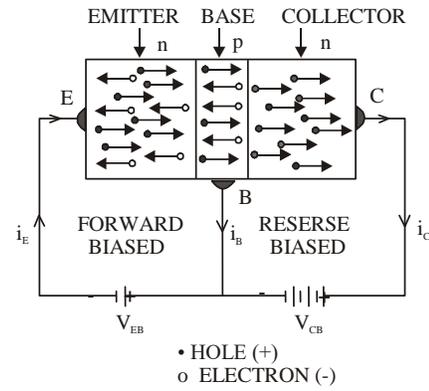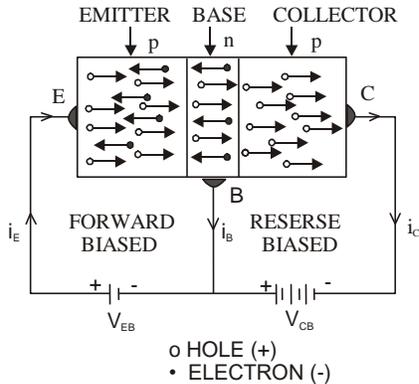

A transistor can be connected in a circuit in three difference ways. They are :

(i) common-base configuration, (ii) common-emitter configuration and (iii) common-collector configuration. The work 'common' is related with that electrode which is common in input and output circuits. This common

electrode is generally grounded. Hence the above three configurations of connection are also called respectively as grounded -base configuration, grounded-emitter configuration of connection are also called configuration . Each configuration has its own characteristics.

13.3 Working of p-n-p Transistor

A 'common-base ' circuit of a p-n-p transistor is shown in Fig. 14. The emitter- base (p-n) junction on the left is given a small forward bias (fraction of a volt) while the base-collector (n-p) junction is given a large reverse-bias (a few volts).

o HOLE (+)
• ELECTRON (-)

Holes are the charge-carriers with in the p-n-p transistor, while electrons are the charge-carriers in the external circuit.

The small current which leaves the base terminal B is called the 'i_B 'base-current' the larger current which leaves the collector terminal is called the 'collector - current ' i_C.Both these currents combine to enter the emitter terminal E and constitute the emitter-current i_E. Clearly,

$$i_E = I_B + i_C$$

The base being very thin, the number of hole-electron combinations in it is very small, and almost all the holes entering the base from the emitter reach the collector. . Hence the collector-current i_C is only very slightly less than the emitter current i_E.

13.4 Working of n-p-n Transistor

A circuit known as 'common-base' circuit of n-p-n transistor is shown in Fig. The two n-regions contain the mobile electrons while the central thin p-region contains the mobile (positive) holes. The emitter-base by means of a battery V_{EB}, while the base-collector (p-n)junction on the right has been given a large reverse-bias by means of battery V_{CB}.

• HOLE (+)
o ELECTRON (-)

The electrons are the charge-carriers with in the n-p-n transistor as will as in the external circuit (whereas hole sate the charge-carriers with in p-n-p transistor).

The small current entering the base terminal B is the base current i_B, while the larger current entering that collector terminal C is the collector-current i_C. Both currents combine to leave the emitter terminal E and constitute the emitter current i_E. Thus

$$i_E = i_B + i_C$$

13. Transistor action

There are four possible ways of biasing the two PN junctions (emitter junction and collectro junction) of a transistor .These are tabulated below.

Emitter junction bias	Collector junction bias	Transistor operation
Forward	Reverse	Active
Forward	Forward	Saturation
Reverse	Reverse	Cut off
Reverse	Forward	inverted
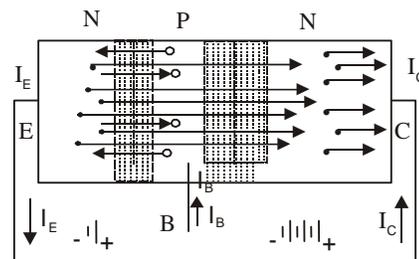
$$I_E = I_C + I_B$$

$$I_B \ll I_C, \text{ and}$$

$I_B \ll I_E$

Thus I_C is always less than I_E, but the difference is small.

Since the emitter junction is forward biased its resistance is small, while the collectro jucntion is reverse biased, therefore its resistance is large. Thus , a transistor is a device which transfers I_E current from low resistance circuit to a high resistance circuit ($I_C \sim I_E$). Thus it is,

transfer + resistor = transistor

(The name transistor originated from the above action of the transistor).

## 15. Transistor configuration and its use as an Amplifier

A junction diode cannot amplify a signal . A transistor consisting of two p-n junctions, one forward-biased and the other reverse-biased ,can , however , be used for amplifying a weak signal The forward-biased junction has a low-resistance path whereas the reverse-biased junction has a high-resistances path. The weak input signal is applied across the forward-biased (low resistance) junction and the output currents are signal is taken appears with a much higher voltage. The transistor thus acts as an amplifier .
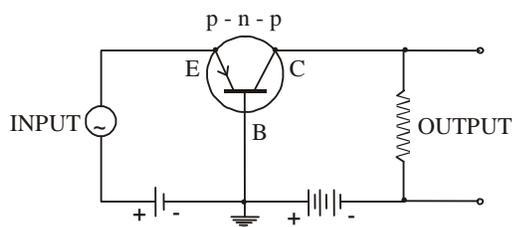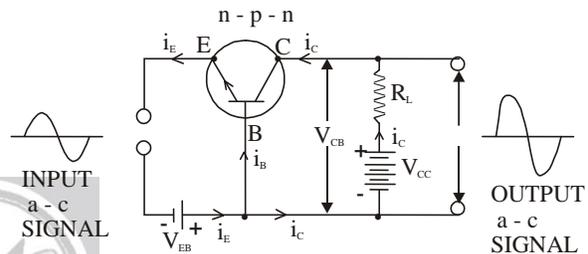

(a) COMMON-BASE
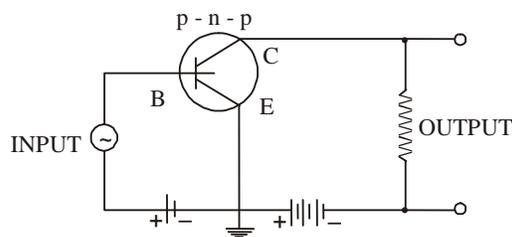
(b) COMMON-EMITTER
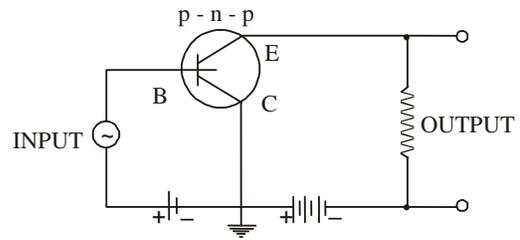
(b) COMMON-COLLECTOR

When a transistor is to be operated as amplifier, three different basic circuit connection are possible, as illustrated inFig. These are (a) common-base (b) common emitter and (c) common-collector circuits.

15.1 Transistor as Common-Base Amplifier

15.2 Common-Base Amplifier using an n-p-n Transistor :

Fig. shows the common-base amplifier circuit using an n-p-n transistor. The base is made common to the input and the output circuits.

The emitter-base input circuit is forward-biased by a low-voltage battery V_{EB} so that the resistance of the input circuit is small . The collector -base output circuit is reverse-biased by means of a high-voltage battery VCC so the at the resistance of the output circuit is quite large. R_L is a load resistance connected in the collector-base circuit. The weak input a-c voltage signal is applied across the emitter-base circuit and the amplified output signal is obtained across the collector-base circuit.

Let i_E , i_B and i_C be the emitter -current and collector-current irrespectively when no a-c voltage signal is applied to the input circuit. (The arrows represent the direction of hole current, that is conventional current which is opposite to the direction of electron current) . By Kirchhoff's first law, we have

$$i_E = i_B + i_C \qquad .....(1)$$

Due to the collector- current i_C, the voltage drop across R_L is $i_C R_L$. Therefore, the collector-to- base voltage

(potential difference between collector and base)V_{CB} would be given by

$$V_{CB} = V_{CC} - i_C R_L \qquad .....(2)$$

When the input a-c voltage signal is applied across the emitter-base circuit, it changes the emitter-base voltage and hence the emitter-current i_E which, in turn , changes the collector current i_C. Consequently , the collector to base voltage V_{CB} varies in accordance with equation (2) . This variation in V_{CB} , when the input signal is applied, appears as an amplified output.

Phase Relationship between Input and Output voltage Signals in CB circuit :

The output voltage signal is in phase with the input voltage signal in the common -base amplifier.

15.3 Gains in Common-Base Amplifier :

The various gains in a common-base amplifier are as follow:

(i) a-c Current Gain : It is defined as the ratio of the change i the colllector-current to the change in the emitter-current at a constant collector-to-base voltage, and is denoted by α. Thus

$$\alpha\ (a-c)\left(\frac{\Delta i_C}{\Delta i_E}\right)_{V_{CB}}$$

The value of α is slightly less than 1 (actually, there is a little current loss).

(ii) a - c Voltage Gain: It is defined as the ratio of the changes in the output voltage to thechange in the input voltage , and is denoted by A_V .

Suppose, on applying an a-c input voltage signal, the emitter current changes by Δi_C and correspondingly the collector-current changes by Δi_C . If R_{in} and R_{out} be the resistances of the input and the output circuits respectively, then

$$A_V = \frac{\Delta i_C \times R_{out}}{\Delta i_E \times R_{in}} = \frac{\Delta i_C}{\Delta i_E} \times \frac{R_{out}}{R_{in}}$$

Now , $\Delta i_C / \Delta i_E$ is the a-c current-gain and R_{out} / R_{in} is called the 'resistance gain'.

$$\therefore A_V = \alpha \times \text{resistance gain}$$

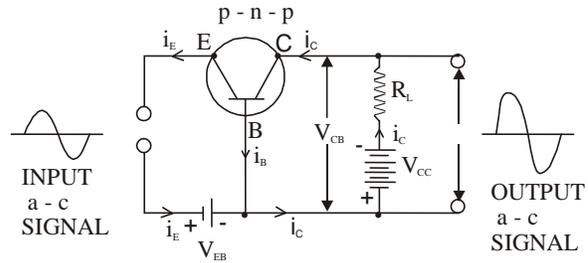Since the resistance gain is quite high, A_V is also quite high although α is slightly less than 1.

(iii) a-c Power Gain: it is defined as the ratio of the change in the output power to the change in the input power.

Since power = current x voltage, we have

a-c power gain = a-c current gain $\times$ a-c voltage-gain

$$= \alpha^2 \times \text{resistance gain}$$

15.4 Common-Base Amplifier using a p-n-p Transistor :

15.5 Transistor as Common-Emitter Amplifier :

Common-Emitter Amplifier using an n-p-n Transistor: Fig.shows the common-emitter amplifier circuit using an n-p-n transistor. The emitter is made common to the input and the output circuits.

The input (base-emitter) circuit is forward-biased by a low-voltage battery V_{BE} so theat the resistance of the input circuit is small. The output (collector-emitter) circuit is reverse-biased by means of a high voltage battery V_{CC} so that the resistanc eof the outputcircuit is high. R_L is a load resistanc econnected in the collector-emitter output circuit. The weak input a-c signal is applied across the base-emitter circuit and the camplified output signal is obtained across the collector -emitter circuit.
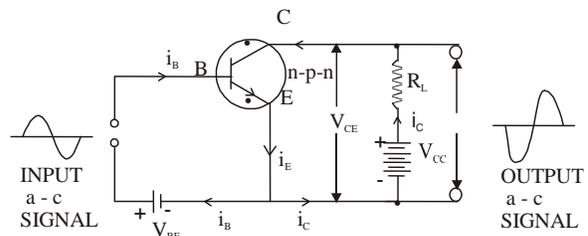
Let i_E, i_B and i_C be the emitter-current, base-current and collector- current respectively when no a-c voltage signal is applied to the input curcuit. (The arrows represent the direction of the hole current, that is conventional current which is opposite to the direction of electron current.) By Kirchhoff's first law, we have

$$i_E = i_B + i_C =$$

Due to the collector current i_C (Which is only slightly smaller that i_E), the voltage drop across R_L is i_C R_L. Therefore , the collector -to -emitter voltage (potential between collector and emitter) V_{CE} would be given by

$$V_{CE} = V_{CC} - i_C R_L$$

When the input a-c voltage signal is applied across the base-emitter circuit, it changes the base-emitter voltage and hence the emitter -current i_E which, in turn , changes the collector current iC. Consequently, the collector-to-emitter voltage V_{CE} varies in accordance with equation. (ii). This variation in V_{CE} , when the input signal is applied , appears as an amplidied output.

15.6 Phase Relationship between Input an Output Voltage Signals :

In a common-emitter amplifier the input voltage signal and the output voltage signal obtained across the collector and the emitter are out of phase with each other.

The output voltage signal is 180° out of phase with the input voltage signal in the common-emitter amplifier.
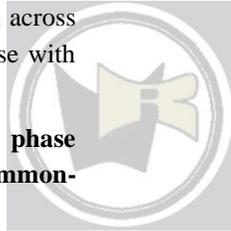
16. Gains in Common-Emitter Amplifier

The various gains in a common-emitter amplifier are as follows:

(i) d-c Current Gains: it is defined as the ratio of the collector current to the base current, and is denoted by β (d-c) . Thus

$$\beta\ (d\text{-}c) = \frac{i_C}{i_B}$$

In a typical transistor , a small base- current $(10\mu A)$ produces a large collector -current $(500\mu A)$. Thus

$$\beta\ (d\text{-}c) = \frac{500}{10} = 50$$

(ii) a-c Current Gain: It is defined as the ratio of the change in the collector -current to the change in the in the base -current at a constant collector to emitter voltage , and is denoted by β (a-c) . Thus

$$\beta\ (a\text{-}c) = \left(\frac{\Delta i_C}{\Delta i_B}\right)_{V_{CE}}$$

(iii) Voltage gain : Suppose , on applying an a-c input voltage signal, the input base-current changes by Δi_B and correspondingly the output collector-current changes by Δi_C. If R_{in} and R_{out} be the resistance of the input an dthe output circuits respectively , then

$$A_V = \frac{\Delta i_C \times R_{out}}{\Delta i_B \times R_{in}} = \frac{\Delta i_C}{\Delta i_B} \times \frac{R_{out}}{R_{in}}$$

Now, $\Delta i_C/\Delta i_B$ is the a-c current gain (a-c) and R_{out} / R_{in} is the resistance gain

$\therefore$ $A_V = \beta$ (a-c) $\times$ resistance gain.

Since β (a-c) $\gg \alpha$ (a-c), the a-c voltage gain in common-emitter amplifier is larger compared to that is common -base amplifier., although the resistance gain is smaller .

From equation (i) and (ii), it follows that

$$A_V = g_m \times R_{out}$$

(iv) a-c Power Gain : It is defined as the ratio of the change in the output power to the change in the input power.

Since power = current $\times$ voltage , we have

a-c power gain = a-c current gain $\times$ a-c voltage gain

$= \beta$ (a-c) $\times A_V$

$= \beta$ (a -c) $\times \{ \beta$ (a-c) x resistance gain$\}$

$= \beta^2$ (a-c) $\times$ resistance gain.

Since β (a-c) $\gg \alpha$ (a-c) , the a-c power gain in common-emitter amplifier is extremely large compared to that in common-base amplifier.

(v) Common-Emitter Amplifier using a p-n-p Transistor :
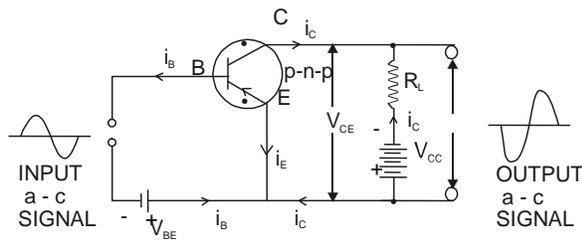
17. Relation between α and β

CB current gain (α)

CB current gain (α) is the ratio of output current to the input current in common base configuration of a transistor.

$$\alpha_{dc} = \frac{I_C}{I_E}$$

$$\alpha_{ac} = \frac{\Delta I_C}{\Delta I_E}$$

CE current gain (β)

CE current gain (β) is the ratio of the output current to the input current in emitter cofiguration of the transistor.

$$\beta_{dc} = \frac{I_C}{I_B}$$

$$\beta_{ac} = \frac{\Delta I_C}{\Delta I_B}$$

The CB current gain α and CE current gain β are related by the rollowing relations.

$$\frac{1}{\alpha} = 1 + \frac{1}{\beta}$$

$$\alpha = \frac{\beta}{\beta + 1}$$

$$\beta = \frac{\alpha}{1 - \alpha}$$

The above relations are applicable for both dc and ac current gains.

Comment. The value or α is always less than 1. α ~ 0.9 to 0.99 or more. The value of β is always much greater than 1. β ~ 95 to 999 or so.

18. Point to Remember

(1) The electrical conductivity in materials is on account of these free electrons.

(2) In semiconductors the number of free electrons is less than that in conductors but more than that in insulators.

(3) Diode can be used as rectifier, modulator, detector.

(4) Voltage gain = $A_V = A_R.A_i$

(5) Energy gap for Ge and Si are respectively 0.7 eV and 1.1 eV.

(6) Holes contribute to current flow.

(7) In Junction diode P-part behaves like a plate and N-part behaves like a cathode.

(8) On account of current in diode being unidirectional , it is also known as a valve.

(9) Fermi energy depends on the nature of the material.

(10) The number of electrons emitted by an emitter depends more on work-function than on temperature.

(11) The work function of cathode decreases by mixing impurity in it.

(12)   Common-base configuration

(i) Current amplification factor α_c

= Rate of $\alpha = 0.95 - 0.99$

(ii) Voltage amplification factor = α

   R_L = load resistance, R_i = Input resistance

(iii) Power amplification factor = current amplification x voltage amp. factor = α^2

(13)   Common - emitter configuration

(i)   Current amplification factor = β,

   Range of β = 50 to 200

(ii)   Voltage amplification = βR_L

(iii) Power application = $\beta^2 R_L$