SEMI CONDUCTOR - ELECTRONICS

ENERGY BANDS IN SOLIDS

Based on Pauli's exclusion principle

In an isolated atom electrons present in energy level but in solid, atoms are not isolated, there is interaction among each other, due to this energy level splitted into different energy levels. Quantity of these different energy levels depends on the quantity of interacting atoms. Splitting of sharp and closely compact energy levels result into energy bands. They are discrete in nature. Order of energy levels in a band is 10^{23} and their energy difference = 10^{-23} eV.

Energy Band

Range of energy possessed by an electron in a solid is known as energy band.

Valence Band (VB)

Range of energies possessed by valence electron is known as valence band.

(a) Have bonded electrons.

(b) No flow of current due to such electrons.

(c) Always fulfill by electrons.

Conduction Band (CB)

Range of energies possessed by free electron is known as conduction band.

(a) It has conducting electrons.

(b) Current flows due to such electrons.

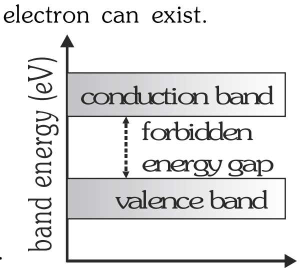
(c) If conduction band is fully empty then current conduction is not possible.

(d) Electrons may exist or not in it.

Forbidden Energy gap (FEG) (ΔEg)

$$\Delta E_g = (C\ B)_{min} - (V\ B)_{max}$$

Energy gap between conduction band and valence band, where no free electron can exist.



- Width of forbidden energy gap depends upon the nature of substance.
- Width is more, then valence electrons are strongly attached with nucleus
- Width of forbidden energy gap is represented in eV.
- As temperature increases forbidden energy gap decreases (very slightly).

CLASSIFICATION OF CONDUCTORS, INSULATORS AND SEMICONDUCTOR : -

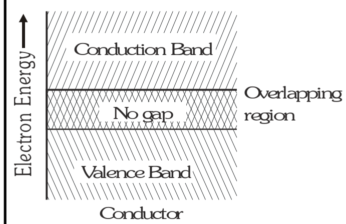
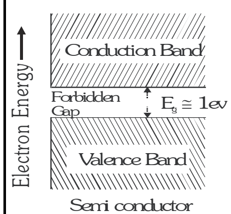
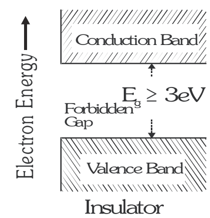
On the basis of the relative values of electrical conductivity and energy bands the solids are broadly classified into three categories

(i) Conductors

(ii) Semiconductors

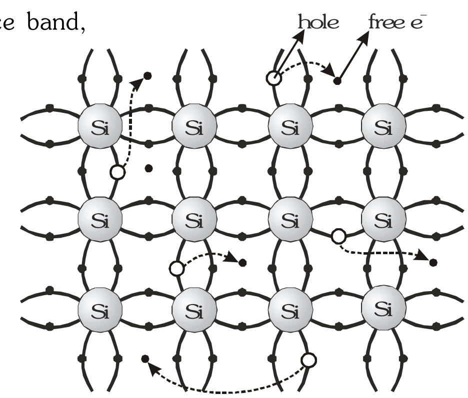
(iii) Insulator

Comparison between conductor, semiconductor and insulator :

Properties	Conductor	Semiconductor	Insulator
Resistivity	$10^{-2} - 10^{-8}\ \Omega m$	$10^{-5} - 10^{6}\ \Omega m$	$10^{11} - 10^{19}\ \Omega m$
Conductivity	$10^{2} - 10^{8}$ mho/m	$10^{5} - 10^{-6}$ mho/m	$10^{-11} - 10^{-19}$ mho/m
Temp. Coefficient of resistance (α)	Positive	Negative	Negative (Very slightly)
Current	Due to free electrons	Due to electrons and holes	No current
Energy band diagram			
Forbidden energy gap	$\cong$ 0eV	$\cong$ 1eV	$\geq$ 3eV
Example :	Pt, Al, Cu, Ag	Ge, Si, GaAs, GaF_2	Wood, plastic, Diamond, Mica

CONCEPT OF "HOLES" IN SEMICONDUCTORS

Due to external energy (temp. or radiation) when electron goes from valence band to conduction band (i.e. bonded electrons becomes free) a vacancy of free e^- creats in valence band, which has same charge as electron but positive. This positively charged vacancy is termed as hole and shown in figure.



- It is deficiency of electron in VB.
- It's acts as positive charge carrier.
- It's effective mass is more than electron.
- It's mobility is less than electron.

Note : Hole acts as virtual charge carrier, although it has no physical significance.

GOLDEN KEY POINTS

- Number of electrons reaching from VB to CB at temperature T kelvin

$$\boxed{n = A\,T^{3/2}\,e^{-\frac{E_g}{2kT}} = AT^{3/2}\exp\left[-\frac{E_g}{2kT}\right]}$$

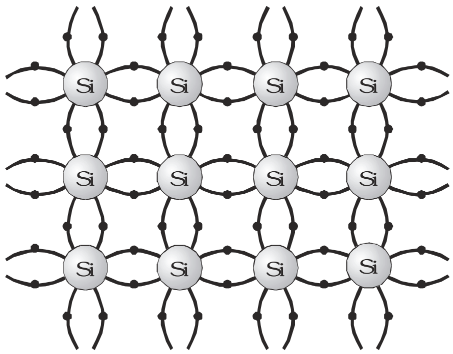
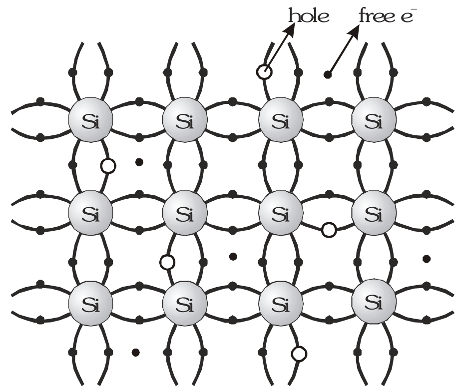
where

k = Boltzmann constant = 1.38×10^{-23} J/K T = absolute temperature

A = constant E_g = energy gap between CB and VB

- In silicon at room temperature out of 10^{12} Si atoms only one electron goes from VB to CB.
- In germanium at room temperature out of 10^{9} Ge atoms only one electron goes from VB to CB.

EFFECT OF TEMPERATURE ON SEMICONDUCTOR

At absolute zero kelvin temperature	Above absolute temperature
At this temperautre covalent bonds are very strong and there are no free electrons and semiconductor behaves as perfect insulator.	With increase in temperature few valence electrons jump into conduction band and hence it behaves as poor conductor.
 at 0 K Valence band fully filled Conduction band fully empty	 at high temperature Valence band partially empty Conduction band partially filled

EFFECT OF IMPURITY IN SEMICONDUCTOR

Doping is a method of addition of "desirable" impurity atoms to pure semiconductor to increase conductivity of semiconductor. or

Doping is a process of deliberate addition of a desirable impurity atoms to a pure semiconductor to modify its properties in controlled manner.

Added impurity atoms are called dopants.

The impurity added may be ≈ 1 part per million (ppm).

- The dopant atom should take the position of semiconductor atom in the lattice.
- The presence of the dopant atom should not distort the crystal lattice.
- The size of the dopant atom should be almost the same as that of the crystal atom.
- The concentration of dopant atoms should not be large (not more than 1% of the crystal atom).

It is to be noted that the doping of a semiconductor increases its electrical conductivity to a great extent.

GOLDEN KEY POINTS

- The concentration of dopant atoms be very low, doping ratio is vary from impure : pure :: $1 : 10^6$ to $1 : 10^{10}$ In general it is $1 : 10^8$
- There are two main method of doping.
  (i) Alloy method (ii) Diffusion method (The best)
- The size of dopant atom (impurity) should be almost the same as that of crystal atom. So that crystalline structure of solid remain unchanged.

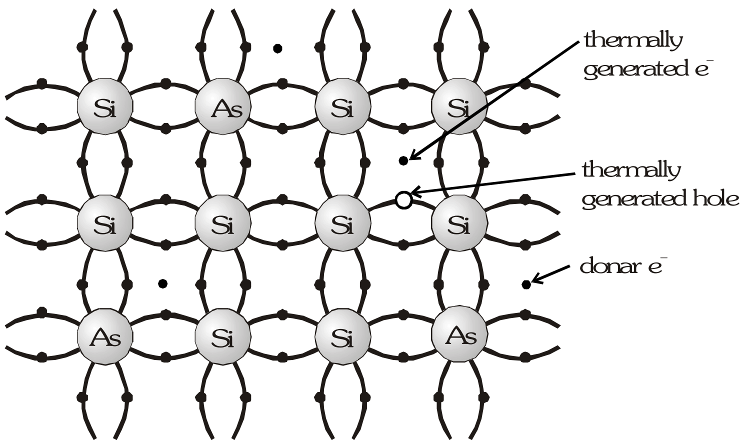
CLASSIFICATION OF SEMICONDUCTOR

SEMICONDUCTOR

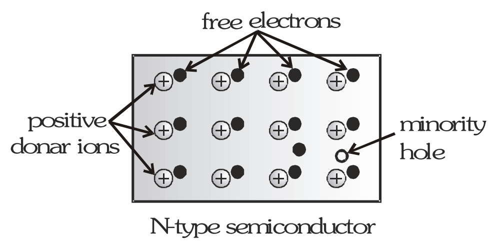
- Intrinsic semiconductor
  - (pure form of Ge, Si)
  - $n_e = n_h = n_i$
- Extrinsic semiconductor (doped semicondutor)
  - N-type
    - pentavalent impurity
    - (P, As, Sb etc.)
    - donar impurity (N_D)
    - $n_e >> n_h$
  - P-type
    - trivalent impurity
    - (Ga, B, In, Al)
    - acceptor impurity (N_A)
    - $n_h >> n_e$

N type semiconductor

When a pure semiconductor (Si or Ge) is doped by pentavalent impurity (P, As, Sb, Bi) then four electrons out of the five valence electrons of impurity take part, in covalent bonding, with four silicon atoms surrounding it and the fifth electron is set free. These impurity atoms which donate free e^- for conduction are called as Donar impurity (N_D). Due to donar impurity free e^- increases very much so it is called as "N" type semiconductor. By donating e^- impurity atoms get positive charge and hence known as "Immobile Donar positive Ion". In N-type semiconductor free e^- are called as "majority" charge carriers and "holes" are called as "minority" charge carriers.



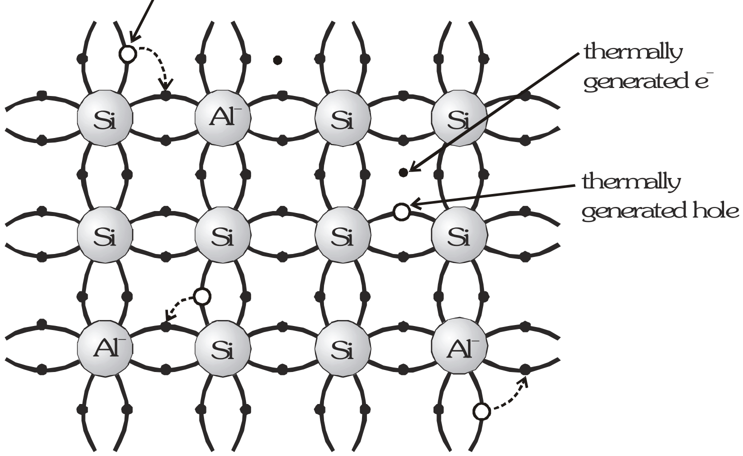
N-type semiconducting crystal



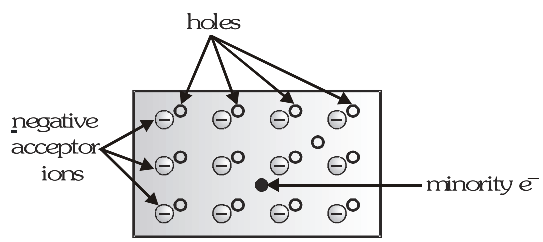
N-type semiconductor

P type semiconductor

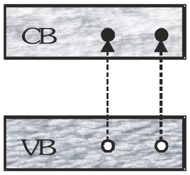
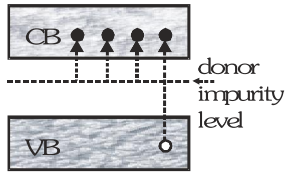
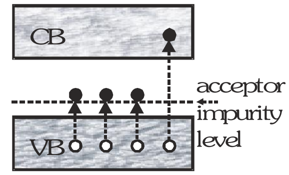
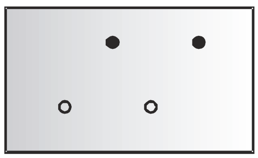
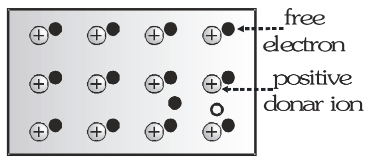
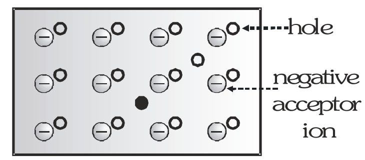
When a pure semiconductor (Si or Ge) is doped by trivalent impurity (B, Al, In, Ga) then outer most three electrons of the valence band of impurity take part, in covalent bonding with four silicon atoms surrounding it and except one electron from semiconductor and make hole in semiconductor. These impurity atoms which accept bonded e^- from valance band are called as Acceptor impurity (N_A). Here holes increases very much so it is called as "P" type semiconductor and impurity ions known as "Immobile Acceptor negative Ion". In P-type semiconductor free e^- are called as minority charge carries and holes are called as majority charge carriers.



P-type semiconducting crystal



P-type semiconductor

	Intrinsic Semiconductor	N-type (Pentavalent impurity)	P-type(Trivalent impurity)
1.			
2.			
3.	Current due to electron and hole	Mainly due to electrons	Mainly due to holes
4.	$n_e = n_h = n_i$	$n_h << n_e$ ($N_D \simeq n_e$)	$n_h >> n_e$ ($N_A \simeq n_h$)
5.	$I = I_e + I_h$	$I \simeq I_e$	$I \simeq I_h$
6.	Entirely neutral	Entirely neutral	Entirely neutral
7.	Quantity of electrons and holes are equal	Majority - Electrons Minority - Holes	Majority - Holes Minority - Electrons

Mass action Law

In semiconductors due to thermal effect, generation of free e^- and hole takes place.

Apart from the process of generation, recombination also occurs simultaneously, in which free e^- further recombine with hole.

At equilibrium rate of generation of charge carries is equal to rate of recombination of charge carrier.

The recombination occurs due to e^- colliding with a hole, larger value of n_e or n_h, higher is the probability of their recombination.

Hence for a given semiconductor rate of recombination $\propto n_e \quad n_h$

so rate of recombination $= R\ n_e \quad n_h$ R = recombination coefficient,

The value of R remains constant for a solid, according to the law of thermodynamics until crystalline lattice structure remains same.

For intrinsic semiconductor $n_e = n_h = n_i$

so rate of recombination $= R\ n_i^2$

$$R\ n_e \quad n_h = R\ n_i^2 \quad \Rightarrow \quad n_i^2 = n_e \quad n_h$$

Under thermal equilibrium, the product of the concentration 'n_e' of free electrons and the concentration n_h of holes is a constant and it is independent of the amount of doping by acceptor and donor impurities.

Thus from mass action law $\boxed{n_e \times n_h = n_1^2}$

Electron-hole Recombination :

It is necessarly to complete a bond that electron is shared from neighbouring atoms or it may also be received from conduction bond. In the second case electron recombines with the hole of valnce bond. This process is known as electron-hole recombination.

The breaking of bonds or generation of electron-hole pairs, and completion of bonds due to recombination is taking place continuously.

At equilibrium, the rate of generation becomes equal to the rate of recombination, giving a fixed number of free electrons and holes.

Ex.1 The energy of a photon of sodium light (λ = 589 nm) equals the band gap of a semiconducting material. Find :

(a) the minimum energy E required to create a hole-electron pair.

(b) the value of $\frac{E}{kT}$ at a temperature of 300 K.

Sol. (a) $E = \frac{hc}{e\lambda}$ (in eV) so $E = \frac{12400}{\lambda}$ (E is in eV and λ is in Å) λ = 5890 Å

so $E = \frac{12400}{5890} = 2.1\text{eV}$ (b) $\frac{E}{kT} = \frac{2.1 \times 1.6 \times 10^{-19}\,J}{1.38 \times 10^{-23} \times 300} = 81$

Ex.2 A P type semiconductor has acceptor level 57 meV above the valence band. What is maximum wavelength of light required to create a hole ?

Sol. $E = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E} = \frac{6.62 \times 10^{-34} \times 3 \times 10^{8}}{57 \times 10^{-3} \times 1.6 \times 10^{-19}} =$ 217100 Å

Ex.3 A silicon specimen is made into a p-type semiconductor by doping on an average one indium atom per 5 10^7silicon atoms. If the number density of atoms in the silicon specimen is 5 10^{28} atoms/m^3; find the number of acceptor atoms in silicon per cubic centimeter.

Sol. The doping of one indium atom in silicon semiconductor will produce one acceptor atom in p-type semiconductor. Since one indium atom has been dopped per 5 10^7 silicon atoms, so number density of acceptor atoms in silicon $= \frac{5 \times 10^{28}}{5 \times 10^{7}} = 10^{21}$ atom/m^3 = = 10^{15} atoms/cm^3

Ex.4 A pure Ge specimen is doped with Aℓ. The number density of acceptor atoms is approximately 10^{21} m^{-3}. If density of electron holes pair in an intrinsuc semiconductor is approximately $10^{19}m^{-3}$, the number density of electrons in the specimen is :

Sol. In pure semiconductor electron-hole pair n_i = 10^{19} m^{-3}

acceptor impurity N_A = 10^{21} m^{-3}

Holes concentration n_h = 10^{21} m^{-3}

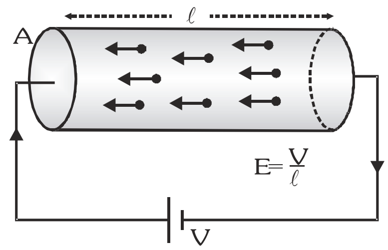
electrons concentration = $n_e = \frac{n_i^2}{n_h} = \frac{(10^{19})^2}{10^{21}}$ = 10^{17} m^{-3}

Ex.5 Pure Si at 300 K has equal electron (n_e) and hole (n_h) concentrations of 1.5 10^{16} m^{-3}. Dopping by indium increases n_h to 3 10^{22} m^{-3}. Calculate n_e in the doped Si.

Sol. For a doped semi-conductor in thermal equilebrium $n_e n_h = n_i^2$ (Law of mass action)

$$n_e = \frac{n_i^2}{h_h} = \frac{(1.5\times10^{16})^2}{3\times10^{22}} = 7.5 \quad 10^9 \ m^{-3}$$

RESISTIVITY AND CONDUCTIVITY OF SEMICONDUCTOR



Conduction in conductor

Relation between current (I) and drift velocity (v_d)

$I = ne \ A \ v_d$ n = number of electron in unit volume
A= cross sectional area

current density $J = \dfrac{I}{A}$ amp/m² = ne v_d drift velocity of electron $v_d = \mu E$

$J = ne\,\mu E$ $J = \sigma E$

Conductivity $\sigma = ne\mu = 1/\rho$ ρ = Resistivity

Mobility $\mu = \dfrac{v_d}{E}$

Conduction in Semiconductor

Intrinsic semiconductor	P - type	N - type
$n_e = n_h$	$n_h >> n_e$	$n_e >> n_h$
$J = ne\,[v_e + v_h]$	$J \cong e\,n_h\,v_h$	$J \cong e\,n_e\,v_e$
$\sigma = \dfrac{1}{\rho} = en\,[\mu_e + \mu_h]$	$\sigma = \dfrac{1}{\rho} \cong e\,n_h\,\mu_h$	$\sigma = \dfrac{1}{\rho} \cong e\,n_e\,\mu_e$

GOLDEN KEY POINTS

- Due to impurity the conductivity increases approximately 10^5 times
- $\sigma_{sc} = \sigma_e + \sigma_h = n_e e\mu_e + n_h e\mu_h = e(n_e\mu_e + n_h\mu_h)$

Ex.6 What will be conductance of pure silicon crystal at 300K Temp.. If electron hole pairs per cm³ is 1.072 x 10^{10} at this Temp, μ_n = 1350 cm² / volt sec & μ_p = 480 cm² / volt sec

Sol. $\sigma = n_i e\mu_e + n_i e\mu_h = n_i e\,(\mu_e + \mu_h) = 3.14\ 10^{-6}$ mho/cm

Ex.7 Pure Si at 300 K has equal electron n_e and hole n_h concentration of 1.5 10^{16}/m³. Doping by indium increases n_h to 4.5 10^{22}/m³. Calculate n_e in doped silicon.

Sol. $$n_e = \frac{n_i^2}{n_h} = \frac{(1.5\times10^{16})^2}{(4.5\times10^{22})} = 5\times10^9\,m^{-3}$$

Ex.8 A semiconductor has equal electron and hole concentration of $6\ \ 10^{8}/m^{3}$. On doping with certain impurity electron concentration increases to $9\ \ 10^{12}/m^{3}$.

(i) Identify the new semiconductor obtained after doping.

(ii) Calculate the new hole concentration.

Sol. $n_i = 6\ \ 10^{8}/m^{3}$ and $n_e = 9\ \ 10^{12}\ /m^{3}$

(i) $n_e > n_i$ so it is N-type semiconductor

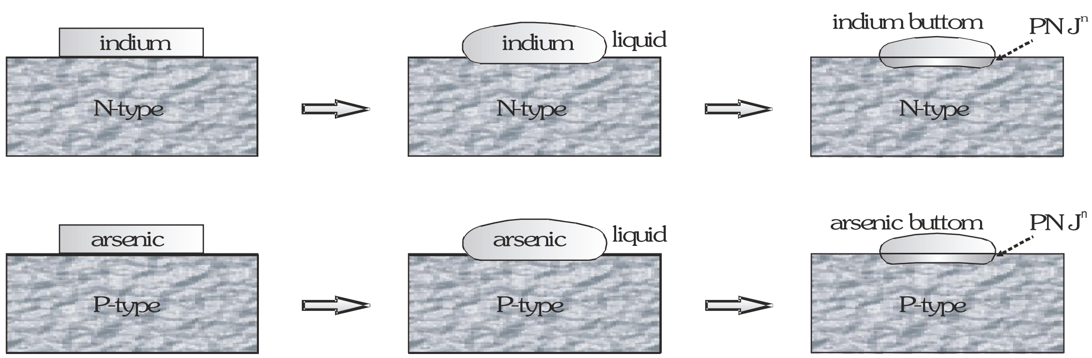
(ii) $\because \quad n_i^2 = n_e n_h \qquad n_h = \dfrac{n_i^2}{n_e} = \dfrac{36\times10^{16}}{9\times10^{12}} = 4\ \ 10^{4}\ /m^{3}$

P - N JUNCTION

Techniques for making P-N junction

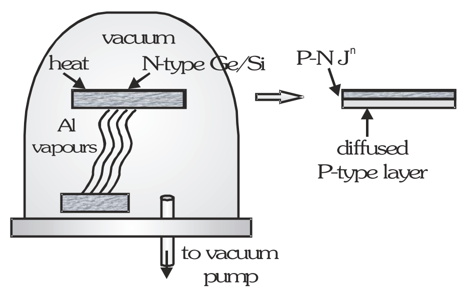
(i) Alloy Method or Alloy Junction

Here a small piece of III group impurity like indium is placed over n–Ge or n–Si and melted as shown in figure ultimetely P – N junction form.



(ii) Diffusion Junction

A heated P–type semiconductor is kept in pentavalent impurity vapours which diffuse into P–type semiconductor as shown and make P–N junction.



(iii) Vapour deposited junction or epitaxial junction

If we want to grow a layer of n–Si or p–Si then p–Si wafer is kept in an atmosphere of Silane (a silicon compound which dissociates into Si at high temperatures) plus phosphorous vapours. On craking of silane at high temperature a fresh layer on n–Si grows on p–Si giving the "P–N junction". Since this junction growth is layer by so it is also referred as layer growth or epitaxial junction formation of P–N junction.

Description of P-N Junction without applied voltage or bias

Given diagram shows a P–N junction immediately after it is formed.

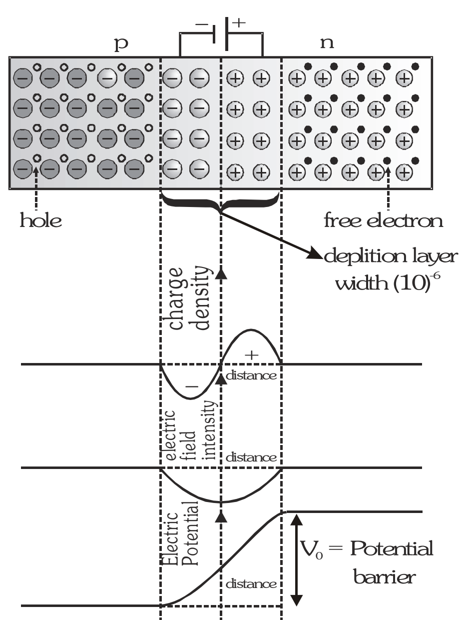
P region has mobile majority holes and immobile negatively charged impurity ions.

N region has mobile majority free electrons and immobile positively charged impurity ions.

Due to concentration difference diffusion of holes starts from P to N side and diffusion of e^- s starts N to P side.

Due to this a layer of only positive (in N side) and negative (in P–side) started to form which generate an electric field (N to P side) which oppose diffusion process, during diffusion magnitude of electric field increases due to this diffusion it gradually decreased and ultimately stopes.

The layer of immobile positive and negative ions, which have no free electrons and holes called as **depletion layer** as shown in diagram.



GOLDEN KEY POINTS

- **Width of depletion layer $\cong$ 10^{-6} m**

  (a) As doping increases depletion layer decreases

  (b) As temperature is increased depletion layer also increases.

  (c) P-N junction $\rightarrow$ unohmic, due to nonlinear relation between I and V.

- **Potential Barrier or contact potential**

  Ge $\longrightarrow$ 0.3 V   Si $\longrightarrow$ 0.7 V

- Electric field, produce due to potential barrier $E = \dfrac{V}{d} = \dfrac{0.5}{10^{-6}}$ $\Rightarrow$ $E \cong 10^5$ V/m

  This field prevents the respective majority carrier from crossing barrier region

DIFFUSION AND DRIFT CURRENT

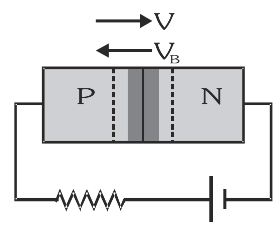
(1) Diffusion current – P to N side   (2) Drift current – N to P side

If there is no biasing diffusion current = drift current

So total current is zero

BEHAVIOUR OF P–N JUNCTION WITH AN EXTERNAL VOLTAGE APPLIED OR BIAS

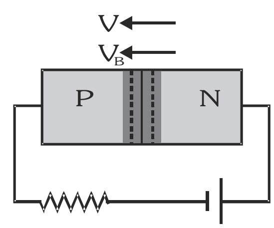
Forward Bias



If we apply a voltage "V" such that P–side is positive and N–side is negative as shown in diagram.

The applied voltage is opposite to the junction barrier potential.Due to this effective potential barrier decreases, junction width also decreases, so more majority carriers will be allowed to flow across junction. It means the current flow in principally due to majority charge carriers and it is in the order of mA called as forward Bias.

Reverse Bias



If we apply a voltage "V" such that P–side is negative and N–side is positive as shown in diagram.

The applied voltage is in same direction as the junction barrier potential. Due to this effective potential barrier increase junction, width also increases, so no majority carriers will be allowed to flow across junction.

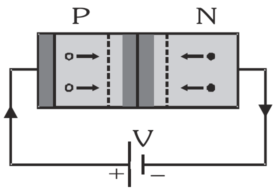
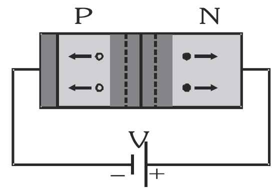
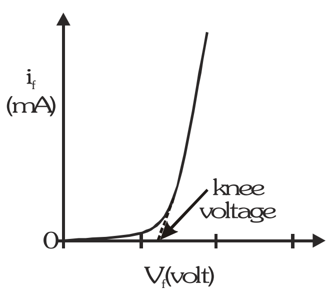
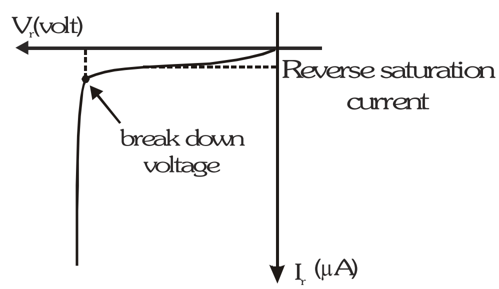
Only minority carriers will drifted. It means the current flow in principally due to minority charge carriers and is very small (in the order of μA). This bias is called as reversed Bias.

GOLDEN KEY POINTS

- In reverse bias, the current is very small and nearly constant with bias (termed as reverse saturation current). However interesting behaviour results in some special cases if the reverse bias is increased further beyond a certain limit, above particular high voltage breakdown of depletion layer started.
- Breakdown of a diode is of following two types :

  (i) Zener breakdown   (ii) Avalanche breakdown

Comparison between Forward Bias and Reverse Bias

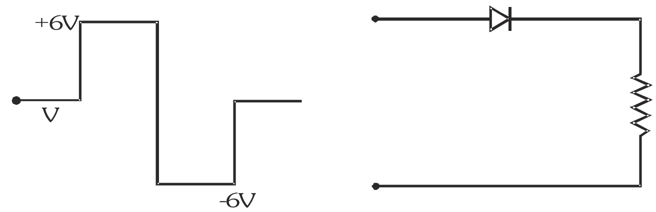
Forward Bias	Reverse Bias
P → positive N → negative	P → negative N → positive
 	
1. Potential Barrier reduces	1. Potential Barrier increases.
2. Width of depletion layer decreases	2. Width of depletion layer increases.
3. P-N jn. provide very small resistance	3. P-N jn. provide high resistance
4 Forward current flows in the circuit	4. Very small current flows.
5. Order of forward current is milli ampere.	5. Order of current is micro ampere for Ge or Neno ampere for Si.
6. Current flows mainly due to majority carriers.	6. Current flows mainly due to minority carriers.
7. Forward characteristic curves.	7. Reverse characteristic curve
 	
8. Forward resistance $R_f = \frac{\Delta V_f}{\Delta I_f} \cong 100\Omega$	8. Reverse resistance $R_r = \frac{\Delta V_r}{\Delta I_r} \cong 10^6\,\Omega$
9. Order of knee or cut in voltage Ge → 0.3 V Si → 0.7 V	9. Breakdown voltage Ge → 25 V Si → 35 V
Special point : Generally $\frac{R_r}{R_f} = 10^3 : 1$ for Ge	$\frac{R_r}{R_f} = 10^4 : 1$ for Si

Ex.9 The resistance of p-n junction diode decreases when forward biased and increases when reverse biased. Why?

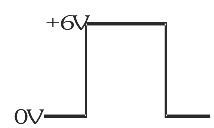
Sol. When p-n junction is forward biased, the width of depletion layer decreases and the barrier potential is opposed by the forward bias. In other words, potential barrier decreases. Hence the diffusion of holes and electrons through the junction increases. Due to this, the diode current increases and hence resistance decreases.

When p-n junction is reverse biased, the barrier potential is supported and the width of depletion layer increases. As a result of this, the diode current becomes almost zero as there is no diffusion of majority carriers (electrons and holes) through the junction. Hence the resistance of the junction diode increases when reverse biased.

Ex.10 What is an ideal diode ? Draw the output waveform across the load resistor R, if the input waveform is as shown in the figure.

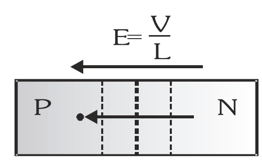


Sol. An ideal diode has zero resistance when forward biased and infiniter resistance when it is reversed biased. Output wave form is shown in fig.



Ex.11 A potential barrier of 0.5 V exists across a p-n junction (i) If the depletion region is 5 10^{-7} m wide. What is the intensity of the electric field in this region ? (ii) An electron with speed 5 10^{5} m/s approaches the p-n junction from the n-side with what speed will it enter the p-side.

Sol.: (i) Width of depletion layer ΔL = 5 10^{-7} m

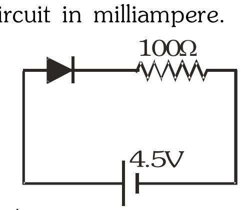


$$E = \frac{V}{\Delta L} = \frac{0.5V}{5\times10^{-7}} = 10^{6} \text{ volt/m}$$

(ii) Work energy theorm $\frac{1}{2}Mv_i^2 = eV + \frac{1}{2}Mv_f^2$

$$v_f = \sqrt{\frac{Mv_i^2 - 2eV}{M}} = 2.7 \quad 10^{5} \text{ m/s}$$

Ex.12 Figure shows a diode connected to an external resistance and an e.m.f. Assuming that the barrier potential developed in diode is 0.5 V_1 obtain the value of current in the circuit in milliampere.



Sol. E = 45 V_1R = 100 Ω,

voltage drop across p-n junction = 0.5 V

effective voltage in the circuit V = 4.5 – 0.5 = 4.0 V

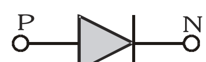
current in the circuit $I = \frac{V}{R} = \frac{4.0}{100} = 0.04A$ = 0.04   1000 mA = 40mA

Ex.13 Differentiate zener and avalanche breakdown.

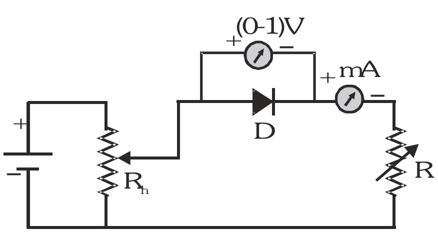
Sol. The difference between these two are as follows

Zener Break down	Avalanche Break down
Where covalent bonds of depletion layer, its self break, due to high electric field of very high Reverse bias voltage.	Here covalent bonds of depletion layers are broken by collision of "Minorities" which aquire high kinetic energy from high electric field of very-very high reverse bias voltage.
This phenomena predominant	This phenomena predominant
(i) At lower voltage after "break down"	(i) At high voltage after breakdown
(ii) In P – N having "High doping"	(ii) In P – N having "Low doping"
(iii) P – N Jn. having thin depletion layer	(iii) P – N Jn. having thick depletion layer
Here P – N not demage paramanently	Here P – N damage peramanentaly due to "Heating effect" due to abruptly increament of minorities during repeatative collisoins.
"In D.C voltage stablizer zener phenomenan is used".	

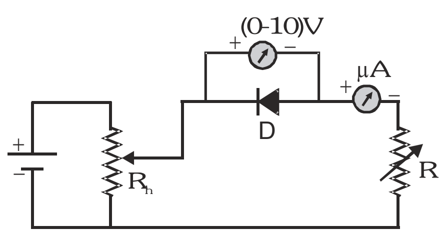
CHARACTERISTIC CURVE OF P-N JUNCTION DIODE



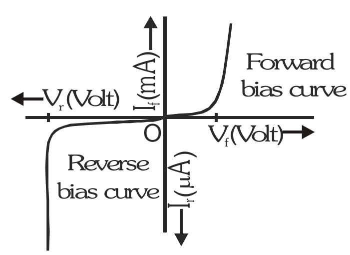
symbol



Forward bias



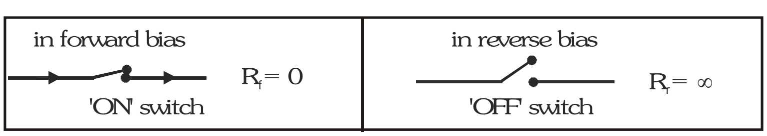
Reverse bias



In forward bias when voltage is increased from 0V is steps and corresponding value of current is measured, the curve comes as OB of figure. We may note that current increase very sharply after a certain voltage knee voltage. At this voltage, barrier potential is completely eliminated and diode offers a low resistance.

In reverse bias a microammeter has been used as current is very very small. When reverse voltage is increased from 0V and corresponding values of current measured the plot comes as OCD. We may note that reverse current is almost constant hence called reverse saturation current. It implies that diode resistance is very high. As reverse voltage reaches value V_B, called breakdown voltage, current increases very sharply.

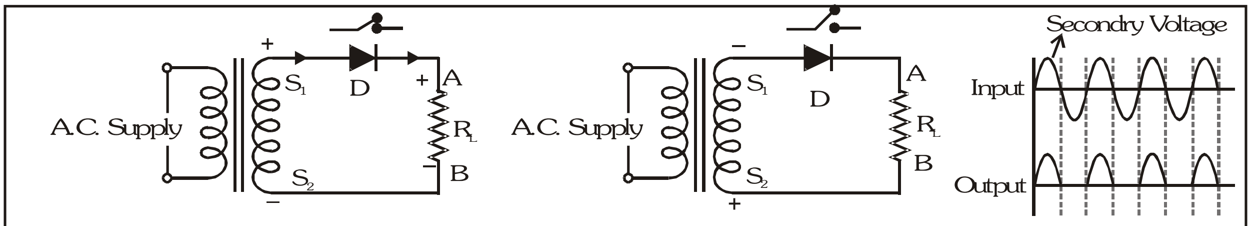
For Ideal Diode



RECTIFIER

It is device which is used for converting alternating current into direct current.

Half wave rectifier



For positive half cycle
For negative half cycle

During the first half (positive) of the input signal, let S_1 is at positive and S_2 is at negative potential. So, the PN junction diode D is forward biased. The current flows through the load resistance R_L and output voltage is obtained.

During the second half (negative) of the input signal, S_1 and S_2 would be negative and positive respectively. The PN junction diode will be reversed biased. In this case, practically no current would flow through the load resistance. So, there will be no output voltage.

Thus, corresponding to an alternating input signal, we get a unidirectional pulsating output as shown.

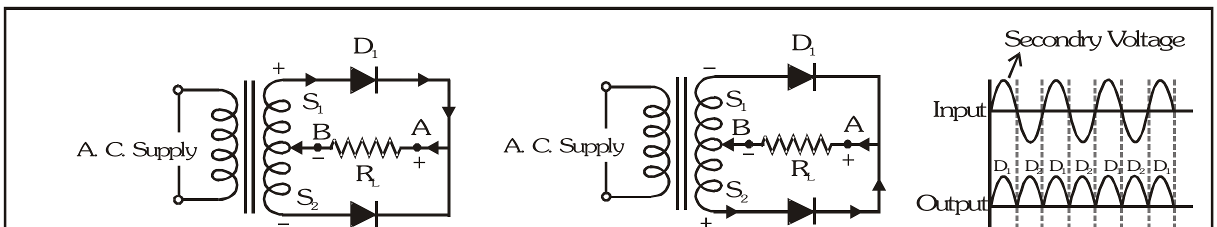
Peak inverse voltage (PIV)

In half wave rectifier PIV = maximum voltage across secondary coil of transformer (V_s)

= Peak value of output (V_m)

Full wave rectifier

When the diode rectifies the whole of the AC wave, it is called full wave rectifier. Figure shows the experiemental arrangement for using diode as full wave rectifier. The alternating signal is fed to the primary a transformer. The output signal appears across the load resistance R_L.



For positive half cycle
For negative half cycle

During the positive half of the input signal :

Let S_1 positive and S_2 negative.

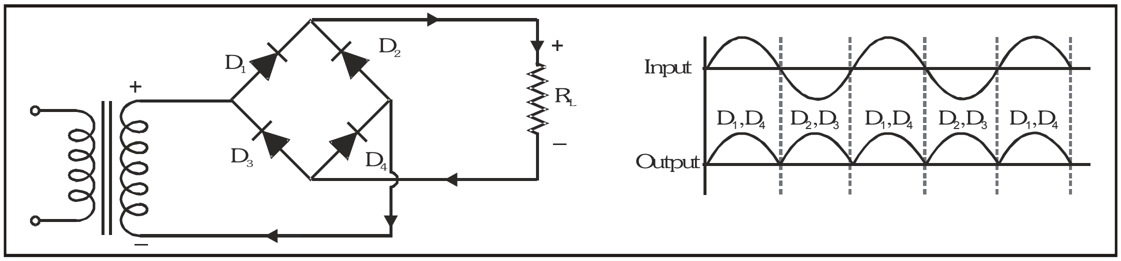
In this case diode D_1 is forward biased and D_2 is reverse biased. So only D_1 conducts and hence the flow of current in the load resistance R_L is from A to B.

During the negative half of the input signal :

Now S_1 is negative and S_2 is positive. So D_1 is reverse-biased and D_2 is forward biased. So only D_2 conducts and hence the current flows through the load resistance R_L from A to B.

It is clear that whether the input signal is positive or negative, the current always flows through the load resistance in the same direction and full wave rectification is obtained.

Bridge Rectifier



During positive half cycle

D_1 and D_4 are forward biased $\rightarrow$ on switch

D_2 and D_3 are reverse biased $\rightarrow$ off switch

During negative half cycle

D_2 and D_3 are forward biased $\rightarrow$ on switch

D_1 and D_4 are reverse biased $\rightarrow$ offswitch

In bridge rectifier peak inverse voltage PIV = V_s = V_m

Form Factor

$$F = \frac{I_{rms}}{I_{dc}} \quad \text{or} \quad \frac{E_{rms}}{E_{dc}}$$

for full wave rectifier $F = \dfrac{\pi}{2\sqrt{2}}$ for half wave rectifier $F = \dfrac{\pi}{2}$

Ripple and ripple factor

In the output of rectifier some A.C. components are present. They are called ripple & there measurement is given by a factor known as ripple factor. For a good rectifier ripple factor must be very low.

Total output current

$I_{rms} = \sqrt{I^2_{ac} + I^2_{dc}}$ Where I_{ac} = rms value of AC component present in output

Ripple factor $r = \dfrac{I_{ac}}{I_{dc}} \Rightarrow r = \sqrt{\dfrac{I^2_{rms}}{I^2_{dc}} - 1} = \sqrt{F^2 - 1}$

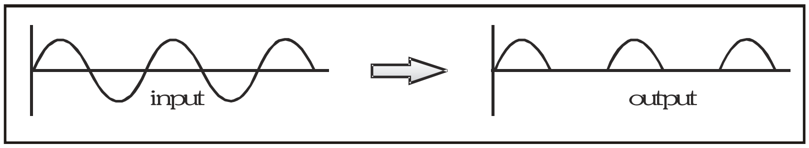
Rectifier efficiency $\eta = \dfrac{P_{dc}}{P_{ac}} = \dfrac{I^2_{dc}\ R_L}{I^2_{rms}\ (R_F + R_L)}$

Half wave rectifier	**Full wave rectifier or bridge wave rectifier**
$\eta = \dfrac{0.406}{1 + \dfrac{R_f}{R_L}}$	$\eta = \dfrac{0.812}{1 + \dfrac{R_f}{R_L}}$
If $\dfrac{R_f}{R_L} << 1$, then η = 40.6%	If $\dfrac{R_f}{R_L} << 1$, then η = 81.2%
Special Note If $R_f = R_L$ η = 20.3%	Special Note If $R_f = R_L$ η = 40.6%

Note : In brige full wave rectifier R_f is two times of resistance of P-N jn. diode in FB.

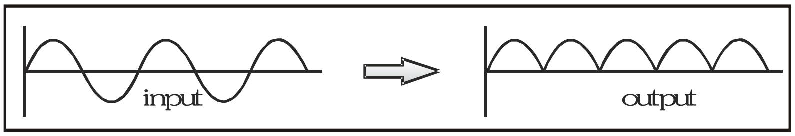
Ripple Frequency

(i) For half wave rectifier



input frequency = 50Hz ripple frequency = 50Hz

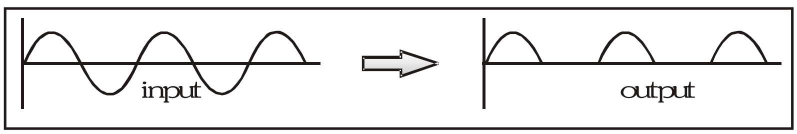
(ii) for full wave rectifier



input frequency = 50Hz ripple frequency = 100Hz

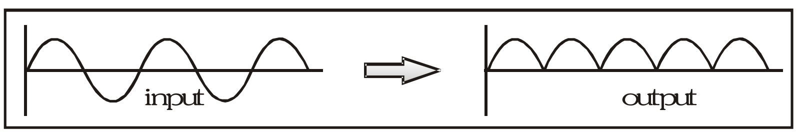
Pulse

(i) For half wave rectifier



Pulse frequency = 100 Hz Pulse frequency = 50 Hz

(ii) For full wave rectifier



Pulse frequency = 100 Hz Pulse frequency = 100 Hz

Comparison Between Average Rectifiers

	Half-wave	Full-wave	
		Centre-tap	Bridge
Number of Diodes	1	2	4
Transformer necessary	No	Yes	No
Peak secondary voltage	V_s	V_s	V_s
Peak Inverse Voltage (when peak of output = V_m)	$V_s = V_m$	$V_s = 2V_m$	$V_s = V_m$
Peak load Current, I_m	$\frac{V_{in}}{r_d + R_L}$	$\frac{V_{in}}{r_d + R_L}$	$\frac{V_{in}}{2r_d + R_L}$
RMS Current, I_{rms}	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$
DC current, I_{dc}	$\frac{I_m}{\pi}$	$\frac{2I_m}{\pi}$	$\frac{2I_m}{\pi}$
Ripple factor, r	1.21	0.482	0.482
Rectification efficiency (max)	40.6%	81.2%	81.2%
Ripple frequency (when input = 50 Hz)	50 Hz	100 Hz	100 Hz

Ex.14 A sinusoidal voltage of amplitude 25 volts and frequency 50 Hz is applied to a half wave rectifier using PN diode. No filter is used and the load resistor is 1000 Ω. The forward resistance R_f ideal diode is 10 Ω. Calculate

(i) Peak, average and rms values of load currrent.

(ii) d.c. power output (iii) a.c. power input

(iv) % Rectifier efficiency (v) Ripple factor

Sol. (i) $I_m = \frac{V_m}{R_f + R_L} = \frac{25}{(10+1000)}$ = 24.75 mA

$I_{dc} = \frac{I_m}{\pi} = \frac{24.75}{3.14} = 7.88\text{mA}$

$I_{rms} = \frac{I_m}{2} = \frac{24.75}{2} = 12.38\text{mA}$

(ii) $P_{dc} = I_{dc}^{2}\ R_L = (7.88\ \ 10^{-3})^2\ \ 10^3 \approx 62$ mW

(iii) $P_{ac} = I_{rms}^{2}(R_f + R_L) = (12.38\ \ 10^{-3})^2\ \ (10 + 1000)$

≈ 155 mW

(iv) Rectifier efficiency $\eta = \frac{P_{dc}}{P_{ac}}\ \ 100$

$= \frac{62}{155}\ \ 100 = 40\ \%$

(v) Ripple factor $= \left[\left(\frac{I_{rms}}{I_{ac}}\right)^2 - 1\right]^{1/2} = \left[\left(\frac{12.38}{7.88}\right)^2 - 1\right] = 1.21$

Ex.15 The halfwave rectifier supplies power to a 1 kΩ load. The input supply voltage is 220 V neglecting forward resistance of the diode, calculate

(i) V_{dc}

(ii) I_{dc} and

(iii) Ripple voltage (rms value)

Sol. (i) $V_{dc} = \frac{V_m}{\pi} = \frac{\sqrt{2}\ V_{rms}}{\pi} = \frac{\sqrt{2}\times 220}{3.14} \approx 99$ volt

(ii) $I_{dc} = \frac{V_{dc}}{R_L} = \frac{99}{1000} = 99$ mA

(iii) $r = \frac{(V_r)_{rms}}{V_{dc}}$

or $(V_r)_{rms} = r\ \ v_{dc} = 1.21\ \ 99 = 119.79$ volt.

Ex.16 A fullwave rectifier supplies a load of 1 KΩ. The a.c. voltage applied to the diodes is 220 volt rms. If diode resistance is neglected, calculate.

(i) Average d.c. voltage (ii) Average d.c. current (iii) Ripple voltage (rms)

Sol. (i) Average d.c. voltage $V_{dc} = \frac{2V_m}{\pi} = 0.636\ V_m$

where V_m = maximum across each half of the secondary winding.

If V be the rms voltage across each half of the secondary winding then $V = \frac{V_m}{\sqrt{2}}$

$\therefore\ \ V_{dc} = 0.636\ \ V\sqrt{2} = 0.9$ V

$= 0.9\ \ 220 = 198$ volt.

(ii) For fullwave rectifier $I_{dc} = \frac{V_{dc}}{R_L} = \frac{198}{1000} = 198$ mA

(iii) $r = \frac{V_{r(rms)}}{V_{dc}} \Rightarrow V_{r(rms)} = r\ \ V_{dc} \Rightarrow V_{r(rms)} = 0.482\ \ 198 = 95.436$ volt

Ex.17 A fullwave P.N. diode rectifier used load ressitor of 1500 Ω. No filter is used. Assume each diode to have idealized charcteristic with R_f = 10Ω and R_r = ∞. Since wave voltage applied to each diode has amplitude of 30 volts and frequency 50Hz. Calculate.

(i) Peak, d.c. rms load current

(ii) d.c. power input

(iii) A.C. power input

(iv) Rectifier efficiency

Sol. (i) Peak current $I_m = \dfrac{V_m}{R_f + R_L}$

$\therefore I_m = \dfrac{30\text{volts}}{10 + 1500} = 19.9$ mA

d.c. load current $I_{dc} = \dfrac{2I_m}{\pi} = 0.636\ I_m$

= 0.636   19.9 mA = 12.66 mA.

$I_{rms} = \dfrac{I_m}{\sqrt{2}} = \dfrac{19.9}{\sqrt{2}} = 14$ mA

(ii) D.C. Power output $P_{dc} = I_{dc}^2\ \ R_L$

= $(12.66\ \ 10^{-3})^2$ 1500 Watt = 240.41 mW

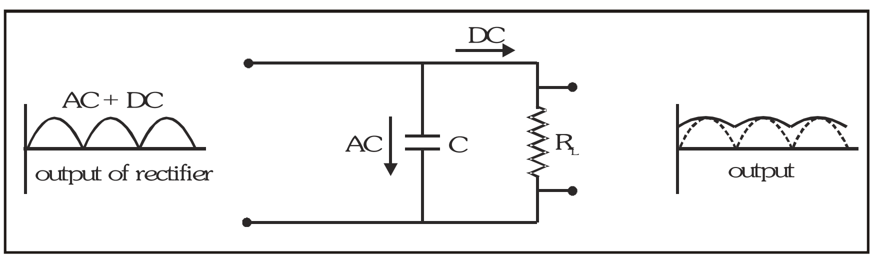
(iii) A.C. power input $P_{in} = I_{rms}^{\ 2}\ (R_f + R_2)$

= $(14\ \ 10^{-3})^2$ (10 + 1500) watt = 295.96 mW

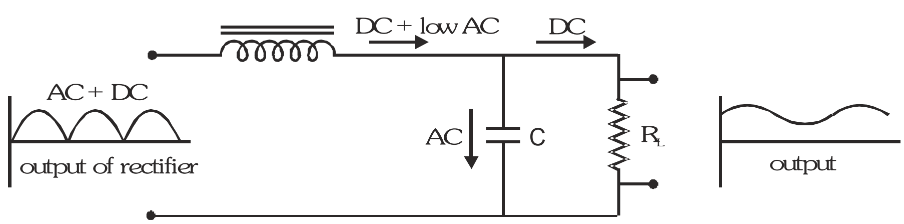
FILTER CIRCUIT

To reduce A.C. Components

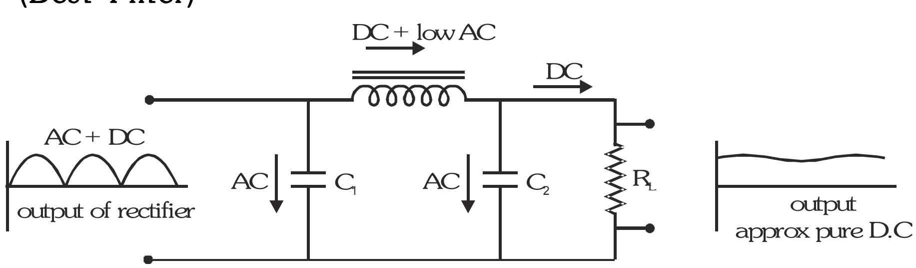
Capacitor Filter



L - C Filter



π - Filter (Best Filter)

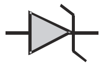


ZENER DIODE

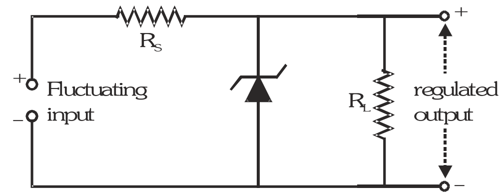
A specifically doped crystal diode which can work in break down region is known as Zener diode.

It is always connected in reverse biased condition manner.

Used as a voltage regulator

Symbol of Zener diode 

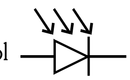
In forward biased it works as a simple diode.



Voltage regulating circuit of Zener diode

SOME OTHER SPECIAL DIODES

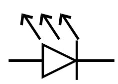
Photodiode

A junction diode made from "light or photo sensitive semiconductor" is called a "photo diode" its symbol .

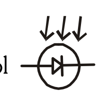
When light of energy "hν" falls on the photodiode (Here hν > energy gap) more electrons move from valence band, to conduction band, due to this current in circuit of photodiode in "Reverse bias", increases. As light intensity is increased, the current goes on increases so photo diode is used, "to detect light intensity" for example it is used in "Vedio camera".

Light emitting diode (L.E.D)

When a junction diode is "forward biased" energy is released at junction in the form of light due to recombination of electrons and holes. In case of Si or Ge diodes, the energy released is in infra-red region.

In the junction diode made of GaAs, InP etc energy is released in visible region such a junction diode is called "light emitting diode" (LED) Its symbol 

Solar cell

Solar cell is a device for converting solar energy into electrical. A junction diode in which one of the P or N sections is made very thin (So that the light energy falling on diode is not greatly asorbed before reaching the junction) can be used to convert light energy into electric energy such diode called as solar cell. Its symbol 

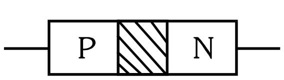
(i) It is operated into photo voltaic mode i.e., generation of voltage due to the bombardment of optical photon.

(ii) No external bias is applied.

(iii) Active junction area is kept large, because we are intrested in more power. Materials most commonly used for solar cell is Si, As, Cds, CdTe, CdSe, etc.

Variable capacitor (Varactor)

P – N junction diode can be used as a "Capacitor" here depletion layer acts as "dielectric material" and remaining "P" and "N" part acts as metallic plates.



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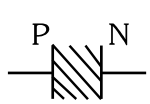


, its symbol 

Diode laser

It is intersting form of LED in which special construction helps to produce stimulated radiation as in laser.

Ex.18 A zener diode of voltage V_Z (=6V) is used to maintain a constant voltage across a load resistance R_L (=1000Ω) by using a series resistance R_S (=100Ω). If the e.m.f. of source is E (= 9 V), calculate the value of current through series resistance, Zener diode and load resistance. What is the power being dissipated in Zener diode.

Sol. Here, $E = 9V$; $V_Z = 6V$; $R_L = 1000\Omega$ and $R_S = 100\Omega$,

Potential drop across series resistor $V_R = E - V_Z = 9 - 6 = 3$ V

Current through series resistance R_S is $I = \frac{V_R}{R} = \frac{3}{100} = 0.03A$

Current through load resistance R_L is $I_L = \frac{V_Z}{R_L} = \frac{6}{1000} = 0.006A$

Current through Zener diode is $I_Z = I - I_L = 0.03 - 0.006 = 0.024$ amp.

Power dissipated in Zener diode is $P_Z = V_Z I_Z = 6 \times 0.024 = 0.144$ Watt

Ex.19 A Zener diode is specified having a breakdown voltage of 9.1 V with a maximum power dissipation of 364 mW. What is the maximum current that the diode can handle.

Sol. Maximum current that the given diode can handle is $\frac{364 \times 10^{-3}}{9.1}$ A i.e., 40 mA.

TRANSISTOR

Inventor William Bradford Shockley, John Bardeen and Walter Houser Brattain.

Transistor is a three terminal device which transfers a singal from low resistance circuit to high resistance circuit.

It is formed when a thin layer of one type of extrinsic semiconductor (P or N type) is sandwitched between two thick layers of other type of extrinsic semiconductor.

Each transistor have three terminals which are :-

(i) Emitter

(ii) Base

(iii) Collector

Emitter : It is the left most part of the transistor. It emit the majority carrier towards base. It is highly doped and medium in size.

Base : It is the middle part of transistor which is sandwitched by emitter (E) and collector (C). It is lightly doped and very thin in size.

Collector : It is right part of the transistor which collect the majority carriers emitted by emitter. It has large size and moderate doping.

There are two semiconducting PN-junctions in a transistor

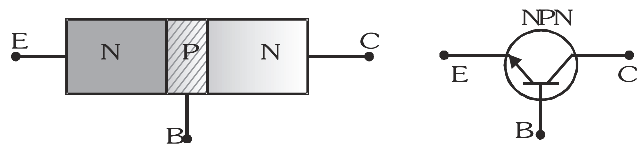
(i) The junction between emitter and base is known as emitter-base junction (J_{EB}).

(ii) The junction between base and collecter is known as base-collector junction (J_{CB}).

TRANSISTOR ARE OF TWO TYPES

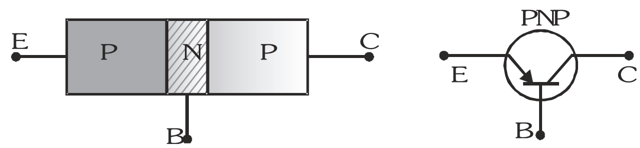
N-P-N Transistor

If a thin layer of P-type semiconductor is sandwitched between two thick layers of N-type semiconductor is known as NPN transistor.



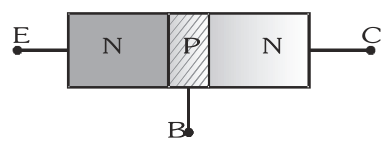
P-N-P Transistor

If a thin layer of N-type of semiconductor is sandwitched between two thick layer of P-type semiconductor is known as PNP transistor.



GOLDEN KEY POINTS

- Transistor have two P-N Junction J_{EB} and J_{CB}, therefore it can be biased in four following ways as given below:



Emitter-Base	Collector-Base	Region of working
Forward biased	Reverse biased	Active
Reverse biased	Forward biased	Inverse Active
Reverse biased	Reverse biased	Cut off
Forward biased	Forward biased	Saturation

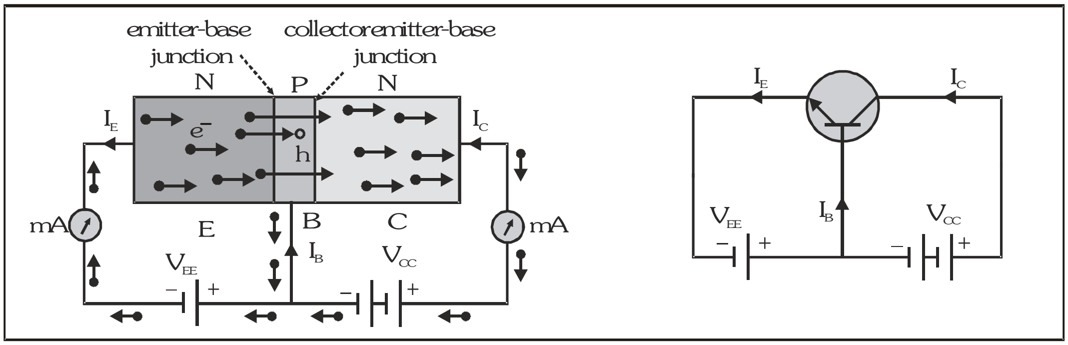
- Comparsion between E, B and C

Emitter	Medium size	High dopping
Base	Smallest size	Low dopping
Collector	Largest size	Medium dopping

- The collector region is made physically larger than the emitter. Because collector has to dissipiate much greater power.
- Transistor all mostly work in active region in electronic devices & transistor work as amplifier in Active region only.
- Transistor i.e. It is a short form of two words "Transfer resistors". Signal is introduced at low resistance circuit and out put is taken at high resistance circuit.
- Base is lightly doped. Otherwise the most of the charge carrier from the emitter recombine in base region and not reaches at collector.
- Transistor is a current operated device i.e. the action of transistor is controlled by the motion of charge carriers. i.e. current

WORKING OF NPN TRANSISTOR

The emitter Base junction is forward bias and collector base junction is reversed biased of n-p-n transistor in circuit (A) and symbolic representation is shown in Figure.



When emitter base junction is forward bias, electrons (majority carriers) in emitter are repelled toward base.

The barrier of emitter base junction is reduced and the electron enter the base, about 5% of these electron recombine with hole in base region result in small current (I_b).

The remaining electron ($\approx$95%) enter the collector region because they are attracted towards the positive terminal of battery.

For each electron entering the positive terminal of the battery is connected with collector base junction an electron from negative terminal of the battery connected with emitter base junction enters the region.

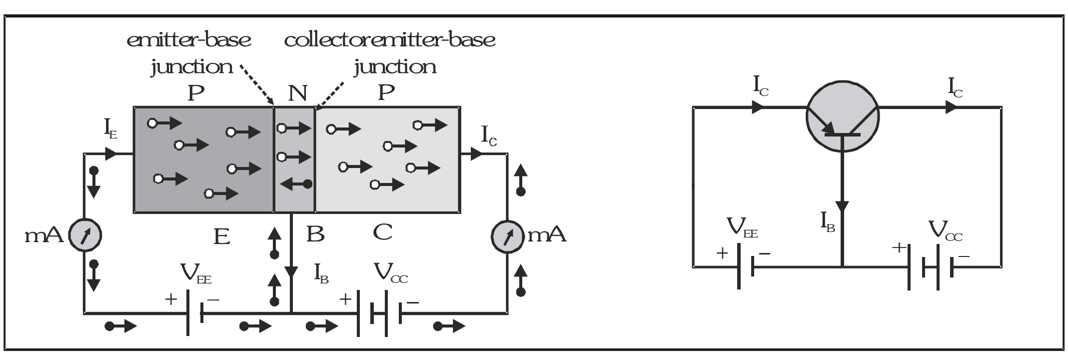
The emitter current (I_e) is more than the collector (I_c).

The base current is the difference between I_e and I_c and proportional to the number of electron hole recombination in the base.

$$I_e = I_b + I_c$$

WORKING OF PNP TRANSISTOR

When emitter-base junction is forward biased holes (majority carriers) in the emitter are repelled towards the base and diffuse through the emitter base junction. The barrier potential of emitter-base junction decreases and hole enter the n-region (i.e. base). A small number of holes ($\approx$5%) combine with electron of base-region resulting small current (I_b). The remaining hole ($\approx$95%) enter into the collector region because they are attracted towards negative terminal of the battery connected with the collector-base junction. These hole constitute the collector current (I_c).



As one hole reaches the collector, it is neutralized by the battery. As soon as one electron and a hole is neutralized in collector a covalent bond is broken in emitter region. The electron hole pair is produced. The released electron enter the positive terminal of bettary and hole more towards the collector.

Basic Transistor Circuit Configurations :-

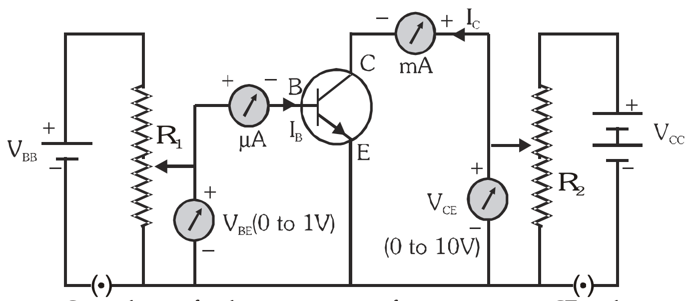
To study about the characterstics of transistor we have to make a circuit [In which four terminals are required. But the transistor have three terminals, so one of the terminal of transistor is made common in input and output both. Thus, we have three possible configuration of transistor circuit.

(i) Common base configuration (ii) Common emitter configuration (iii) Common collector configuration

In these three common emitter is widely used and common collector is rarely used.

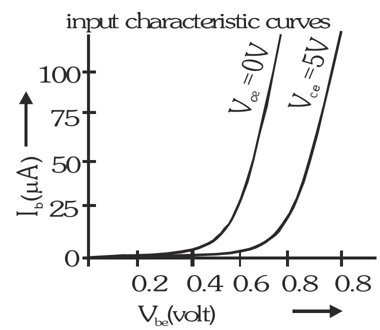
Common emitter characterstics of a transistor

Circuit Diagram :



Circuit diagram for characteristic curve of n-p-n transistor in CE mode

Input characterstics



The variation of base current (I_b) (input) with base emitter voltage (V_{EB}) at constant-emitter voltage (V_{CE}) is called input characterstic.

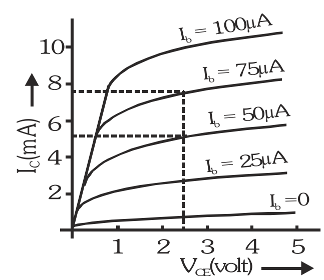
(i) Keep the collector-emitter voltage (V_{CE}) constant (say V_{CE} = 1V)

(ii) Now change emitter base voltage by R_1 and note the corresponding value of base current (I_b).

(iii) Plot the graph between V_{EB} and I_b.

(iv) A set of such curves can be plotted at different (V_{CE} = 2V)

Output characterstics



The variation of collector current I_c (output) with collector-emitter voltage (V_{CE}) at constant base current (I_b) is called output characterstic.

(i) Keep the base current (I_b) constant (say I_b = 10μA)

(ii) Now change the collector-emitter voltage (V_{CE}) using variable resistance R_2 and note the corresponding values of collector current (I_c).

(iii) Plot the graph between (V_{CE} versus I_c)

(iv) A set of such curves can be plotted at different fixed values of base current (say 0, 20 μA, 30 μA etc.)

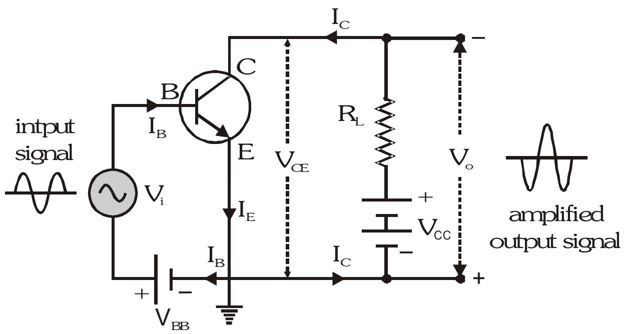
TRANSISTOR AS AN AMPLIFIER

The process of increasing the amplitude of input signal without distorting its wave shape and without changing its frequency is known as amplification.

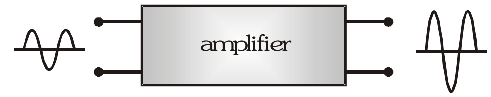
A device which increases the amplitude of the input signal is called amplifier.

A transistor can be used as an amplifier in active state.

A basic circuit of a common emitter transistor amplifier is shown.

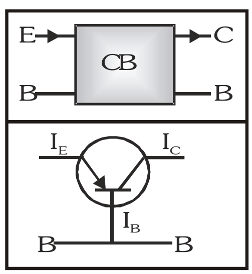
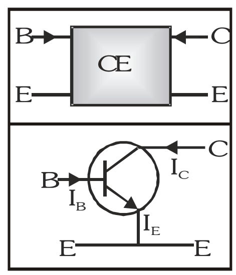
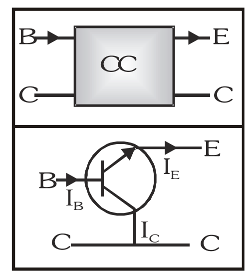


common emitter amplifier
NPN transistor



Comparative study of transistor configurations

1. Common Base **(CB)**　　2. Common Emitter **(CE)**　　3. Common Collector **(CC)**

	C B	C E	C C
			
Input Resistance	Low (100 Ω)	High (750 Ω)	Very High ≅ 750 kΩ
Output resistance	Very High	High	Low
Current Gain	(A_I or α)	(A_I or β)	(A_I or γ)
	$\alpha = \frac{I_C}{I_E} < 1$	$\beta = \frac{I_C}{I_B} > 1$	$\gamma = \frac{I_E}{I_B} > 1$
Voltage Gain	$A_V = \frac{V_o}{V_i} = \frac{I_C R_L}{I_E R_i}$	$A_V = \frac{V_o}{V_i} = \frac{I_C R_L}{I_B R_i}$	$A_V = \frac{V_o}{V_i} = \frac{I_E R_L}{I_B R_i}$
	$A_v = \alpha \frac{R_L}{R_i}$	$A_v = \beta \frac{R_L}{R_i}$	$A_v = \gamma \frac{R_L}{R_i}$
	$\cong 150$	$\cong 500$	less than 1
Power Gain	$A_p = \frac{P_o}{P_i}$	$A_p = \frac{P_o}{P_i}$	$A_p = \frac{P_o}{P_i}$
	$A_p = \alpha^2 \frac{R_L}{R_i}$	$A_p = \beta^2 \frac{R_L}{R_i}$	$A_p = \gamma^2 \frac{R_L}{R_i}$
Phase difference (between output and input)	same phase	opposite phase	same phase
Application	For High Fequency	For Audible fequency	For Impedance Matching

Relation Between α, β and γ

α , β	β , γ	α , γ
$I_E = I_B + I_C$ divide by I_C $\frac{I_E}{I_C} = \frac{I_B}{I_C} + 1$ $\frac{1}{\alpha} = \frac{1}{\beta} + 1$ $\beta = \frac{\alpha}{1-\alpha}$	$I_E = I_B + I_C$ divide by I_B $\frac{I_E}{I_B} = 1 + \frac{I_C}{I_B}$ $\gamma = 1 + \beta$	- $\gamma = 1 + \frac{\alpha}{1-\alpha}$ $\gamma = \frac{1}{1-\alpha}$

GOLDEN KEY POINTS

- In transistor charge carriers move from emitter to collector. Emitter send the charge carriers and collector collect them this happen only when emitter-base junction is forward bias and collector-base junction is reverse bias (base of amplifier)
- In transistor reverse bias is high as compared to forward bias so that the charge carriers move from emitter to base exert a large attractive force to enter in collector region so base current is very less.
- CE configuration is widely used becasue it have large voltage and power gain as compared to other amplifiers.
- In amplifier negative feed back is used to stabilized the gain.
- CC is used for impdence matching for connecting two transistors in cascade.

Q.20 A transistor is a current operated device. Explain why ?

Ans. The action of a transistor is controlled by the charge carriers (electrons or holes). That is why a transistor is a current operated device.

Q.21 In a transistor, reverse bias is quite high as compared to the forward bias. Why ?

Ans. In a transistor, charge carriers (electrons or holes) move from emitter to collector through the base. The reverse bias on collector is made quite high so that it may exert a large attractive force on the charge carriers to enter the collector region. These moving carriers in the collector constitute a collector current.

Q.22 A transistor is a temperature sensitive device. Explain.

Ans. In a transistor, conduction is due to the movement of current carriers electrons and holes. When temperature of the transistor increases, many covalent bonds may break up, resulting in the formation of more electrons and holes. Thus, the current will increase in the transistor. This current gives rise to the production of more heat energy. the excess heat causes complete breakdown of the transistor.

Q.23 The use of a transistor in common-emitter configuration is preferred over the common-base configuration. Explain why ?

Ans. The current gain and hence voltage gain in the common-emitter configuration is much more than i of common-base configuration. Hence the former is preferred over the later.

Q.24 Why do we prefer transistor over the vacuum tubes in the portable radio receivers ?

Ans. This is because of two reasons :

(i) Transistor is compact and small in size than the vacuum tube.

(ii) Transistor can operate even at low voltage which can be supplied with two or three dry cells.

Q.25 Why a transistor cannot be used as a rectifier ?

Ans. If transistor is to be used as a rectifier the either emitter-base or base-collector has to used as diode. For equated working of the said set of diodes, the number density of charge carriers in emitter and base or base and collector must be approximately same. As base is lightly doped and comparatively thin, so emitter cannot work as a rectifier.

Ex.26 In a transistor, the value of β is 50. Calculate the value of α.

Sol. $\beta = 50 \qquad \beta = \dfrac{\alpha}{1-\alpha} \quad \Rightarrow \quad 50 = \dfrac{\alpha}{1-\alpha} \quad \Rightarrow \quad 50 - 50\,\alpha = \alpha \quad \Rightarrow \quad \alpha = \dfrac{50}{51} = 0.98$

Ex.27 Calculate the collector and emitter current for which $I_b = 20\ \mu A$, $\beta = 100$

Sol. $\beta = 100, \quad I_b = 20\ \mu A$

$I_c = \beta\ I_b = 100 \quad 20 \quad 10^{-6} = 2000\ \mu A$

$I_e = I_b + I_c = 20 + 2000 = 2020\ \mu A = 2.02 \quad 10^{-3}\ A = 2.02\ mA$

Ex.28 For a common emitter amplifier, current gain = 50. If the emitter current is 6.6 mA, calculate the collector and base current. Also calculate current gain, When emitter is working as common base amplifier.

Sol. $\beta = 50\ ; \quad I_e = 6.6\ mA$

$\because \quad \beta = \dfrac{I_c}{I_b} \qquad \therefore \qquad I_c = \beta I_b = 50 I_b \qquad \ldots(i)$

$I_e = I_c + I_b$ using equation (i) we get $6.6 = 50\ I_b + I_b = 51 I_b$

or $\quad I_b = \dfrac{6.6}{51} = 0.129\ mA$

Hence$I_c = 50 \quad \dfrac{6.6}{51} = 6.47\ mA$ and $\alpha = \dfrac{\beta}{1+\beta} = \dfrac{50}{51} = 0.98$

Ex.29 Transistor with $\beta = 75$ is connected to common-base configuration. What will be the maximu collector current for an emitter current of 5 mA ?

Sol. $\beta = 75,\ I_e = 5\ mA$

$\beta = \dfrac{\alpha}{1-\alpha} \quad \Rightarrow \quad 75 = \dfrac{\alpha}{1-\alpha} \quad \Rightarrow \quad 75 - 75\alpha = \alpha$

or $\quad 76\alpha = 75 \quad$ or $\quad \alpha = \dfrac{75}{76}$

$\alpha = \dfrac{I_c}{I_e} \qquad \therefore \qquad I_c = \alpha I_e = \dfrac{75}{76} \quad 5 = 4.93\ mA$

Ex.30 The base current is 100 μA and collector current is 3 mA.

(a) Calculate the values of β, I_e and α

(b) A change of 20 μA in the base current produces a change of 0.5 mA in the collector current. Calculate $\beta_{a.c.}$.

Sol. I_b = 100 μA = 0.100 mA, I_c = 3 mA

(a) $\beta = \frac{I_c}{I_b} = \frac{3}{0.100} = 30$

$\alpha = \frac{\beta}{1+\beta} = \frac{30}{1+30} = \frac{30}{31} = 0.97$ and $I_e = \frac{I_c}{\alpha} = \frac{3\times 31}{30} = 3.1$ mA

(b) ΔI_b = 20 μA = 0.02 mA , ΔI_c = 0.5 mA

$\therefore \quad \beta_{ac} = \frac{\Delta I_c}{\Delta I_b} = \frac{0.5}{0.02} = 25$

Ex.31 In npn transistor circuit, the collector current is 10 mA. If 95% of the electrons emitted reach the collector, what is the base current ?

Sol. I_c = 95% $\quad I_c = 0.95\ I_e$

$\therefore \quad I_e = \frac{100}{95}\times I_c = \frac{100}{95}\times 10\text{mA} = 10.53$ mA $\quad (\because \quad I_c = 10$ mA$)$

Now $I_e = I_c + I_b \quad \therefore \quad I_b = I_e - I_c = 10.53 - 10 = 0.53$ mA

Ex.32 In an NPN transistor 10^{10} electrons enter the emitter in 10^{-6} s and 2% electrons recombine with holes in base, then current gain α and β are :

Sol. Emitter current $I_e = \frac{Ne}{t} = \frac{10^{10}\times 1.6\times 10^{-19}}{10^{-6}} = 1.6$ mA

Base current $I_b = \frac{2}{100}\times 1.6 = 0.032$ mA

but $I_e = I_c + I_b \quad \therefore \quad I_c = I_e - I_b = 1.6 - 0.032 = 1.568$ mA

$\therefore \quad \alpha = \frac{I_c}{I_e} = \frac{1.568}{1.6} = 0.98$

and $\quad \beta = \frac{I_c}{I_b} = \frac{1.568}{0.032} = 49$

FEEDBACK

Feedback are two types :

Positive feedback

When input and output are in the same phase then positive feedback is there. It is used in oscillators.

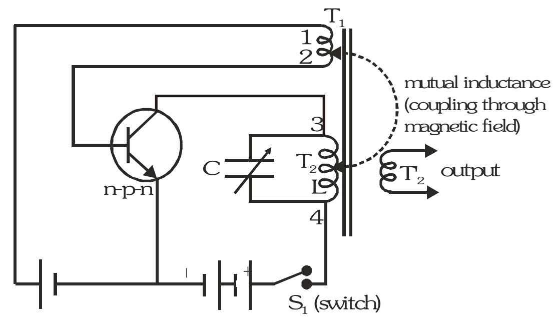
Negative feedback

If input and output are out of phase and some part of that is feedback to input is known as negative feedback. It is used to get constant gain amplifier.

TRANSISTOR AS AN OSCILLATOR

Oscillator is device which delivers a.c. output wave form of desired frequency from d.c. power even without input singal excitation.

The electric oscillations are produced by L– C circuit



(i.e. tank circuit containing inductor and capacitor). These oscillations are damped one i.e. their amplitude decrease with the passage of time due to the small resistance of the inductor. In other words, the energy of the L – C oscillations decreases. If this loss of energy is compensated from outside, then undamped oscillations (of constant amplitude) can be obtained.

This can be done by using feed back arrangement and a transistor in the circuit.

L – C circuit producing L – C oscillations consists of an inductor of inductance L and capacitor of

variable capacitance C inductor of inductance L' is connected in the collector-emitter circuit through a battery and a tapping key (K). Inductors L and L' are inductively coupled (Figure)

Working

When key K is closed, collector current begins to flow through the coil L. As this current grows, magnetic flux linked with coil L increase (i.e. changes).

Since coil L is inductively coupled with L, so magnetic flux linked with coil L' also changes. Due to change in magnetic flux, induced e.m.f. is set up across the coil L'.

The direction of induced e.m.f. is such that the emitter-base junction is forward biased. As a result of this biasing, emitter current I_e increases which in turn increases the collector current I_c [$\therefore$ $I_e = I_b + I_c$].

With the increase in collector current, magnetic flux linked with coil L also increases. This increases the e.m.f. induced in the coil L'.

The increased induced e.m.f. increases the forward bias of emitter-base junction. Hence emitter current is further increased which in turn increases the collector current. The process of increasing the collector current continues till the magnetic flux linked with coil L' becomess maximum (i.e. constant). At this stage, the induced e.m.f. in coil L' becomes zero.

The upper plate of the capacitor C gets positively charged during this process.

When induced e.m.f. becomes zero, the capacitor C starts discharging through the inductor L.

The emitter current starts decreasing resulting in the collector current. With decreasing collector current which flows through L', e.m.f. is again induced in the coil L' but in the opposite direction. It opposes the emitter current and hence collector current ultimately decreases to zero.

The change in magnetic flux linked with coil L' stops and hence induced e.m.f. in the coil L becomes zero. At this stage, the capacitor gets discharged through coil L but now in the opposite direction. Now the emitter current and hence collector current increase but now in the opposite direction .

This process repeats and the collector current oscillates between maximum and minimum values.

$$f = \frac{1}{2\pi\sqrt{LC}}$$

ADVANTAGES OF SEMICONDUCTOR DEVICES OVER VACUUM TUBES

Advantages

- Semiconductor devices are very small in size as compared to the vacuum tubes. Hence the circuits using semiconductor devices are more compact.
- In vacuum tubes, current flows when the filament is heated and starts emitting electrons. So, we have to wait for some time for the operation of the circuit. On the other hand, in semiconductor devices no heating is required and the circuit begins to operate as soon as it switched on.
- Semiconductor devices require low voltage for their operation as compared to the vacuum tube. So a lot of electrical power is saved.
- Semiconductor devices do not produce any humming noise which is large in case of vacuum tube.
- Semiconductor devices have longer life than the vacuum tube. Vacuum tube gets damaged when its filament is burnt.
- Semiconductor devices are shock proof.
- The cost of production of semiconductor-devices is very small as compared to the vacuum tubes.
- Semiconductor devices can be easily transported as compared to vacuum tube.

Disadvantages

- Semiconductor devices are heat sensitive. They get damaged due to overheating and high voltages. So they have to be housed in a controlled temperature room.
- The noise level in semiconductor devices is very high.
- Semiconductor devices have poor response in high frequency range.

Q.33 Why is a transistor so called ?

Ans. The word Transistor can be treated as short form of two words 'transfer resistor'. In a transistor, a signal is introduced in the low resistance circuit and output is taken across the high resistance circuit. Thus, a transistor helps to transfer the current from low resistance part to the high resistance part.

Q.34 The base region of a transistor is lightly doped. Explain why ?

Ans. In a transistor, the majority carriers (holes or electrons) from emtter region move towards the collector region through base. If base is made thick and highly doped, then majority of carriers from emitter will combine with the carriers in the base and only small number of carriers will reach the collector. Thus the output or collector current will be considerably small. To get large output or collector current, base is made thin and lightly doped so that only few electron-hole combination may take place in the base region.

Q.35 Explain why the emitter is forward biased and the collector is reverse biased in a transistor ?

Ans. In a transistor, the charge carriers move from emitter to collector. The emitter sends the charge carriers and collector collects them. This can happen only if emitter is forward biased and the collector is reverse biased so that it may attract the carriers.