SEMICONDUCTOR ELECTRONICS

1 SOLID STATE ELECTRONICS (SEMICONDUCTORS)

(A) Energy bands in solids:

(i) *In solids, the group of closely lying energy levels is known as energy band.*

(ii) *In solids the energy bands are analogous to energy levels in an atom.*

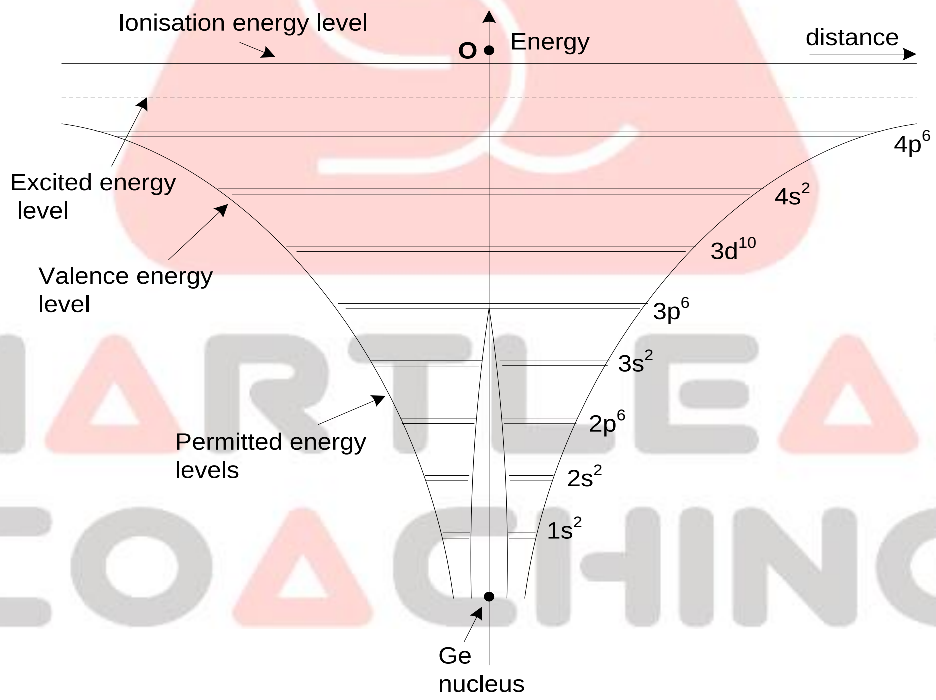
(iii) *In solids the atoms are arranged very close to each other. In these atoms there are discrete energy levels of electrons. For the formation of crystal these atoms come close together, then due to nucleus-nucleus, electron-electron and electron-nucleus interactions the discrete energy levels of atom distort and consequently each energy level spits into a large number of closely lying energy levels.*

(iv) *The number of split energy levels is proportional to the number of atoms interacting with each other. If two atoms interact then each energy level splits into two out of which one will be somewhat above and another will be somewhat below the main energy level. In solids the number of atoms is very large ($\approx 10^{23}$). Hence each energy level splits into large number of closely lying energy levels. Being very close to each other these energy levels assume the shape of a band.*

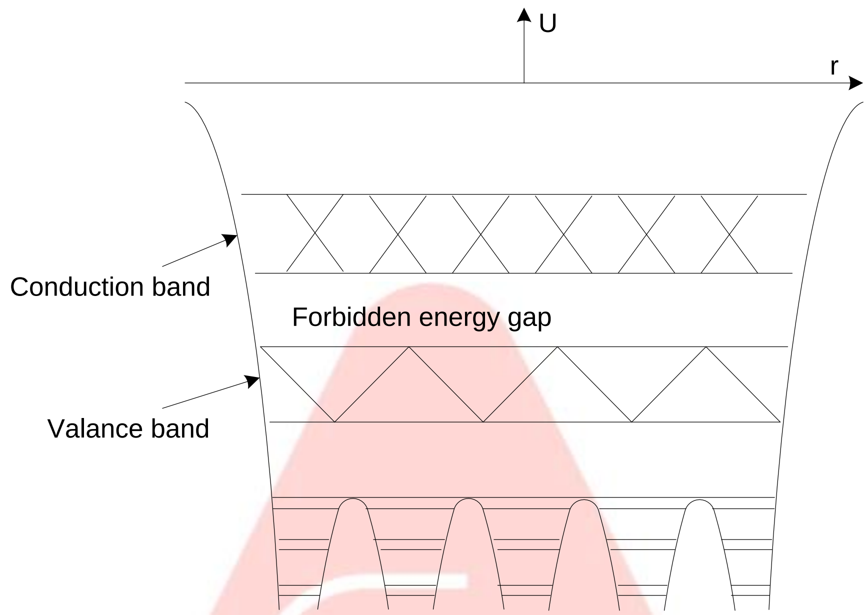
(v) *In an energy band there are 10^{23} energy levels with energy difference of 10^{-23} ev.*

(vi) *Curve between energy and distance i.e. U-r curve*

(a) When two atoms are interacting



(b) When 10^{23} atoms are mutually interacting



(vii) The are three types of energy bands in a solid viz.

(a) Valence energy band

(b) Conduction energy band

(c) Forbidden energy gap.

(viii) Difference between valence, forbidden and conduction energy bands.

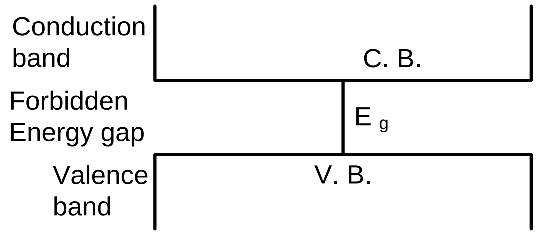
Valance Energy Band	Forbidden Energy Band	Conduction Energy Band
In this band there are valence electrons.	No electrons are found in this band	In this band the electrons are rarely found
This band may be partially or completely filled with electrons.	This band is completely empty.	This band is either empty or partially filled with electrons.
In this band the electrons are not capable of gaining energy from external electric field.		In this band the electrons can gain energy from electric field.
The electrons in this band do not contribute to electric current.		Electrons in this band contribute in this band contribute to electric current.
In this band there are electrons of outermost orbit of atom which contribute in band formation.		In this band there are electrons which are obtained on breaking the covalent bands.
This is the band of maximum energy in which the electrons are always present.		This is the band of minimum energy which is empty.
This band can never be empty.		This band can be empty.

(ix) The conduction band is also known as first permitted energy band or first band.

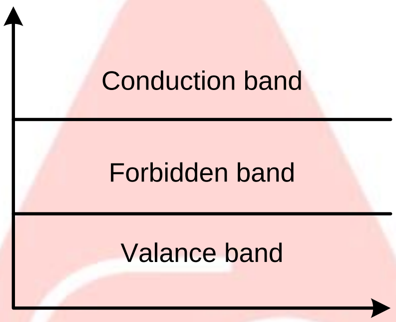
(x) Energy gap or Band gap (E_g):

(a) The minimum energy which is necessary for shifting electrons from valence band to conduction band is defined as band gap (E_g)

(b) The forbidden energy gap between the valence band and the conduction band is known as band gap (E_g). i.e. $E_g = E_c - E_v$



(xi) *As there are energy levels f electrons in an atom, similarly there are three specific energy bands for the electrons in the crystal formed by these atoms as shown in the figure*



(xii) *Completely filled energy bands: The energy band, in which maximum possible number of electrons are present according to capacity is known as completely filled bank.*

(xiii) *Partially filled energy bands: The energy band, in which number of electrons present is less than the capacity of the band, is known as partially filled energy band.*

(xiv) *Electric conduction is possible only in those solids which have empty energy band or partially filled energy band.*

2 VARIOUS TYPES OF SOLIDS

(i) On the basis of band structure of crystals, solids are divided in three categories.

(a) Insulators
(b) Semi-conductors
(c) Conductors.

(ii) Difference between Conductors, Semi-conductors and Insulators

S.No.	Property	Conductors	Semi-conductors	Insulators
1.	Electrical conductivity and its value	Very high 10^{-7} mho/m	Between those of conductors and insulators i.e. 10^{-7} mho/m to 10^{-13} mho/m	Negligible 10^{-13} mho/m
2.	Resistivity and its value	Negligible Less than 10^{-5} Ω-m	Between those of conductors and insulators i.e. 10^{-5} Ω-m to 10^{5} Ω-m	Very high more than 10^{5} Ω-m
3.	Energy gap and its value	Zero or very small	More that in con-ductors but less than that in insu-lators e.g. in Ge, ΔE_g =0.72 eV is Si, ΔE_g =1.1 eV in Ga As ΔE_g =1.3 eV	Very large e.g. in diamond ΔE_g = 7 eV

4.	Current carriers and current flow	Due to free electrons and very high	Due to free electrons and holes more than that in insulators	Due to free electrons but negligible.
5.	Number of current carriers (electrons or holes) at ordinary temperature	Very high	very low	negligible
6.	Condition of valence band and conduction band at ordinary temperature	The valence and conduction bands are completely filled or conduction band is some what empty (e.g. in Na)	Valence band in somewhat empty and conduction band is somewhat filled	Valence band is completely filled and conduction band is completely empty.
7.	Behaviour at 0 K	Behaves like a superconductor.	Behaves like an insulator	Behaves like an insulator
8.	Temperature coefficient of resistance (α)	Positive	Negative	Negative
9.	Effects of temperature on conductivity	Conductivity decreases	Conductivity increases	Conductivity increases
10.	On increasing temperature the number of current carriers	Decreases	Increases	Increases
11.	On mixing impurities their resistance	Increases	Decreases	Remains unchanged
12.	Current flow in these takes place	Easily	Very slow	Does not take place
13.	Examples	Cu, Ag, Au, Na, Pt, Hg etc.	Ge, Si, Ga, As etc.	Wood, plastic, mica, diamond, glass etc.

(iii) **Other properties of semiconductors:**

(a) Semi conducting elements are tetravalent i.e. there are four electrons in their outermost orbit.

(b) Their lattice is face centered cubic (F.C.C.)

(c) The number of electrons or cotters is given by

$$n_i = p_i = AT^{3/2}e^{-E_g/2kT}$$

i.e. on increasing temperature, the number of current carriers increases.

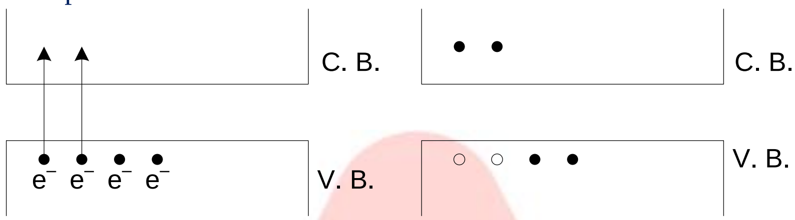
(d) There are uncharged

(iv) **Holes or cotters:**

(a) The deficiency of electrons in covalent band formation in the valence band in defined as hole or cotter.

(b) These are positively charged. The value of positive charge on them is equal to the electron charge.

(c) Their effective mass is less than that of electrons.
(d) In an external electric field, holes move in a direction opposite to that of electrons i.e. they move from positive to negative terminal.
(e) They contribute to current flow.
(f) Holes are produced when covalent bonds in valence band break.



3 TYPES OF SEMICONDUCTORS AND DIFFERENCE BETWEEN THEM

(i) The semiconductors are of two types.
(a) Intrinsic or pure semiconductors
(b) Extrinsic or dopes semiconductors

(ii) **Difference between intrinsic and extrinsic semiconductors:**

S.No.	Intrinsic semiconductors	Extrinsic semiconductors
1.	Pure Ge or Si is known as intrinsic semiconductor	The semiconductor, resulting from mixing impurity in it, is known as extrinsic semiconductors.
2.	Their conductivity is low (because only one electron in 10^9 contribute)	Their conductivity is high
3.	The number of free electrons (n_i in conduction band is equal to the number of holes p_i in valence band.)	In these $n_i \neq p_i$
4.	These are not practically used	These are practically used
5.	In these the energy gap is very small	In these the energy gap is more than that in pure semiconductors.
6.	In these the Fermi energy level lies in the middle of valence band and conduction	In these the Fermi level shifts towards valence or conduction energy bands.

(iii) **Properties of intrinsic semiconductors:**
(a) At absolute zero temperature (0 K) there are no free electrons in them.
(b) At room temperature, the electron-hole pair in sufficient number are produced.
(c) Electric conduction takes place via both electrons and holes.
(d) The drift velocities of electrons and holes are different.
(e) The drift velocity of electrons (V_{dn}) is greater than that of holes (V_{dp}).
(f) The total current is $I = I_n + I_p$
(g) In connecting wires the current flows only via electrons.
(h) The current density is given by

$$J = nqV_{dn} + pqV_{dp}$$

$$\vec{J} = nq\mu_n E + pq\mu_p E = \sigma \vec{E}$$

Where V_{dn} = drift velocity of electrons
μ_n = mobility of electrons
V_{dp} = drift velocity of holes
μ_p = mobility of holes

(i) The electric conductivity is given by $\sigma = nq(\mu_n + \mu_p)$
(j) Mobility of electron $\mu_n = V_{dn}/E$

(k) Mobility of holes $\mu_p = V_{dp}/E$

(l) At room temperature $\sigma_{Ge} > \sigma_{Si}$ because $n_{Ge} > n_{Si}$

where $n_{Ge} = 2.5 \times 10^{13}/cm^3$ and $n_{Si} = 1.4 \times 10^{10}/cm^3$

(iv) **Extrinsic semiconductors:**

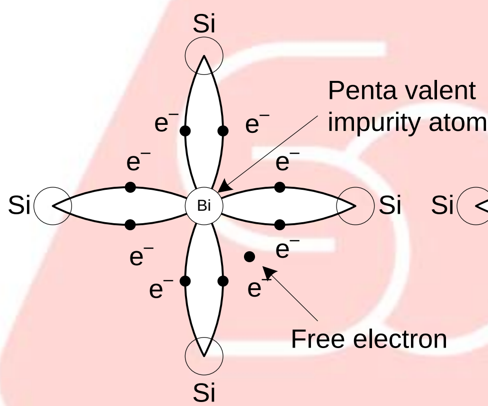
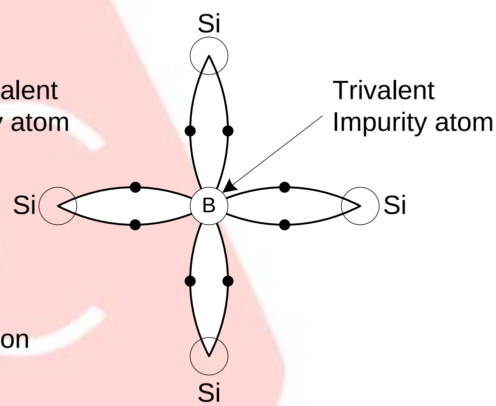
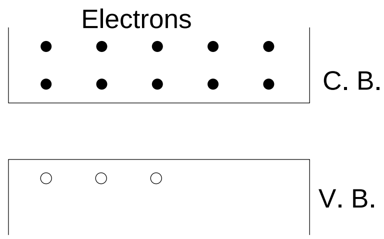
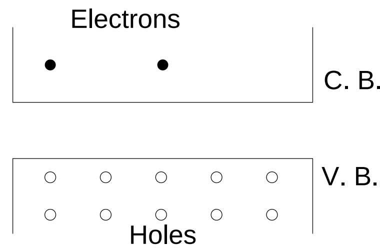
(a) **Doping:** The process of mixing impurities of other elements in pure semiconductors is known as doping.

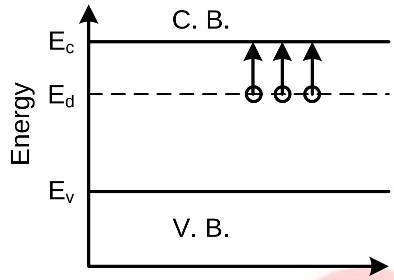
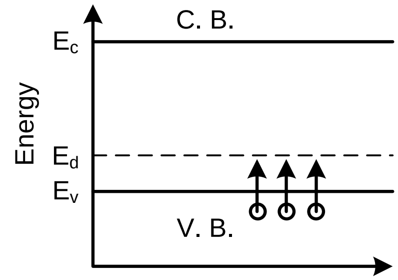
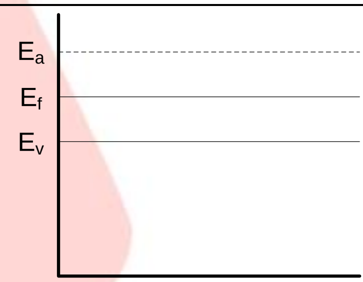
(b) **Extrinsic semiconductors:** the semiconductors, in which trivalent and pentavalent elements are mixed as impurities, are known as extrinsic semiconductors.

(c) The extrinsic semiconductors are of two types

(i) N-type semiconductors (ii) P-type semiconductors.

(d) **Difference between N-type and P-type semiconductors**

S.No.	N-type semiconductors	P-type semiconductors
1.	In these the impurity of some pentavalent element like P, As, Sb, Bi, etc. is mixed	In these, the impurity of some trivalent element like b, Al, In, Ga etc. is mixed
2.		
3.	In these the impurity atom donates one electrons, hence these are known as donor type semiconductors	In these, the impurity atom can accept one electron, hence these are known as acceptor type semiconductors.
4.	In these the electrons are majority current carriers and holes are minority current carriers. (i.e. the electron density is more than hole density $n_n >> n_p$)	In these the holes are majority current carriers and electrons are minority current carriers i.e. $n_p >> n_n$
5.	In these there is majority of negative particles (electrons) and hence are known as N-type semiconductors 	In these there is majority of positive particles (cotters) and hence are known as P-type semiconductors. 
6.	In these the donor energy level is close to the conduction band and far away from valence band.	In these the acceptor energy level is close to the valence band and far away from conduction band.

		
7.	Current density $J_n = nq\,V_{dn}$	$J_p = pq\,V_{dp}$
8.	Electric conductivity $\sigma_n = nq\mu_n$ $\approx n_d\, q\mu_n$ Where nd = number of donor atoms / cm^3.	$\sigma_p = nq\mu_p$ $\approx n_p\, q\mu_p$ Where np = number of acceptor atoms / cm^3.
9.	The Fermi energy level lies close to conduction band (i.e. the Fermi energy level lies in between the donor energy level and conduction band)	The Fermi energy level lies close to the valence band (i.e. the Fermi energy level lies in between the acceptor energy level and valence band)
		

(v) **Conductivity formulae:**

(a) $\dfrac{\sigma_n}{\sigma_p} = \dfrac{n\mu_n}{p\mu_p}$

(b) $\dfrac{\sigma_n}{\sigma_p} = \dfrac{\mu_n}{\mu_p}$ if $n = p$

(c) $\dfrac{\sigma_n}{\sigma_p} = \dfrac{n_d\,\mu_n}{n_a\,\mu_p}$

(d) $\dfrac{\sigma_{ext}}{\sigma_{int}} = \dfrac{n_d}{n_i}$

(vi) **Resistivity formulae:**

(a) $\rho_i = \dfrac{1}{qn_i(\mu_n + \mu_p)}$

(b) $\rho_n = \dfrac{1}{\mu_n\, q_n}$

(c) $\rho_p = \dfrac{1}{\mu_p\, qp}$

(d) $\frac{r_n}{r_p} = \frac{m_p P}{m_n n}$

(e) $\frac{r_n}{r_p} = \frac{m_p}{m_n}$

(f) $\frac{r_1}{r_2} = \frac{s_1}{s_2}$

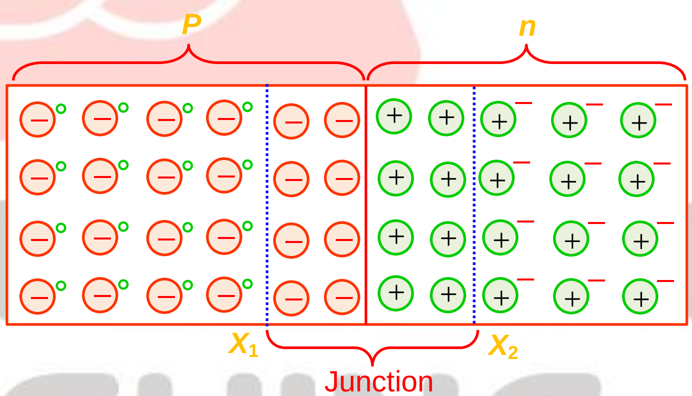
(vii) **Characterizes Si and Ge at 300 K**

Characteristics	Ge	Si
Energy gap	0.7 (eV)	1.1 (eV)
Electron mobility (μ_n)	0.39 ($M^2V^{-1}S^{-1}$)	0.135 ($M^2V^{-1}S^{-1}$)
Cotter mobility (μ_p)	0.19 ($M^2V^{-1}S^{-1}$)	0.048 ($M^2V^{-1}S^{-1}$)
Intrinsic current concentration	$n_i = 2.4 \times 10^{19}$ cm^{-3}	$n_i = 1.5 \times 10^{16}$ cm^{-3}
Resistivity	0.46 Ω-m	2300 Ω-m
Potential barrier	0.3 V	0.7 V

4 SEMICONDUCTOR DIODE OR P-N JUNCTION, CONDUCTION IN P-N JUNCTION, DEPLETION LAYER AND BARRIER ENERGY

P-N Junction

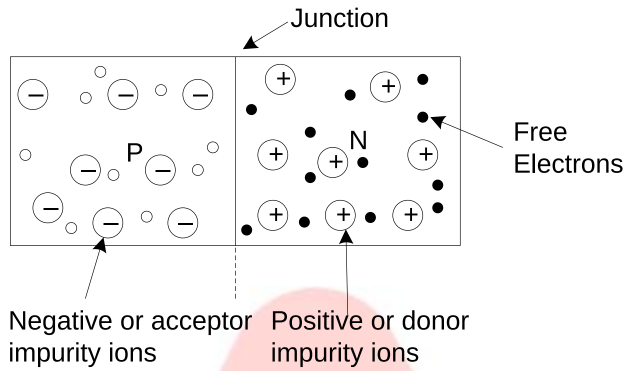
(a) The device formed by joining atomically a wafer of P-type semiconductor to the wafer of N-type semiconductor is known as P-N junction.

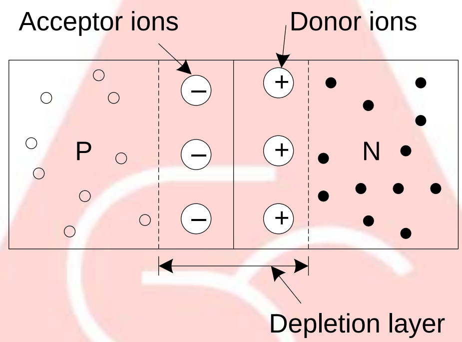


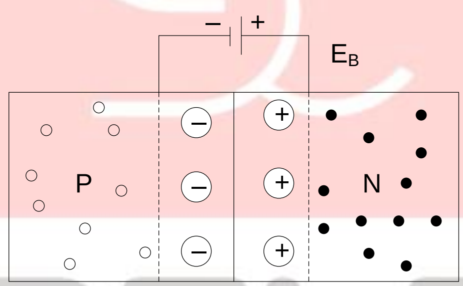
(a)

(b) There are three processes of making junctions
(i) Diffusion (ii) Alloying (iii) Growth
In majority of cases P-N junction is formed by diffusion process. The impurity concentration is maximum at surface and decreases gradually inside the semiconductor.

(c) **Conduction of current in P-N Junction:**







(i) In P-N junction the majority cotters in P-region and majority electrons in N-region start diffusing due to concentration gradient and thermal disturbance towards N-region and P-region respectively and combine respectively with electrons and cotters and become neutral.

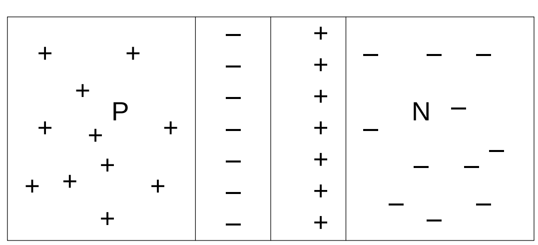
(ii) In this process of neutralization there occurs deficiency of free current carriers near the junction and layers of positive ions in N-region and negative ions in P-region are formed. These ions are immobile. Due to this an imaginary battery or internal electric field is formed at the junction which is directed from N to P.

(iii) **Depletion layer:**

(a) The region on both sides of P-N junction in which there is deficiency of free current carriers, is known as the depletion layer.

(b) Its thickness is of the order of 1μm (= 10^{-6})

(c) On two sides of it, there are ions of opposite nature. i.e. donor ion (+ve) on N-side and acceptor ions (–ve) on P-side.



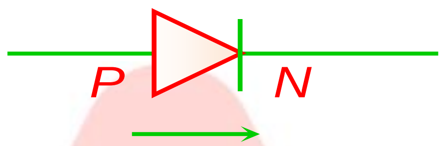
(d) This stops the free current carriers to crossover the junction and consequently a potential barrier is formed at the junction.

(e) The potential difference between the ends of this layer is defined as the contact potential or potential barrier (V_B).

(f) The value of V_B is from 0.1 to 0.7 volt which depends on the temperature of the junction. It also depends on the nature of semiconductor and the doping concentration. For germanium and silicon its values are 0.3 V and 0.7 V respectively.

(g) **P-N Junction diode or semiconductor diode:**

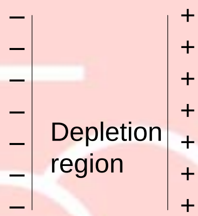
(i) **Symbolic representation of diode:**



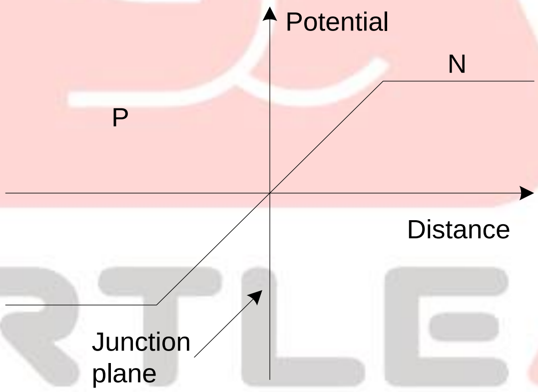
(ii) The direction of current flow is represented by the arrow head.

(iii) In equilibrium state current does not flow in the junction diode.

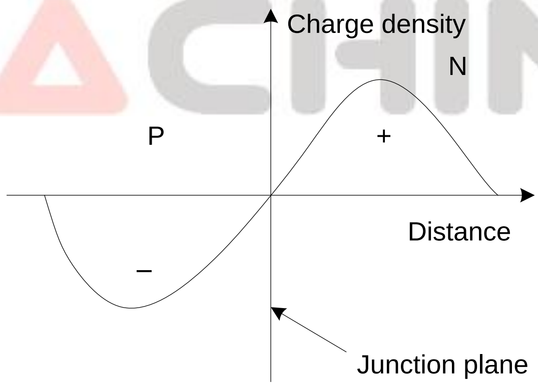
(iv) In can be presumed to be equivalent to a condenser in which the depletion layer acts as a dielectric.



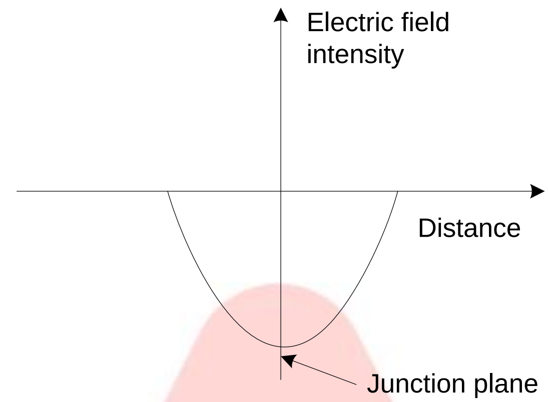
(v) **Potential distance curve at P-N Junction**

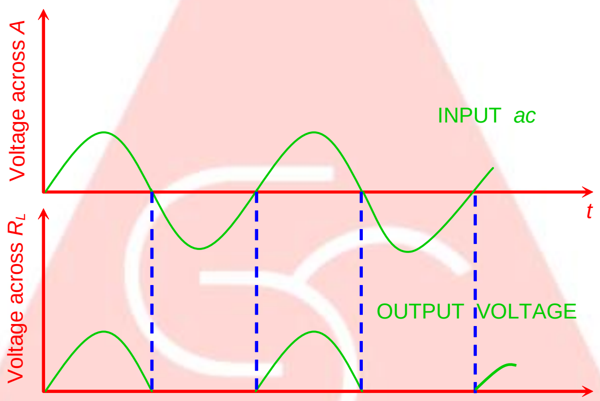


(vi) **Charge density curve at P-N Junction**



(vii) **Curve between electric field and distance near P-N junction**

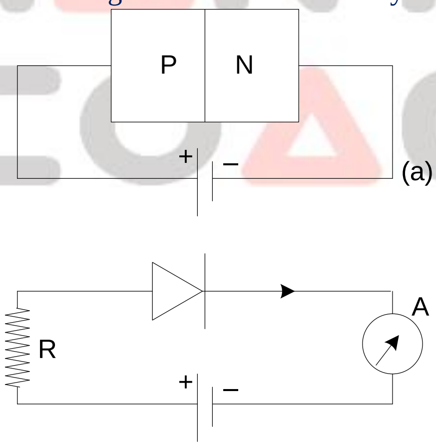
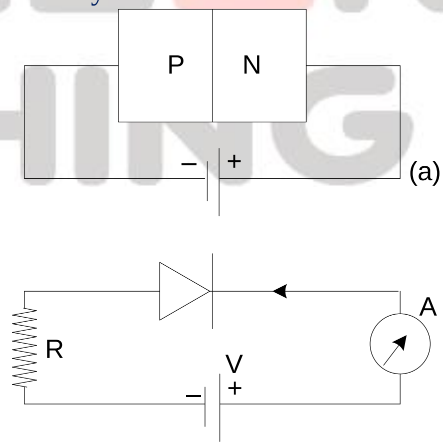


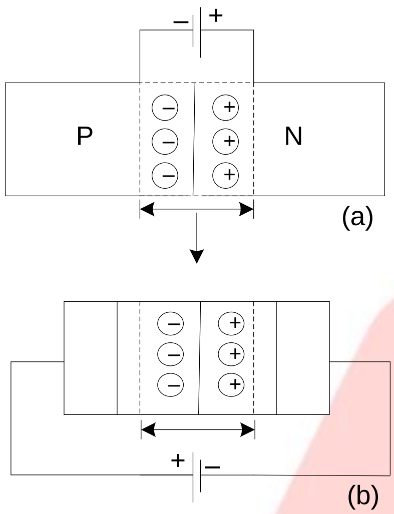
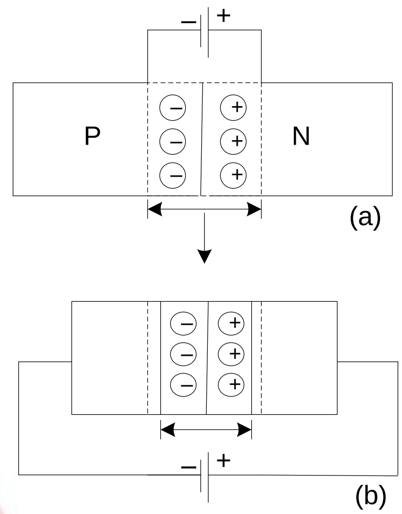
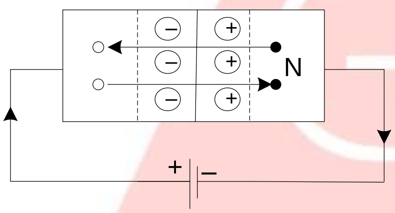
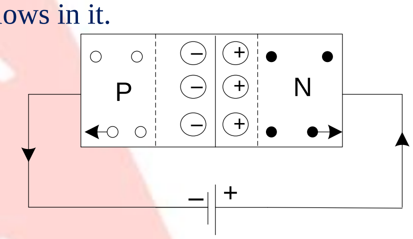
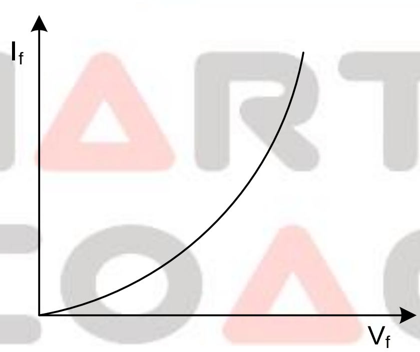
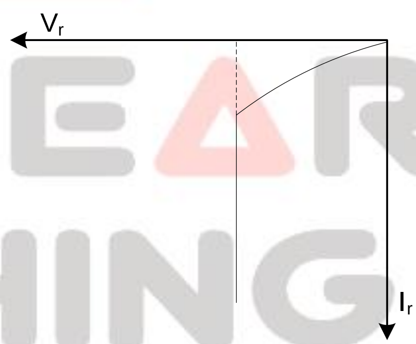


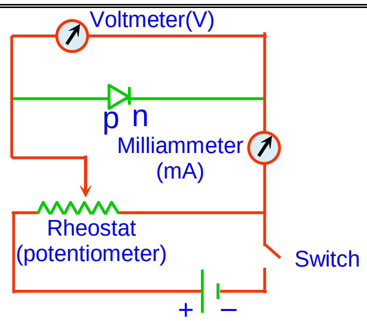
5 BIASING OF JUNCTION DIODE

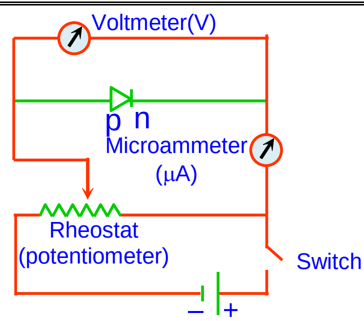
(i) No current flows in the junction diode without an external battery. It is connected to a battery in two different ways. Hence two different bias are possible in junction diode.
(a) Forward bias (b) Reverse bias

(ii) **Difference between forward bias and reverse bias:**

S.No.	Forward bias	Reverse bias
1.	The P-region of junction diode is connected to positive terminal of battery and N-region is connected to negative terminal of battery. 	The P-region is connected to negative terminal and N-region is connected to positive terminal of the battery. 
2.	In this the width of depletion layer decreases	In this the width of depletion layer increases

		
3.	Current flows in it due to majority electrons and majority holes and hence high current (mA) flows in it.  The direction of current in it is from P to N.	Current flows in it due to minority electrons and minority holes and hence negligible current (in μA) flows in it.  Direction of current is from N to P
4.	The junction resistance is low	The junction resistance is high
5.	Curve between forward voltage and forward current 	Curve between reverse voltage and reverse current 





6 CHARACTERISTICS OF JUNCTION DIODE

(i) The characteristic curves of junction diode are of two types

(a) Static characteristic curves

(b) Dynamic characteristic curves

(ii) The static and the dynamic characteristics are also of two types

(A) (a) Static forward characteristics curves

(b) Static reverse characteristic curves

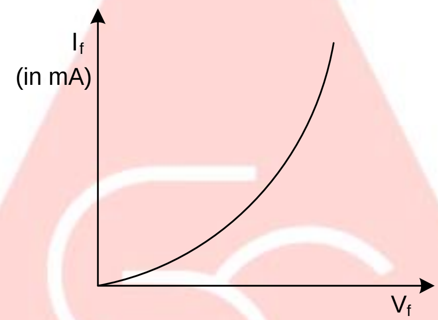
(B) (a) Dynamic forward characteristic curves

(b) Dynamic reverse characteristic curves

(iii) Static forward characteristics

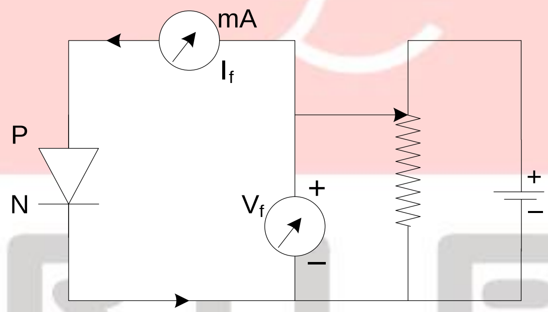
(a) In the absence of load resistance, the curves drawn between the forward voltage (V_f) and forward current (I_f) are known as the static forward characteristics of junction diode.

(b)



(c) On increasing the V_f the value of I_f increases exponentially

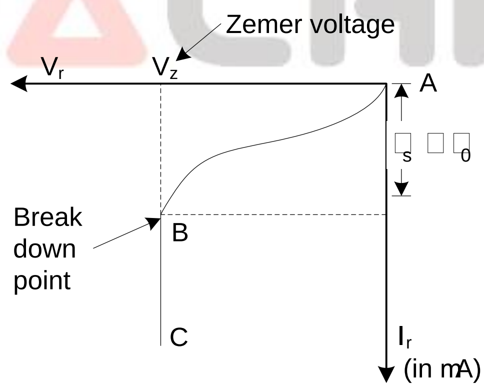
(d) **Circuit diagram:**



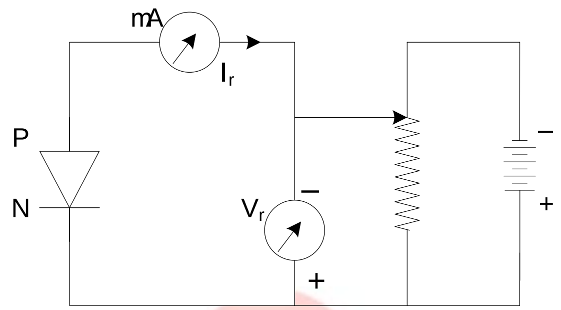
(iv) Static reverse characteristics:

(a) In the absence of load resistance, the curves drawn between the reverse voltage (V_r) and reverse current (I_r) are known as the static reverse characteristics of junctions diode.

(b)



(c)



(d) After the breakdown point at B, the reverse current (I_r) does not depend on the reverse voltage (V_r) in the BC portion of curve.

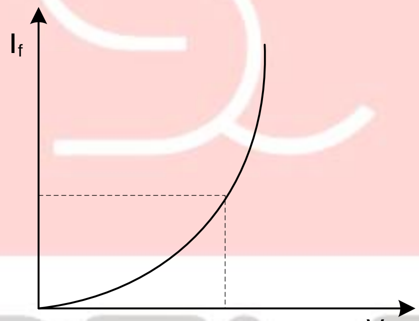
7 CONSTANTS OF JUNCTION DIODE

(A) (i) Static forward and reverse resistances
(ii) Dynamic forward and reverse resistances

(B) **Static forward resistance (R_f):**

(i) The ratio of the forward voltage (V_f) and forward current (I_f) at any point on the static forward characteristic is defined as static forward resistance of junction diode.

$$\text{i.e. } R_f = \frac{V_f}{I_f}$$



(ii) Its value is of the order of $10^2\ \Omega$.

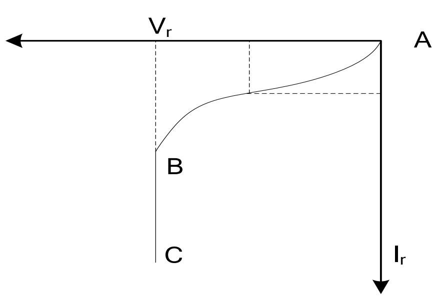
(C) **Static reverse resistance (R_r):**

(i) The ratio of reverse voltage (V_r) and reverse current (I_r) at any point on static reverse characteristic is defined as the static reverse resistance of junction diode.

$$\text{i.e. } R_r = \frac{V_r}{I_r}$$

(ii) Its value of is of the order of 10^6

(iii)



(D) **Dynamic forward resistance (V_r):**

(i) The ratio of small change in forward voltage to the corresponding small change in forwards current on static forward characteristic is defined as the dynamic forward resistance of junction diode (r_f)

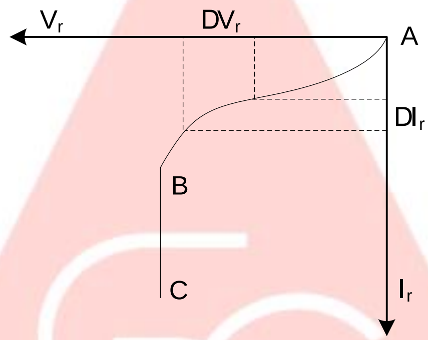
(ii) $r_f = \frac{DV_f}{DI_f} = \frac{V_{f_2} - V_{f_1}}{I_{f_2} - I_{f_1}}$

(E) Dynamic reverse resistance (r_r):

(i) The ratio of the small change in reverse voltage to the corresponding small change in reverse current on the static reverse characteristics is defined as the dynamic reverse resistance of junction diode.

(ii) $r_r = \frac{DV_r}{DI_r} = \frac{V_{r_2} - V_{r_1}}{I_{r_2} - I_{r_1}}$

(iii)



8 ZENER BREAKDOWN, AVALANCHE BREAKDOWN AND ZENER DIODE

S.No.	Avalanche breakdown	Zener breakdown
1.	The doping in the formation of P-N Junction is low	The doping in the formation of P-N junction is high
2.	The covalent bonds break as a result of collision of electrons and holes with the valence electrons	In this the covalent bonds break spontaneously.
3.	Higher reverse potential is required for breakdown.	Low reverse potential is required for breakdown
4.	In this the thermally generated electrons due to electric field ionize other atoms and release electrons.	In this the covalent bonds near the junction break due to high reverse potential ~20 V and consequently electrons become free.

(ii) Zener diode:

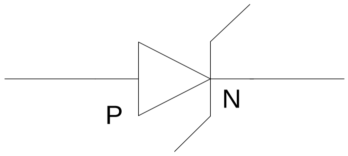
(a) The junction diode made of Si or Ge, whose reverse resistance is very high, is known as Zener diode.

(b) It works at Zener voltage (V_z) i.e. the voltage at which breakdown starts.

Zener voltage (V_z): The voltage at which breakdown starts in Zener diode and consequently the reverse current in the circuit abruptly increases, is defined as Zener voltage.

(c) It is used in power supplies as a voltage regulator.

(d) **Symbolic representation of Zener diode.**



9 SALIENT FEATURES RELATING TO JUNCTION DIODE

(i) In junction diode the current flow is unidirectional as in vacuum diode.

(ii) Current flows in the semiconductor diode when it is forward biased.

(iii) Its P-part behaves like a plate and N-apart behaves like a cathode.

(iv) Relation between forward current and saturation current

$$I_f = I_s(e^{\frac{IV}{kT}} - 1)$$

Where I_f and I_s are forward and saturation currents respectively, K = Boltzmann constant, T = absolute temperature V = potential difference

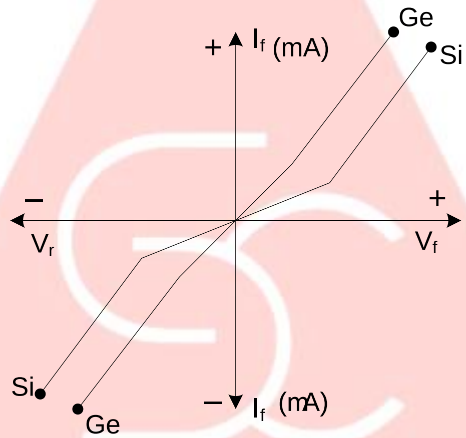
(a) In forward bias $e^{qV/kT} >> 1$ then $I_f = I_s qV/KT$

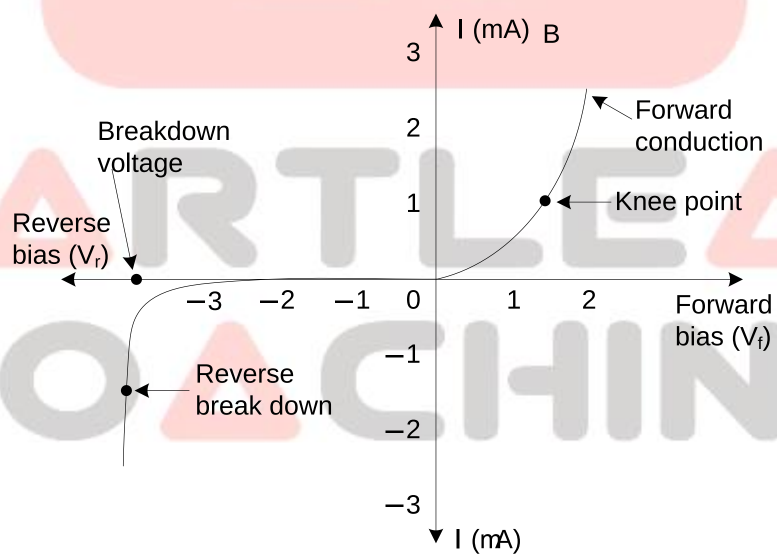
(b) In reverse bias $e^{qV/kT} << 1$ then $I_f = I_s$

(v) The velocity gained by the charge carriers in an electric field of unit intensity, is defined as their mobility

$$m = \frac{V_d}{E} = \frac{\text{Drift Velocity}}{\text{Intensity of electricity field}}$$

(vi) Forward and reverse characteristic curves of Si and Ge diodes:





Knee Point: That point on the forward characteristics of junction diode after which the curve becomes linear, is known as the knee point. In the diagram it is represented by the point A.

Knee voltage: The potential at knee point A is known as the knee potential or forward potential at which the forward current abruptly increases is known as the knee potential.

(a) This potential does not depend on the current.

(b) For Si its value is 0.7 V.

(vii) Greater the value of ΔE_g, stronger will be the binding of valence electrons to the nucleus.

10 USES OF JUNCTION DIODE

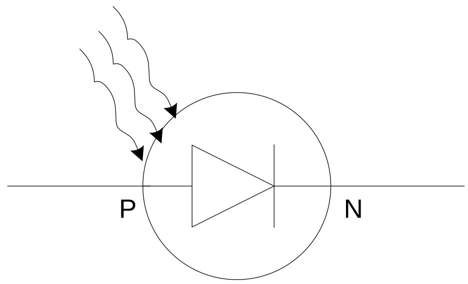
(i) Rectifier

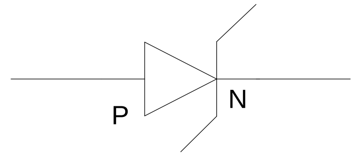
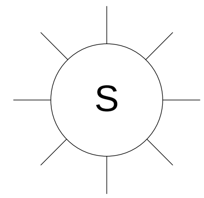
(ii) Off switch
(iii) Condenser

11 DIFFERENT BETWEEN VACUUM TUBE DEVICES AND SEMICONDUCTOR DEVICES

S.No.	Vacuum tube devices	semiconductor devices
1.	These are voltage controlled devices.	These are current driven devices
2.	These work at high voltage	These work at low voltage.
3.	For these a filament battery is required.	For these no filament batteries required
4.	These are not temperature sensitive devices	These are temperature sensitive devices
5.	Their life is less and are more expensive	Their life is longer and are cheap
6.	Their size is big	Their size is small.
7.	Their efficiency is more	Their efficiency is less
8.	Power consumption is maximum	Power consumption is minimum
9.	These can not be used integrated circuit (IC's)	These can be used as integrated circuits
10.	Electric conduction is only via electrons.	Electric conduction takes place both by electrons and cotters.

12 VARIOUS TYPE OF P-N JUNCTION

S.No.	P-N Device	Biasing	Principle	Uses	Explanation
1.	Light Emitting Diode (LED)	Forward	Production of light from electric current	Burglar alarms, calculators, pilot lamps, telephone, digital watch and in switch boards	In Ga, As, Electromagnetic radiations are emitted on account of transitions of electron from conduction band to valance band. 
2.	Photodiode	Reverse	Electric conduction from light	In sound films, computers, tape, in reading computer cards and in light driven switches.	The covalent bonds in semiconductors break due to electromagnetic radiations and more electrons become free and conductivity increases. 

3.	Zener diode	Reverse	Current is controlled	In voltage regulation	Voltage across it remains constant 
4.	Solar cell	No biasing	Production of potential difference by sun light	For generating electrical energy in cooking food etc.	Due to nuclear fusion process sun is constantly emitting light and heat energy. The upper surface of P-N junction is thin in this diode. 

Other salient features

(a) The value of electric field across the P-N junction is 10^5 V/m

(b) $E = \frac{V_B}{d} = \frac{0.5}{10^{-6}} = 5 \times 10^5$

(c) The values of contact potential for Si and Ge are 0.7 V and 0.3 V respectively.

13 SEMICONDUCTOR DIODE AS RECTIFIER

(i) **Rectification:** The process in which an alternating current is converted into direct current, is defined as rectification.

(ii) **Rectifier:** The device employing diode, used to convert an alternating current into direct current, is known as rectifier.

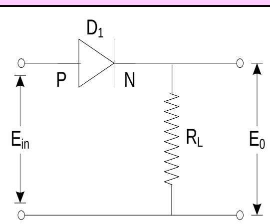
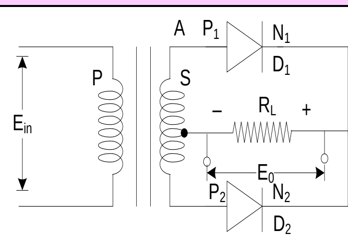
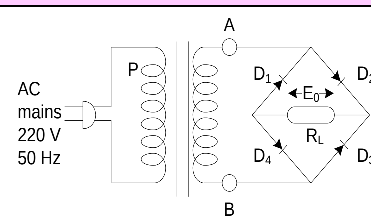
(iii) The rectifiers are of two types:

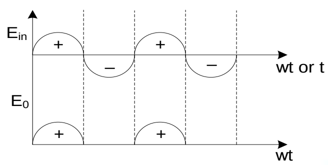
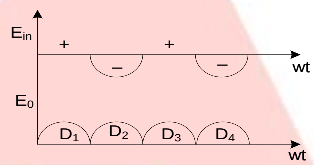
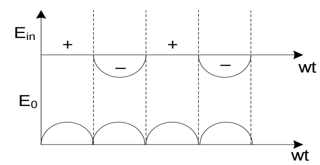
(a) Half wave rectifier (b) Full wave rectifier

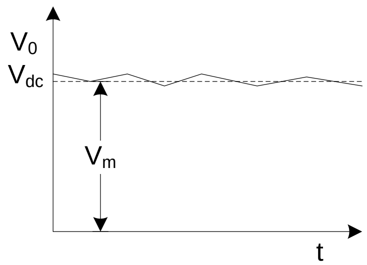
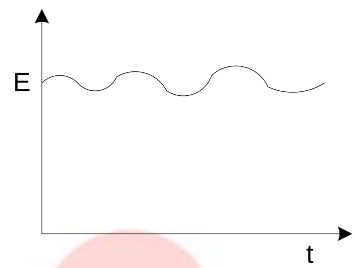
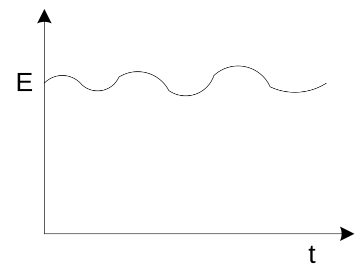
Half wave rectifier: The rectifier, in which only alternate half cycles of applied alternating signal are converted into direct current, is known as half wave rectifier.

Full wave rectifier: The rectifier is which the whole cycle of applied alternating signal is converted into direct current, is known as full wave rectifier.

(iv) **Difference between half wave rectifier and full wave rectifier**

No.	Half-Wave Rectifier	Full Wave Rectifier centre taped	Full wave Bridge Rectifier
1.			

2.	In this, one diode or one semiconductor diode is used	In this, two diodes or one double diode or two junction diodes are used.	In this four junction diodes from the bridge circuit.
3.	Ordinary transformer is used	Centre tap transformer is used	Transformer is not required.
4.	It converts half cycle of applied A.C. signal into D.C. signal	It converts the whole cycle of applied A.C. signal into D.C. signal	It converts the whole cycle of applied A.C. signal into D.C. signal
5.	Input and output curves 	Input and output curves 	Input and output curves 
6.	The value of $I_{rms} = \frac{I_0}{2}$	$I_{rms} = \frac{I_0}{\sqrt{2}}$	$I_{rms} = \frac{I_0}{\sqrt{2}}$
7.	$I_{dc} = \frac{I_0}{\pi}$	$I_{dc} = \frac{2I_0}{\pi}$	$I_{dc} = \frac{2I_0}{\pi}$
8.	The value of ripple factor is $r = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1} = 121\%$	The value of r in it is 48.2%	The value of r in it is 48.2%
9.	Efficiency (η) (a) $\eta = \frac{40.6}{\left(1 + \frac{r_p}{R_L}\right)}$ (b) When $r_p = R_L$ then η = 20.3% (c) When $r_p << R_L$ then η = 40.6%	(a) $\eta = \frac{81.2}{\left(1 + \frac{r_p}{R_L}\right)}$ (b) When $r_p = R_L$ then η = 40.6% (c) When $\frac{r_p}{R_L} << 1$ then η = 81.2%	Its efficiency is 81.2%
10.	Peak inverse voltage PIV = E_0	PIV = $2E_0$	PIV = $2E_0$
11.	Form factor $F = \frac{I_{rms}}{I_{dc}} = \frac{E_{rms}}{E_{dc}} = \frac{\pi}{2} = 1.57$	F = 1.11	F = 1.11
12.	The ripple frequency is equal to the frequency of applied e.m.f.	The ripple frequency is twice that of the applied e.m.f.	The ripple frequency is twice that of the applied e.m.f.
13.	Curve between the output voltage from filter circuit and time	Curve	Curve

			
14.	The value of D.C. component in output voltage is less than the A.C.	The value of D.C. component in output voltage is more than that of A.C.	The value of D.,C. component in output voltage is more than that of A.C.
15.	The value of peak inverse voltage (PIV) is E_0	The value of PIV is E_0	The value of PIV is E_0
16.	The value of peak load current is $\frac{E_0}{r_p + R_L}$	The value of PLC is $\frac{E_0}{r_p + R_L}$	The value of PLC is $\frac{2E_0}{2r_p + 2R_L}$

(v) Similarities between half wave and full wave rectifiers

(a) The alternating input signal to be rectified is connected to the primary of transformer.

(b) The output voltage is obtained across the ends of load resistance.

(c) The output voltage is unidirectional but it is not constant rather pulsating.

(d) The output voltage is the mixture of alternating and direct voltages.

(e) In output, the direct components are more than the alternating components.

(f) Diode conducts only when the plate is positive with respect to the cathode. semiconductor diode conducts only when it is forward biased.

(g) When the plate of diode is negative with respect to the cathode than it does not conduct.

(vi) Definitions:

(a) Efficiency of rectifier

(i) $$\eta = \frac{\text{output D.C. power}}{\text{input A.C. power}}$$

(ii) $$\eta = \frac{P_{dc}}{P_{ac}} \times 100\%$$

(b) Ripple Factor (r):

(i) $$r = \frac{I_{ac}}{I_{dc}} = \frac{E_{ac}}{E_{dc}} = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

(ii) $$r = \frac{\text{r.m.s. of value of fluctuating voltage or current}}{\text{average D.C. value of voltage or current}}$$

(c) Form factor

(i) $$F = \frac{I_{rms}}{I_{dc}}$$

(ii) $F = \frac{E_{rms}}{E_{dc}}$

(iii) $F = \frac{p}{2\sqrt{2}} = 1.11$ For full wave rectifier

(iv) $F = \frac{p}{2} = 1.57$ For half wave rectifier

14 TRANSISTOR

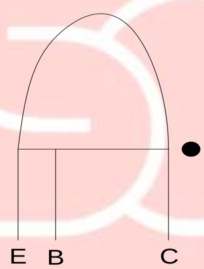
(i) That current driven device, which is formed by three doped semiconductor regions, is known as transistor.

(ii) That current driven device, in which the emitter current controls the collector current, is known as transistor.

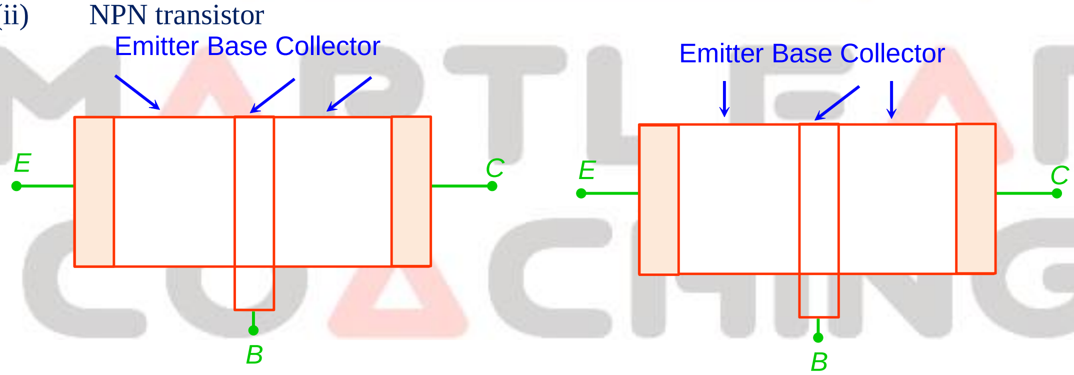
(iii) There are three semiconductor regions in a transistor viz Emitter (E), Base (B) and collector (C).

(iv) **Function of emitter:** To send electrons or cotters into the base
Function of base: To send electrons or cotters received from the emitter into the collector region.
Function of collector: To collect electrons or cotters from the base region.

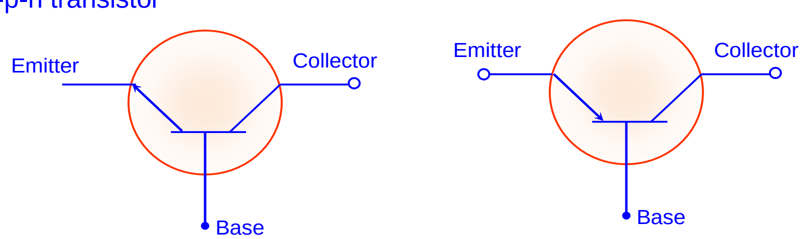
(v) The distance between E and B in a transistor is less than that between B and C and the collector is marked with a dot (.)



(vi) Transistors are of two types:
(i) PNP transistor
(ii) NPN transistor



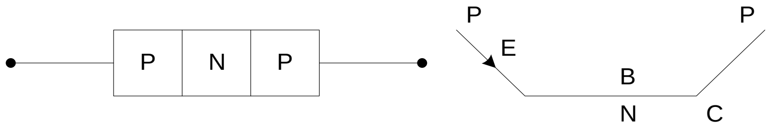
(i) n-p-n transistor (ii) p-n-p transistor



(i) n-p-n transistor (ii) p-n-p transistor

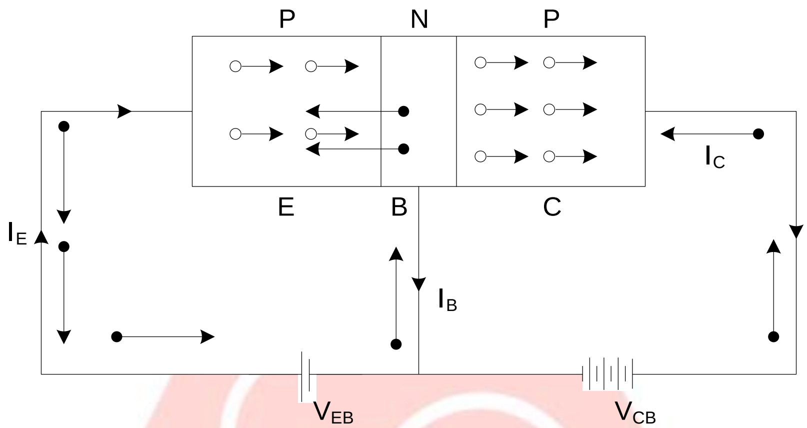
PNP-transistor:

(i) Symbolic representation:



(ii) In this conventional current flows from emitter (E) to base (B) hence the arrow head on emitter is from E to B.

(iii) Sketch diagram



(iv) Working of PNP transistor

(a) The emitter-base junction is forward biased while base-collector junction is reverse biased.

(b) A large number of holes enter from emitter to base and at the same time a very small number of electrons enter from the base to the emitter.

(c) The electrons in the emitter region recombine with an equal number holes and neutralise them.

(d) The loss of total number of holes in the emitter is compensated by the flow of an equal number of electrons from the emitter to the positive terminal of battery.

(e) These electrons are released by breaking of covalent bonds among the crystal atoms in the emitter and an equal number holes is again created.

(f) Thus in PNP transistor emitter current is mainly due to the flow of holes, but in eternal circuit it is due to flow of electron from emitter to the positive terminal of the battery.

(g) The base is very thin and is lightly doped. Therefore only a few holes (~ 1%) combine with electrons in base. Hence the base current I_B is very small.

(h) Nearly 99% of the holes coming from the emitter are collected by the collector.

(i) For each hole reaching the collector, an electron is released from the negative terminal of collector base battery to neutralise the hole.

(j) The relation between three currents is as under

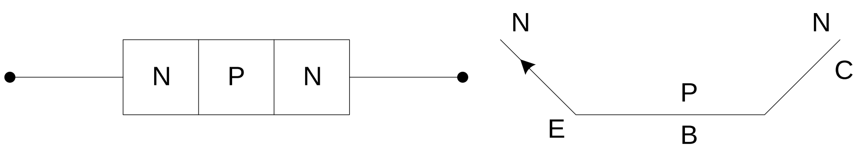
$$I_E = I_B + I_C, I_E >> I_B, I_C < I_E \text{ and } I_B << I_C$$

(k) The input impedance is low and output impedance is high. The output voltage required to be applied is more than the input voltage.

(l) The functions of E, B and C are to send cotters into base region, to send these cotters into collector region and to collect the cotters received from base region respectively.

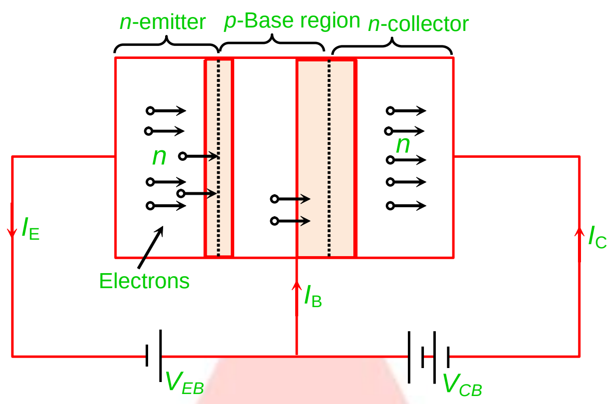
NPN-transistor:

(i) Symbolic representation



(ii) In this conventional current flows from base towards emitter, hence the arrow head on emitter is directed from B to E.

(iii) Sketch diagram



n-p-n transistor

(iv) Working of NPN transistor

(a) The emitter-base junction is forward biased whereas the collector-base junction is reverse biased.
(b) The majority electrons in the emitter are pushed into the base.
(c) The base is thin and is lightly doped. Therefore a very small fraction (say 1%) of incoming electrons combine with the holes. Hence base current is very small.
(d) The majority of electrons are rushing towards the collector under the electrostatic influence of C-B battery.
(e) The electrons collected by the collector move towards the positive terminal of C-B battery.
(f) The deficiency of these electron is compensated by the electrons released from the negative terminal of E-B battery.
(g) Thus in NPN transistors current is carried by electron both in the external circuit as well as inside the transistor.
(h) The relation between these current is given by

$$I_E = I_C + I_B$$

$$I_E >> I_B, I_C < I_E \text{ and } I_B << I_C$$

(i) The input impedance is low and output impedance is high. The output voltage required to be applied is more than the input voltage.

Illustration 8: For a common emitter connection the values of constant collector and base current are 5mA and 50 µA respectively. The current gain will be:

(A) 10 (B) 20 (C) 40 (D) 100

Sol. **(D)** $\beta = \left(\frac{\delta I_C}{\delta I_B}\right)_{V_e} = \frac{5\times10^{-3}}{50\times10^{-6}} = 100$

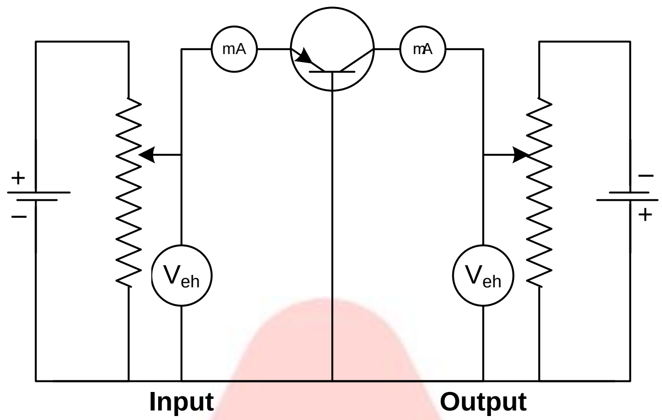
15 CHARACTERISTICS OF TRANSISTOR

The study of variation in current with respect to voltage in a transistor is called its characteristic. For each configuration of transistor, there are two types of characteristics:

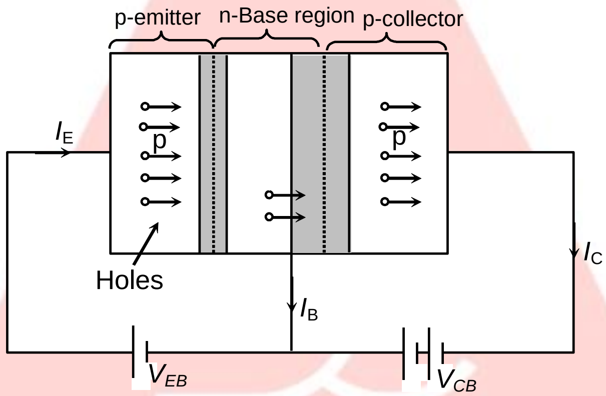
(i) Input characteristics (ii) Output characteristics

(A) Common base configuration

(i) Circuit diagram



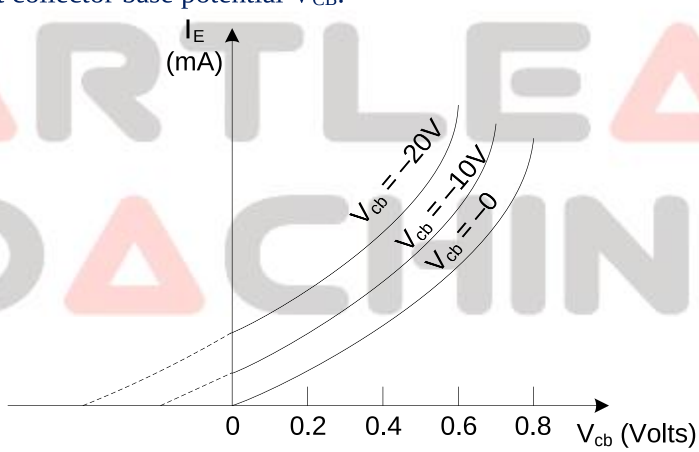
Common base PNP transistor



p-n-p transistor

(ii) **Input characteristics**

(a) Input characteristics are obtained by plotting the emitter current I_E versus emitter-base voltage V_{EB} at constant collector base potential V_{CB}.



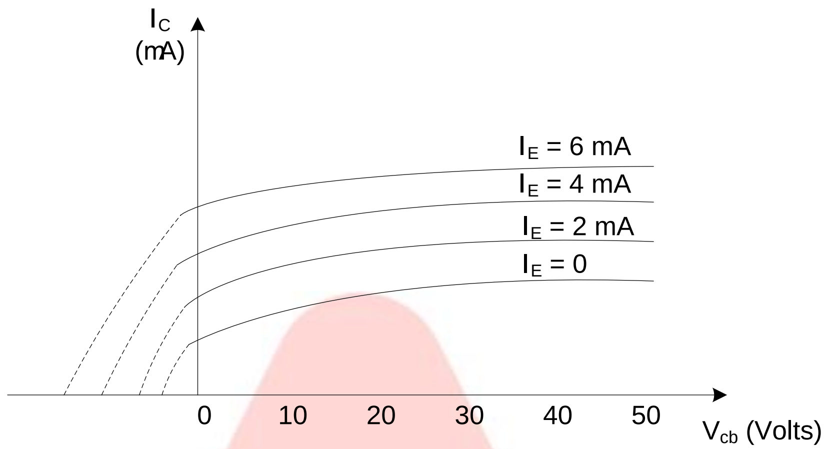
(b) I_E is almost independent of V_{CB}.

(c) Due to very low input impedance, I_E increases rapidly with small increase in V_{EB}.

(d) I_E is finite at finite value of V_{CB} even when V_{EB} is zero. To reduce I_E to zero, the emitter must be reverse biased.

(iii) **Output characteristics:**

(a) The output characteristics are obtained by plotting the collector current (I_C) versus collector-base voltage (V_{CB}) at constant emitter current (I_E).



(b) I_C varies with V_{CB} only at very low voltage (< 1 V). Transistor is not operated in this region.

(c) As V_{CB} increases beyond 1 volt, I_C becomes independent of V_{CB} but depends only upon the emitter current I_E.

(d) Due to high output impedance, a very large change in V_{CB} produces a very small change in I_C.

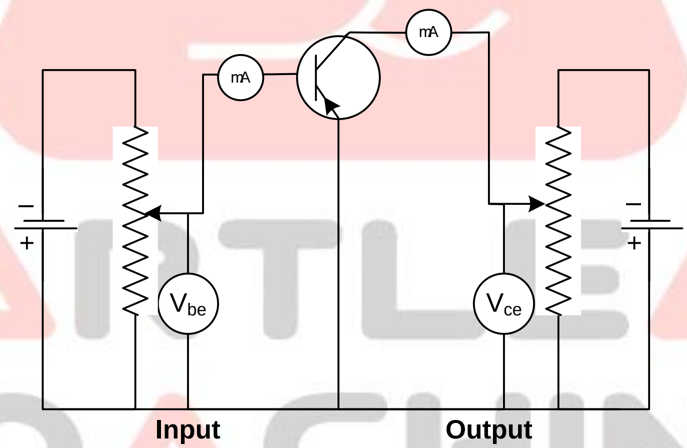
(e) For the region to the left of $V_{CB} = 0$ and for $I_E > 0$, both emitter and collector are forward biased and it is called saturation region.

(f) For $I_E < 0$, both emitter and collector are reverse biased and the region is called the cut-off region.

(g) For central region $V_{CB} > 0$, the curves are parallel and it is called active region. In this region emitter is forward biased and collector is reverse biased.

(B) **Common emitter configuration:** In this configuration emitter is common to input and output circuits.

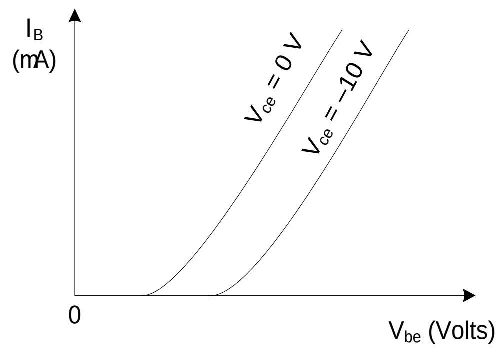
(i) **Circuit diagram**



Common base PNP transistor

(ii) **Input characteristics**

(a) Input characteristics are obtained by plotting the base current (I_B) versus base emitter voltage (V_{BE}) for constant collector-emitter voltage (V_{CE}).

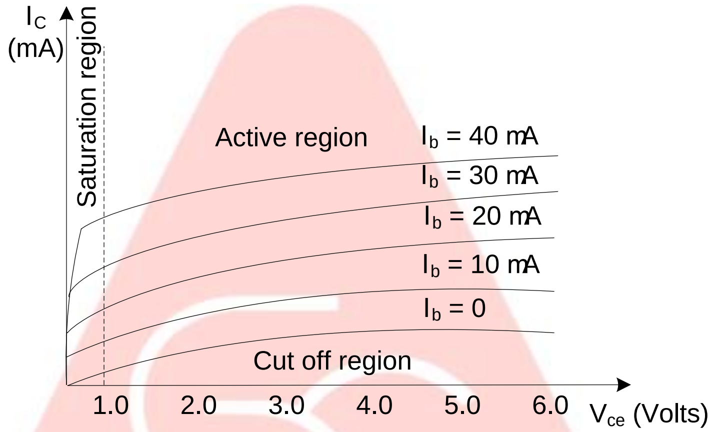


(b) I_B increases with increase in V_{BE}, but less rapidly as compared to common base configuration, indicating that input resistance of common emitter configuration is greater than that of common base configuration.

(c) These characteristics resemble with those of a forward biased junction diode indicating that the base-emitter section of a transistor is essentially a junction diode.

(iii) **Output characteristics:**

(a) The output characteristics are obtained by plotting collector current I_C versus collector-emitter voltage (V_{CE}) at constant value of base current (I_B).



(b) I_C increases with increase of V_{CE} upto 1 volt and beyond 1 volt it becomes almost constant.

(c) The value of V_{CE} upto which I_C increases is called the knee voltage. The transistor always operates above knee voltage.

(d) Above knee voltage, I_C is almost constant.

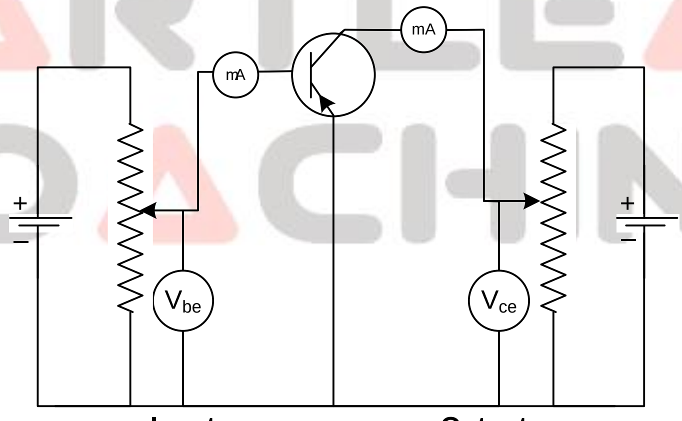
(e) The region for $V_{CE} < 1$ volt is called saturation region as both emitter and collector are forward biased.

(f) In the region $I_B \le 0$, both emitter and collector are reverse biased and it is called the cut-ff region.

(g) The central region, where the curves are uniformly spaced and sloped, is called the active region. In this region the emitter is forward biased and the collector is reverse biased.

(C) **Common collector configuration:** In this configuration collector is common to input and output circuits.

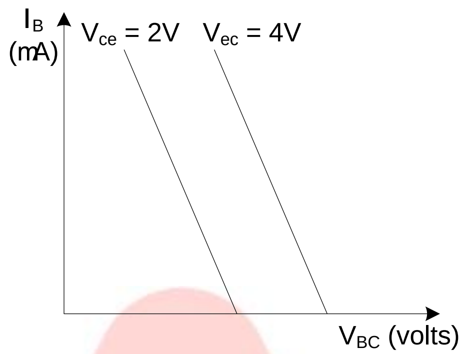
(i) **Circuit diagram**



Common base PNP transistor

(ii) **Input characteristics:**

(a) The input characteristics are obtained by plotting the base current I_B versus base-collector voltage (V_{BC}) for constant emitter-collector voltage (V_{BC}).



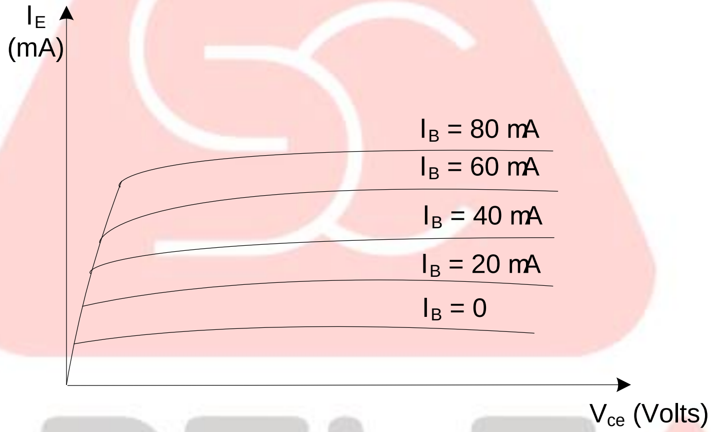
(b) I_B decreases with increase of V_{BC}. These characteristics are quite different from those of common base and common emitter configurations.

(c) $\because V_{BE} = V_{EC} - V_{BC}$

As V_{BC} increases, V_{BE} decreases for constant value of V_{EC}, thereby reducing I_B.

(iii) **Output characteristics:**

(a) Output characteristics are obtained by plotting emitter current I_E versus collector-emitter voltage (V_{CE}) for constant base current (I_B).



(b) The curves are similar to those obtained in output characteristics in common emitter configuration indicating that

$I_E \gg I_C$ ($\because$ I_B is very small)

(c) In this configuration the output can be obtained in either direction and hence it is used for matching the impedance for two way amplifier and switching circuits.

Illustration 9: In a transistor amplifier, $\beta = 62$, $R_L = 5000\ \Omega$ and internal resistance of the transistor is 500 Ω. The voltage amplification of the amplifier will be:

(A) 500 (B) 620
(C) 780 (D) 950

Sol. **(B)** Voltage amplification = $\dfrac{\beta R_L}{R_e} = \dfrac{62 \times 5000}{500}$

Illustration 10: In the above problem, the power amplification will be:

(A) 25580 (B) 33760
(C) 38440 (D) None of these

Sol. **(C)** Power amplification = $\dfrac{\beta^2 R_L}{R_e} = \dfrac{62^2 \times 5000}{500} = 38440$

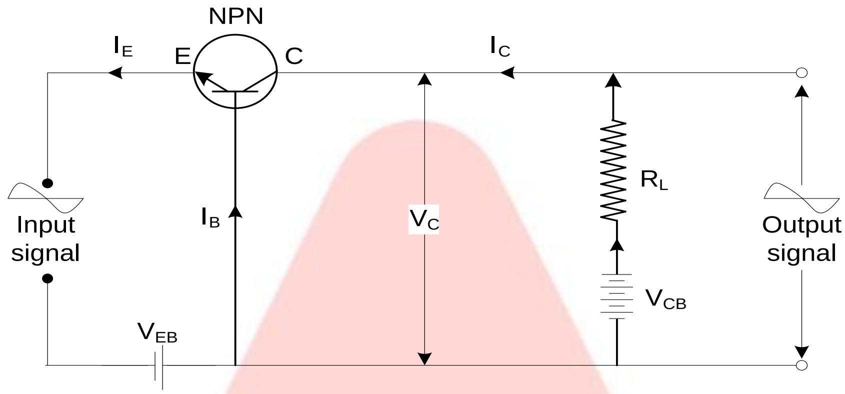
16 TRANSISTOR AS AN AMPLIFIER

(i) Amplification: The phenomenon, in which the amplitude of input signal (Voltage, current or power) is increased, is defined as amplification.

(ii) Amplifier: The device (electronic circuits), used to increase the amplitude of input signal is known as amplifier.

(A) Common base amplifier:

(i) **NPN Transistor:** (a) **Circuit diagram**



(b) When no A.C. signal is applied, then only collector current I_C flowing through the load resistance R_L will produce a voltage drop $I_C R_L$ across the load resistance.

∴ net collector voltage $V_C = V_{CB} - I_C R_L$ . . . (1)

(c) Now input A.C. signal, to be amplified, is applied to the input circuit. During positive half of the input signal, the forward bias is reduced. This reduced emitter current (I_E) and consequently I_C is also reduced. According to Eq. (1) V_C increases.

(d) During negative half cycle of the input signal, the forward bias is increased So, I_E and hence I_C increases. According to Eq. (1), V_C decreases.

(e) The input and the output signals are in same phase.

(f) **Current amplification factor (α):**

(i) DC current gain (α_{DC}): The ratio of the collector current to the emitter current at constant collector voltage is defined as D.C. current gain

$$\alpha_{DC} = \left(\frac{I_C}{I_E}\right)_{V_C}$$

α_{DC} is always less than one.

(ii) AC current gain (α_{AC}): The ratio of change in collector current to the change in emitter current at constant collector voltage is defined as AC current gain.

$$\alpha_{AC} = \left(\frac{\Delta I_C}{\Delta I_E}\right)_{V_C}$$

(g) **Voltage gain:** (i) The ratio of the output voltage across the load resistance to the input signal voltage is defined as voltage gain.

$$\text{Voltage gain} = \frac{V_0}{V_i} = \frac{I_C R_L}{I_E R_0} = \alpha \times \frac{R_L}{R_i}$$

(R_i is the resistance of the input circuit)

(ii) Since α is approximately equal to one and $R_L >> R_i$, hence very high voltage gain can be obtained.

(h) **Power gain:** (i) The ratio of the output power to the input power is defined as power gain.

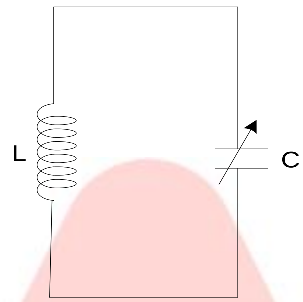
$$\text{Power gain} = \frac{\text{output power}}{\text{input power}} = \frac{\text{output current} \times \text{output voltage}}{\text{input current} \times \text{input voltage}}$$

$$= \text{Current gain} \times \text{voltage gain} = \alpha \times \alpha \times \frac{R_L}{R_i} = \alpha^2 \frac{R_L}{R_i}$$

(ii) Since $R_L >> R_i$, hence power gain is quite large.

17 TRANSISTOR AS AN OSCILLATOR

(i) The simplest electrical oscillating system consists of an inductance L and a capacitor C connected in parallel.



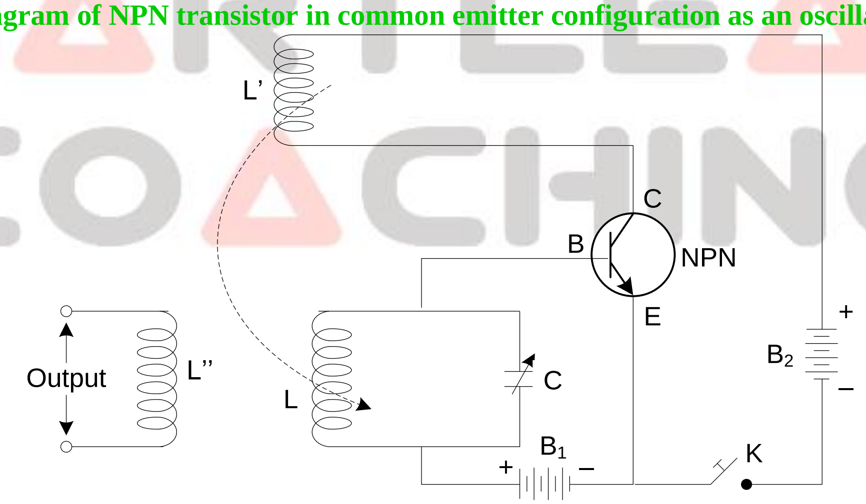
(ii) Once an electrical energy is given to the circuit, this energy oscillates between capacitance (in the form of electrical energy) and inductance (in the form of magnetic energy) with a frequency

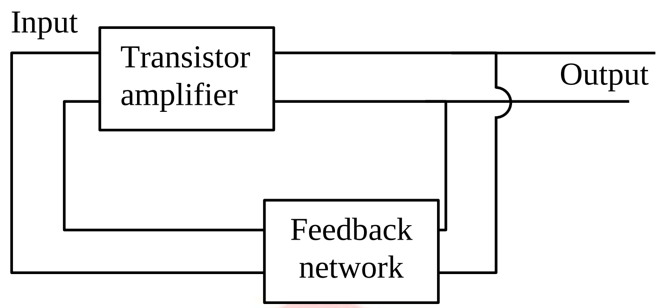
$$v = \frac{1}{2p/\sqrt{LC}}$$

(iii) The amplitude of oscillations is damped due the presence of inherent resistance in the circuit

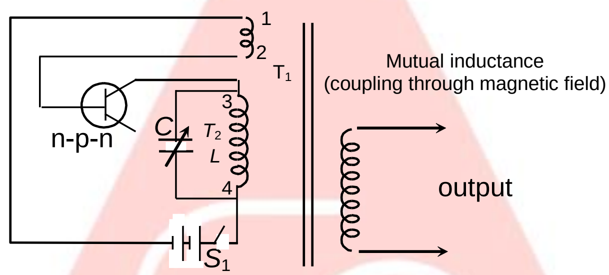
(iv) In order to obtain oscillations of constant amplitude, an arrangement of regenerative or positive feedback from an output circuit to the input circuit is made so that the circuit losses may be compensated.

(v) **Circuit diagram of NPN transistor in common emitter configuration as an oscillator.**





(a)



(vi) The tank circuit is used in emitter-base circuit of the transistor. The E-B circuit is forward biased whereas the C-B circuit is reverse biased.

(vii) The coil L' in the emitter-collector circuit is inductively coupled with coil L.

(viii) When the key K is closed, I_C begins to increase. The magnetic flux linked with coil L' and hence with L also begins to increase. This supports the forward bias of B-E circuit. As a result of this I_E increases. Consequently I_C also continues increase till saturation.

(ix) When I_C attains saturation value, mutual inductance has no role to play.

(x) When the capacitor begins to discharge through inductance L, the I_E and hence I_C begins to decrease. consequently, the magnetic flux linked with L' and hence with L decreases. The forward bias of E-B circuit is opposed thereby further reducing I_E and I_C. This process continues till I_C becomes zero.

(xi) At this stage too, the mutual inductance has once again no role to play.