Solids 7. 11. 2k,

Energy band formation in a solid

From Bohr's model of hydrogen like atoms we have seen that the spectra of this type of atoms consists of several sharp lines which ~~correct by~~ characterise the atom. From quantum mechanics it has been proved that each such energy lable will split onto two such lines when two indentical atoms are brought closer. This is also experimentally found to be correct. When 3 such atoms are brought closer, each line will split into 3 such lines. This type of spliting continues as more and more atoms are brought closer.

Energy levels due to single ~~electron~~ atom

Energy level due to two atoms brought nearear.

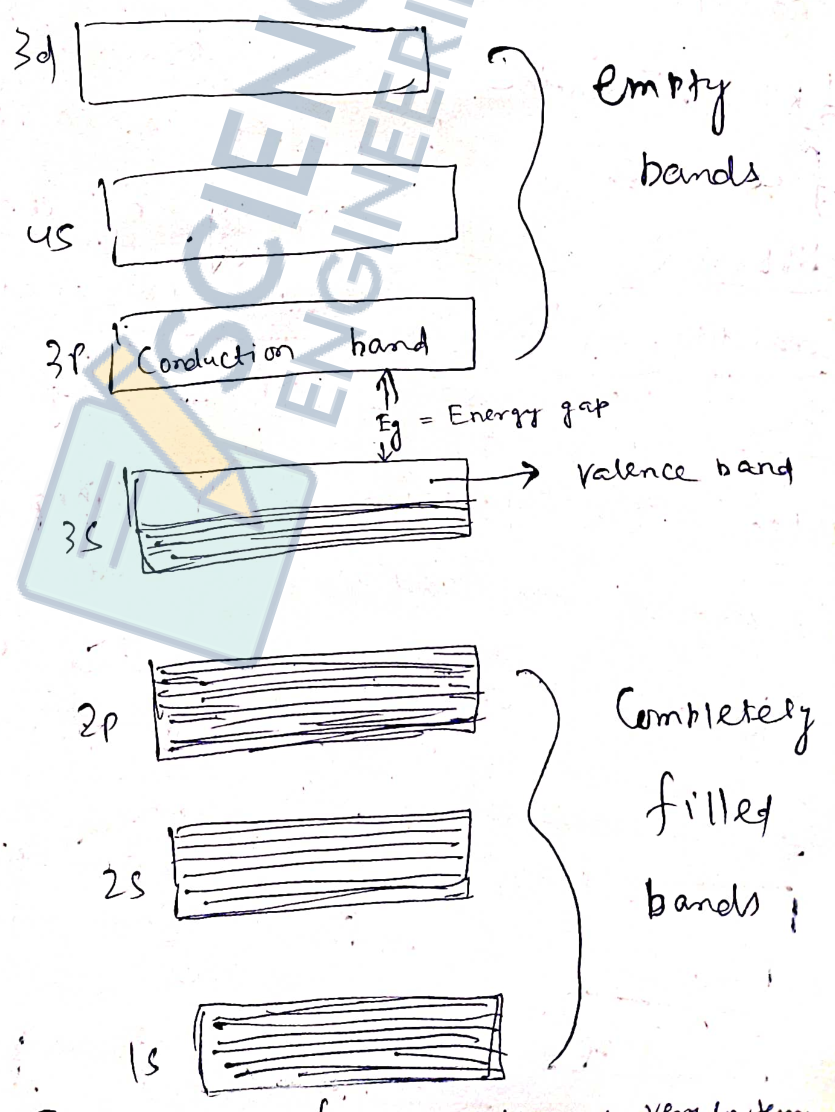
Energy band formed in a solid

In the case of a solid, the atoms are very close to one another. Hence each line will split into large number of lines, being very close to one another. These group of lines will appear as a band. Therefore the solids are characterised by energy bands. which are separated from one another. Depending on the number of outer most electrons & temperature, the bands are occupied.

Ex → Solid Na.

Electronic configuration of a Na atom is

$1s^2 \ 2s^2 \ 2p^6 \ 3s^1$

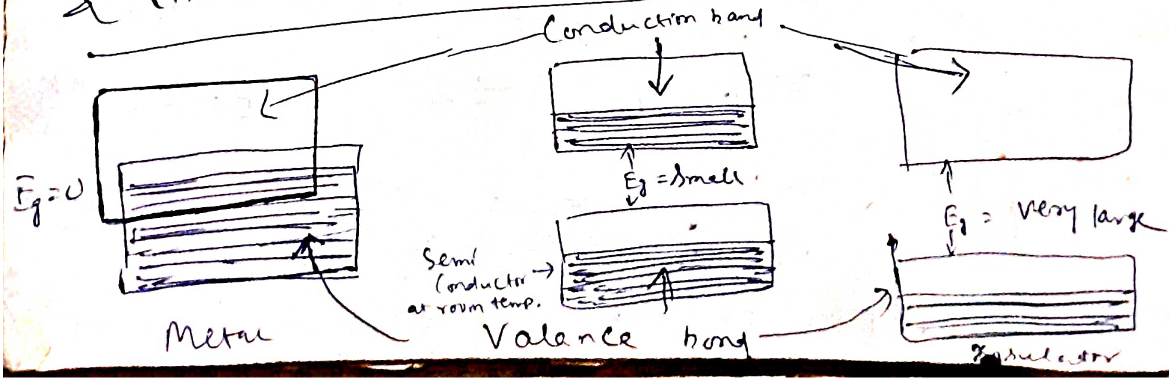


Energy Bands of solid sodium at very low temp.

At very low temperature ~~the~~ the lower bands like 1s, 2s, 2p are completely filled, where as the 3s band is half filled. The other higher ~~ben~~ bands like 3p, 4s & 3d are empty. The highest filled band (may be partly or completely filled) is called the <u>vallancy band</u>.

The empty band that lies just above the valancy band is called <u>Conduction band</u>. When the temperature is increased, it is probable that some of the electrons of the ~~balance~~ valancy band may jump over into the conduction band due to thermal energy ($\frac{1}{2}KT$). Then the electrons practically become free and conductivity increases. The <u>difference of energy between the conduction & valancy band</u> is called <u>energy gap</u> or <u>forbidden gap</u> (E_g). No electron can posses energy lying in between conduction band and valancy band.

<u>Classification of solids into metals, semiconductors & insulator on the basis of band theory</u>



Types of Solids

Metals (Good Conductor)

In the case of metals the outer most electrons of each atom gets deattached from the atom form a sea of electrons. This is due to overlapping of the valance band on the conduction band. The energy gap is zero. and the electrons of the valance band also belong to the conduction band. i.e why metals are good conductors even ~~atom~~ at low temperatures. The energy gap is zero which differentiates metals from the semiconductors & insulators. The highest energy of an electron at low ~~high~~ temp is called fermi energy. (E_f).

Semi-Conductor →

Germanium & Si are good semiconductors. The energy gap is found to be small, of the order of a few electron volts. Even with thermal energy ($\frac{1}{2}KT$ per degree of freedom) it is possible on the part of electrons to go over from the valence to the conduction band even at room temp. That is why semiconductors behave as conductor at high temp. With the rise of temp, the conductivity of semiconductor increases. This character of the semiconductors distinguishes them from conductors.

Where conductivity decreases with the increases of temp.

Insulators → In the case of insulators, the energy gap is found to be very large as a result of which, it is not possible for electrons of the valence band to move into the conduction band so that conductivity can increase. Therefore, insulators remain as non conductors even at high temperature.

For Si $E_g = 1.1 eV$, For Ge $E_g = 0.7 eV$

Types of semiconductors →

- Intrinsic (Pure)
- Extrinsic (Impure)
  - n-type
  - p-type

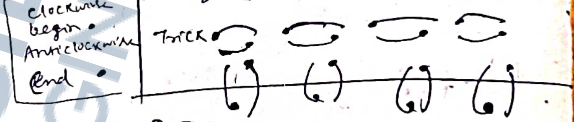
Pure form of Germanium & Silicon are called intrinsic semiconductor. The electronic configuration of Ge & Si are similar to that of C-atom. i.e there are 4 outer most electrons and there is a deficit of 4 electrons to satisfy the octect (nearest inert gas structure).

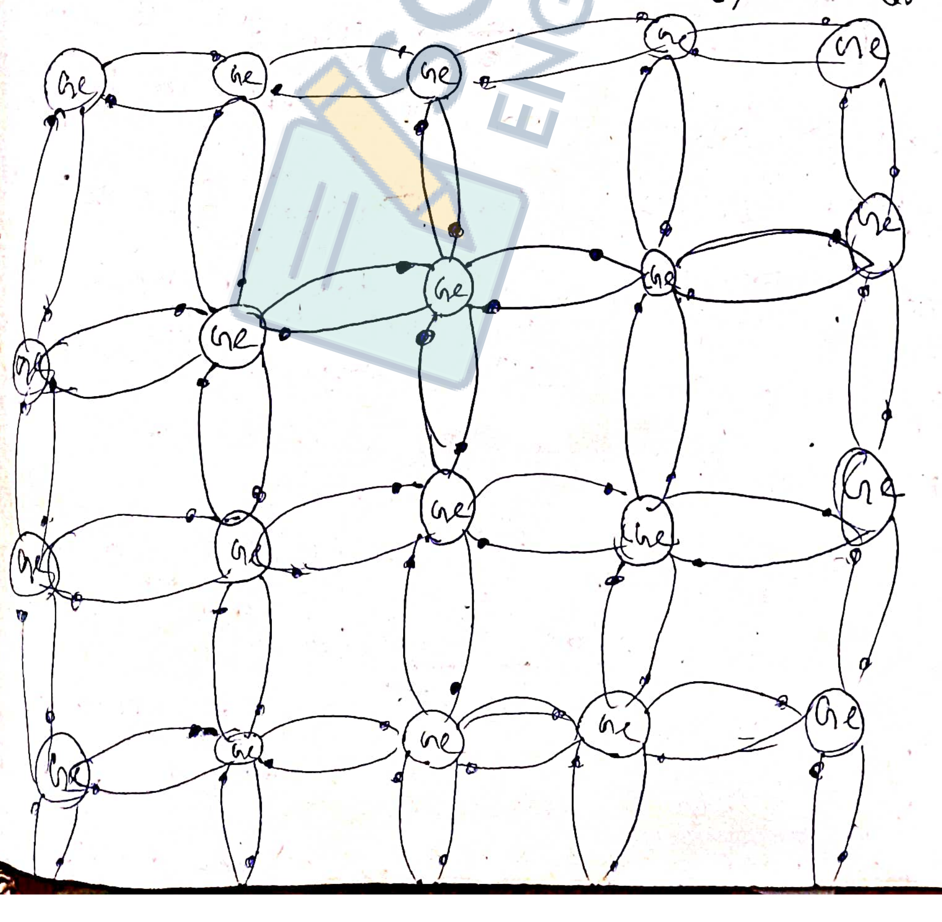
Hence each atom of Ge or Si forms 4 co-valant bonds with the nearest 4 similar atoms. When such a material is kept in between

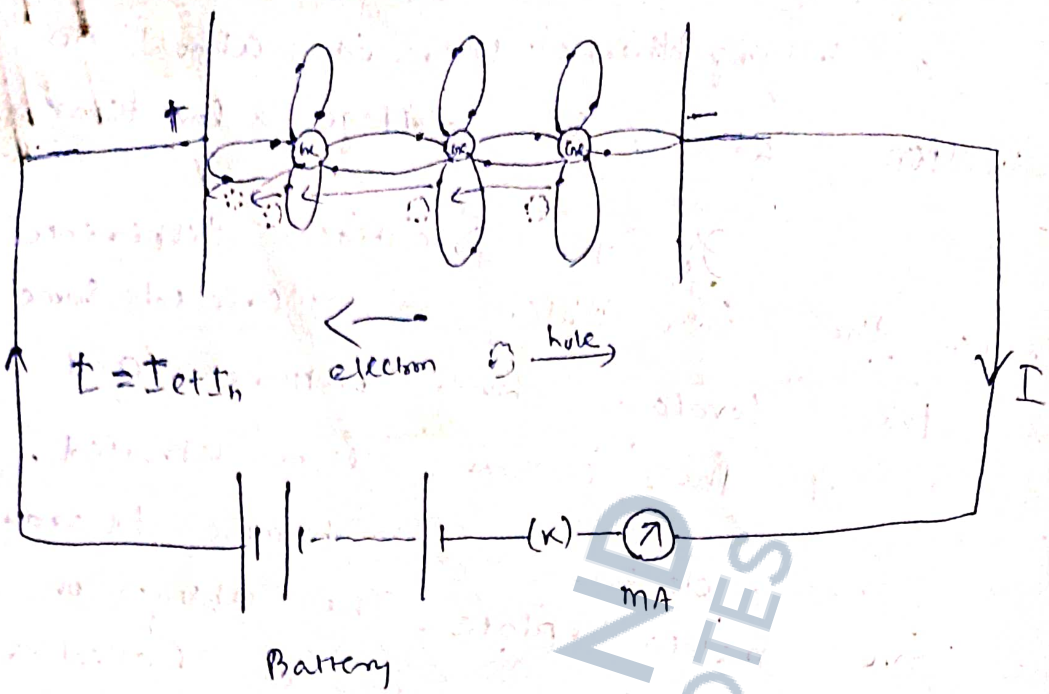
2 Plates, connected to the opposite terminals of a battery, then there is almost no conduction at low voltage & low temp.

If the potential difference between the two plates is increased, some of the covalent bonds rupture and some of the electrons will be uprooted. These free electrons start to move towards the +ve metalic plate. The absence of electron in a covalent bond is called a hole - which appears to move towards the -ve plate. Therefore, a hole is regarded as a +vely charged particle. Equal number of electrons & holes take part in the conduction process.

See BDS for Ge or Si







$I_e = I_h$ because no of free electrons = no of holes.

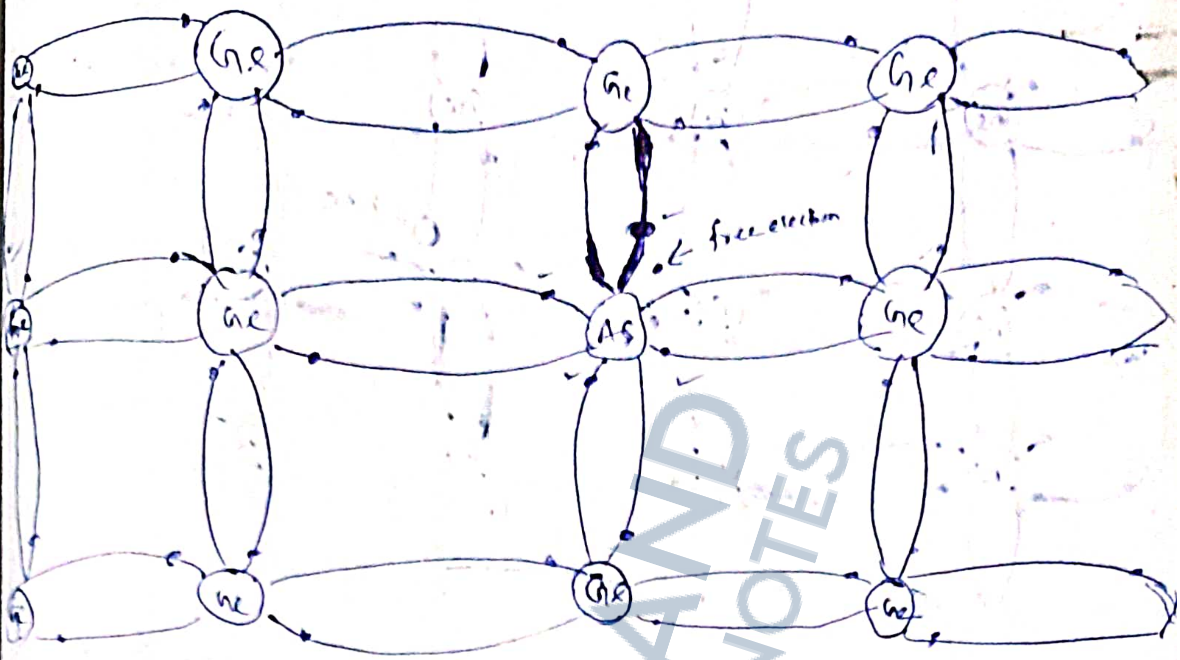
I_e = electron current

I_h = hole current.

Extrinsic Semiconductor →

Naturally occuring semeconductors like Ge, Si are found to be ~~given~~ giving out few electrons & holes which take part in the conduction process (when external field is applied). To increase the number of charge carriers, a procedure is followed called doping

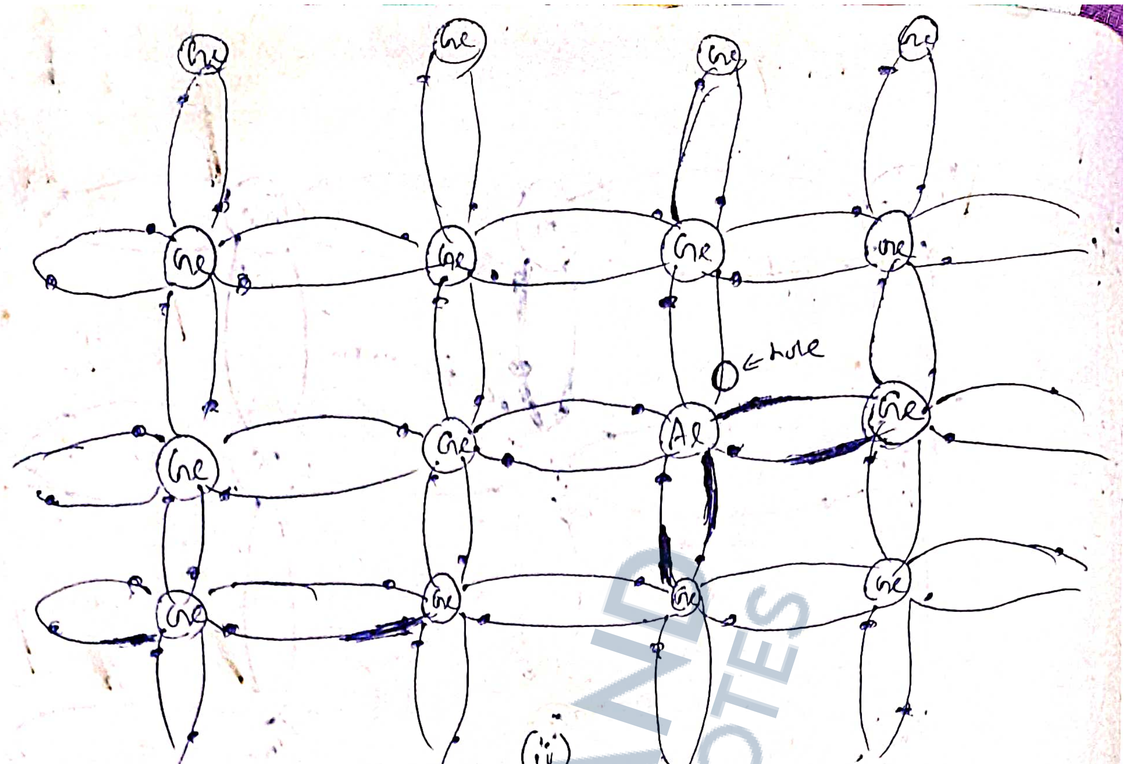
The metal is heated to a high temp when it just starts to melt. Then impurity atoms in powdered form is sprinkled on it. Adsorption takes place & some of the impurities atoms enter into the semeconductor. The



doping is done in such a manner that the number of impure atoms will be found one in every 10^6 atom of Ge or Si.
Depending on the type of impurity atoms extrinsic semiconductors are further classified into (i) n-type (ii) p-type.

n type extrinsic semiconductor

If the impurity atom be pentavalent in nature like As, Sb, P, then there are 5 electrons in the outermost orbit of an impure atom. Out of these 5 electrons 4 will be utilies to satisfy the covalent bonds with the 4 neighbouring semiconducting atoms. One electron is left unattached which behaves as a free electron. Thus, when co-valent bonds rupture equal number of electrons and holes are obtained as before. When the free electron add to this, the number of electrons become greater than the



(ii)

number of holes. Thus the -vely charged electrons dominate. Hence this type of impure semiconductors are called n-type (-ve axis). The impure atom is called ~~dumper~~ donor.

(ii) P-type extrinsic semiconductor (iii).

If trivalent impure atoms be introduced into pure crystals of Ge & Si in the proportion of one impure atom in 10^6 pure atoms, then all the 4 covalent bonds with the four neighbouring semiconductor atoms can not be satisfied. There is deficit of one electron in one of the bonds. This absence of electron in a bond behaves as a hole. Thus, no of holes as charge carrier increases than the number of electrons. Hence such an impure semiconductor is called P-type. The impure atom is called acceptor

The acceptor atom may be Galium, Indium, Boron, Aluminium etc

Source of electrons

Free electrons can be obtained by any of the following 4 methods.

(1) Thermoionic emission

When a metal is heated to a high temp, it is found to emit electrons. These electrons are called thermions & the current arising out of these thermions is called thermionic current.

Richardson & Dushman gave a formula for the thermionic current obtained from the heating of some metal.

$$I = AT^2 e^{-\frac{b}{KT}}$$

Where A & b are constants which differ from metal to metal.

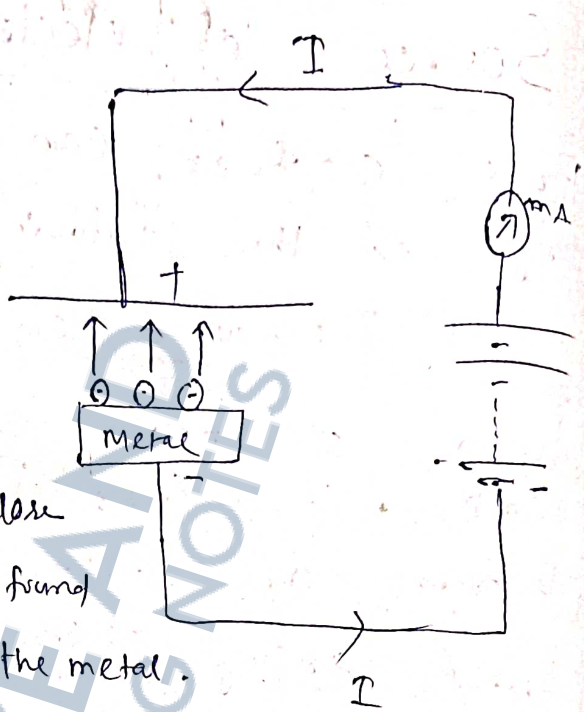
T = Absolute temp. of the metal.

b is found to be equal to the work function (W_0) of the metal.

K = Boltzmann's Constant.

From this formula we see that 2-factors T^2 & $e^{-\frac{b}{KT}}$ determine the current.

(2) Cold emission of field emission

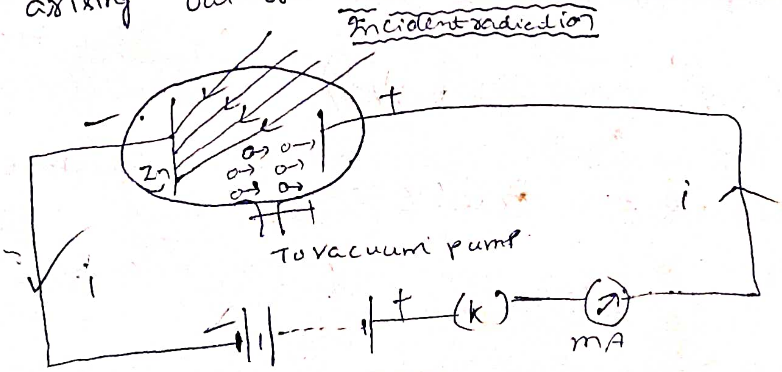


When the metal is connected to the -ve terminal of the battery & another plate is connected to the +ve terminal of the same battery and held over it, quite close to it, electrons are found to be emitted by the metal.

In this case no heating has been done, yet the strong attraction of the +ve plate for the electrons produces free electrons.

(3) Photo electric emission

When light (visible, u.v, X-rays) etc be incident on certain metals like Na, K, Zn Cs etc electrons are found to be emitted by these metals. These electrons are called photoelectrons & the current arising out of these electrons is called photo current.



(4) Secondary emission

When high speed electrons are made to strike a metalic plate, more electrons are found to be ejected from the surface of the metal. This happens because of the fact that the incident energy imparted to the electrons such that the energy exceeds the work function. Then secondary ~~em~~ electrons are found to affect the current & the characteristic curve of a tetrode. In case of pentrode an extra grid is provided to push back the electrons so that the characteristics curve will become ~~smoot~~ smooth.

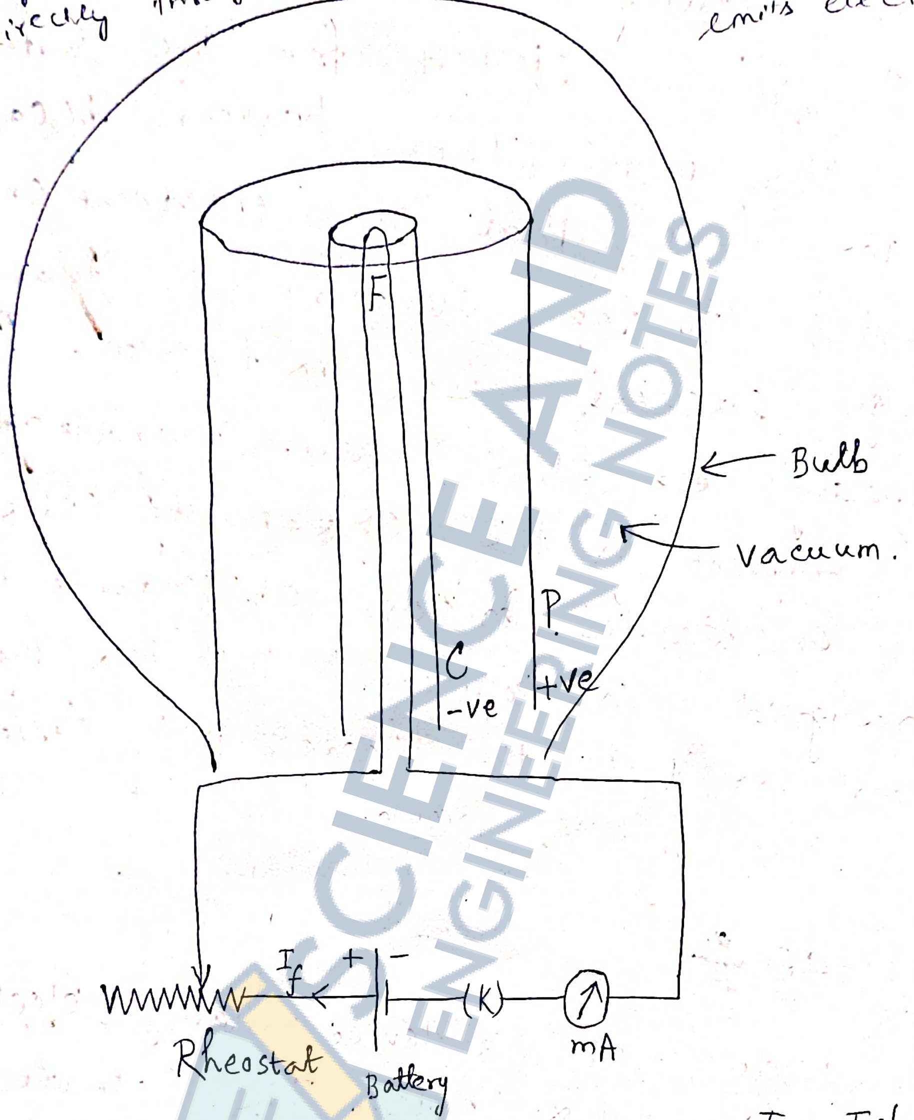
Diode:

A diode is a device having 2 electrodes called Cathode & plate. The Cathode emits the electrons & the plate receives them. Diode is used as a detector in radio circuits & as a rectifier to convert Alternating voltage into direct voltage (A.C to D.C).

Construction:

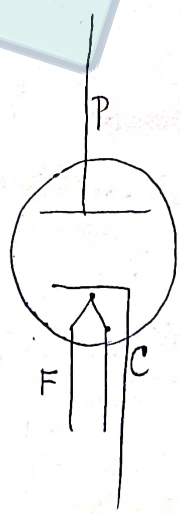
There is a metalic wire heated by direct current or alternating current. It is called filament. It is surrounded by a thin metal sleeve ~~And it emits electrons due to~~

with barium & strontium oxides. called the cathode, ~~thermionic~~ emission. The filament current can be varied by changing the resistance of the rheostat as shown in the figure. There is no electrical connection between heater & cathode. The heating current is passed through filament & cathode is heated indirectly through heat-transfer from filament & the cathode emits electron.



I_f = Filament current

Symbol of diode



P = Plate

C = cathode

F = Filament.

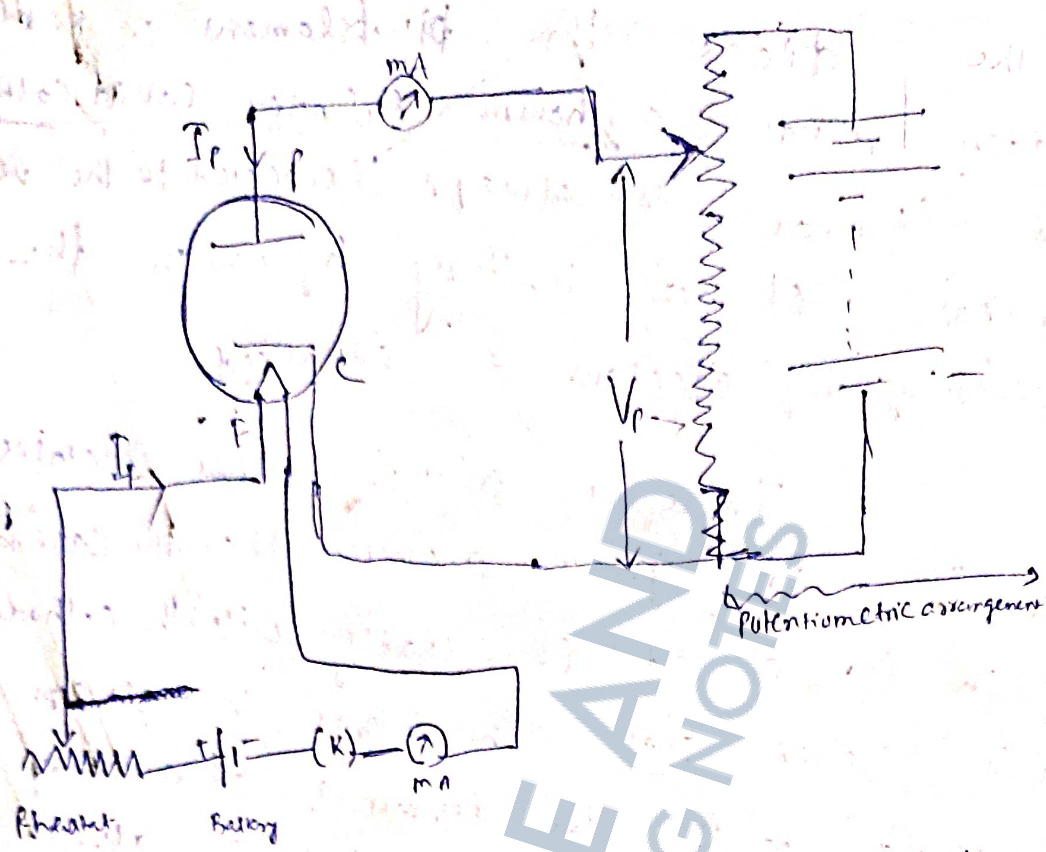
This Cathode is always connected to the -ve terminal of a battery by which the emission of electrons is enhanced.

There is another hollow metallic cylinder of greater diameter than the cathode which is placed co-axially with the cathode. It is called plate. The plate is always connected to the +ve terminal of a battery so that it will be able to attract the electrons. Due to these electrons, there is a small current flowing in the plate circuit called plate current (I_P)

To avoid the collision of electrons with the atoms & molecules of air, the air inside the bulb is completely pumped out & vacuum is created. i.e why diode is also called vaccum diode

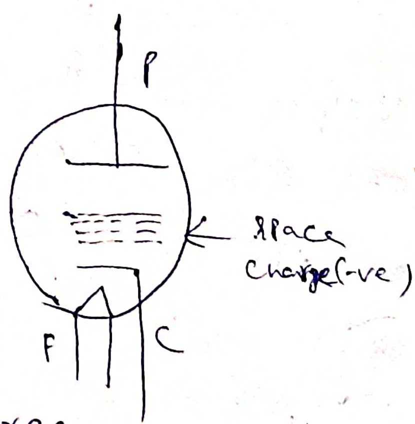
Action

To study the functioning of the diode, the circuit diagram in the ~~previous~~ next page is used where potentiometric arrangement has been shown by which the plate voltage (V_P) or E_b can be gradually changed. The corresponding plate currents (I_P) or I_b



are noted from the milliammeter. For each filament current, a set of observations can be taken.

When the plate voltage is low, all the electrons emitted by the cathode cannot be taken away by the plate. As a result, many electrons form a cloud of -ve charge near the cathode & in between the cathode and the plate. The electron cloud is called <u>space charge</u>. If space charge will be present, further emission of the electrons become difficult i.e the diode will not function smoothly.



Under this space charge limited condition, the square of the plate current is found to be directly proportional to the cube of the plate voltage. This is called Child's law.

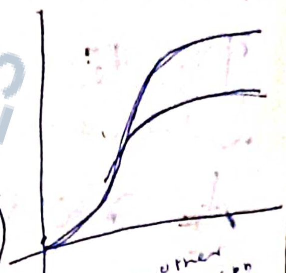
$$\therefore I_p^2 \propto V_p^3$$

$$\text{or} \quad I_p^2 = K V_p^3$$

where K is a constant

$$\text{Also} \quad I_p \propto V_p^{3/2}$$

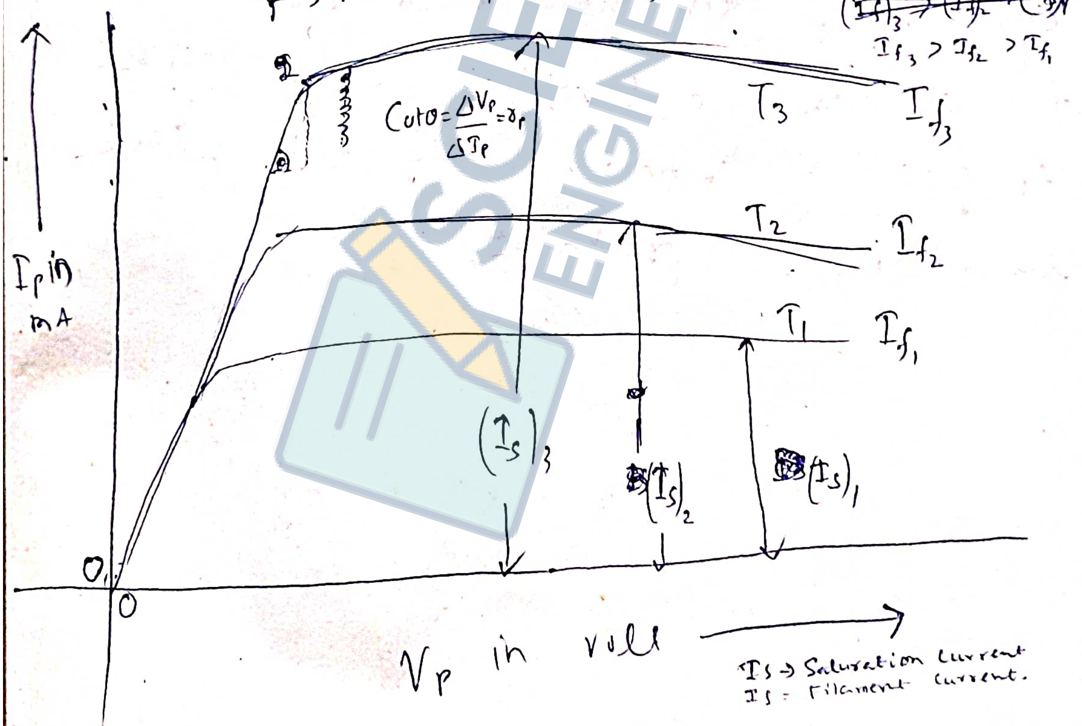
graph should be



Insert all other things in this graph form below graph.

When applied voltage is increased

$T_3 > T_2 > T_1$, $(I_s)_3 > (I_s)_2 > (I_s)_1$ because ~~$(I_f)_3 > (I_f)_2 > (I_f)_1$~~ $I_{f_3} > I_{f_2} > I_{f_1}$



very much, the space charge vanishes because all the electrons emitted by the cathode are taken away by the plate. This is called saturation stage. The current under this condition is called Saturation current (I_s)

For different filament currents, the no of electrons emitted by the Cathode become different. This has been shown in the graph drawn in the previous page.

Diode as a rectifier

A rectifier is a device in which alternating voltage is converted to direct voltage. In this respect, its function resembles that of an eliminator. If one diode be used, then output voltage is found to be discontinuous as shown in the graph no-1. If two diodes be employed, it is possible to get a continuous supply of voltage as shown in graph-2.

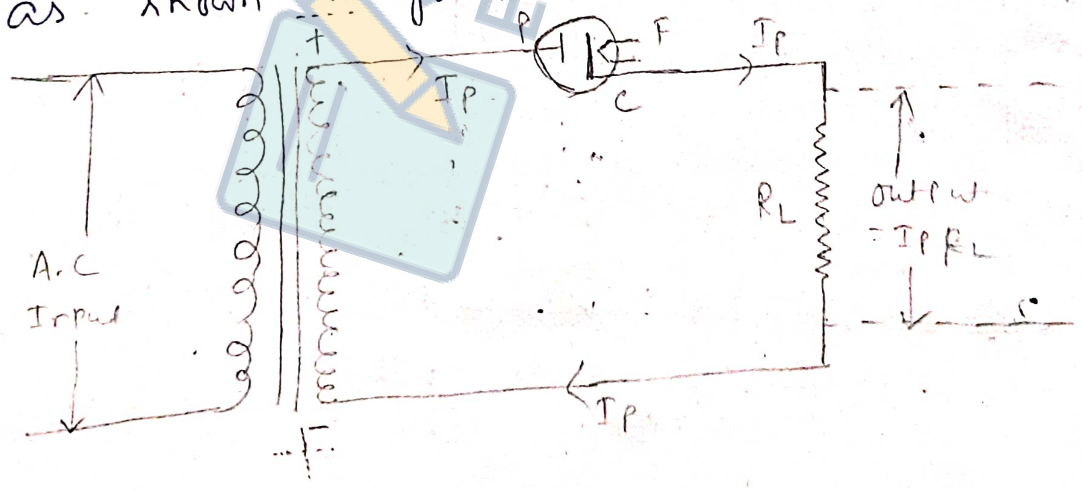
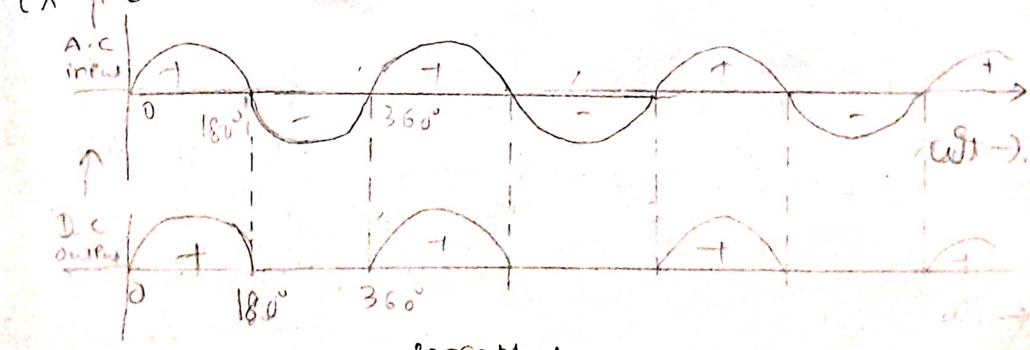


Fig -1

1. Diode as a half wave rectifier

We know that alternating voltage changes sign twice during a complete cycle : when the voltage supplied to the diode is +ve, the plate becomes +ve and it can attract the electrons emitted by the Cathode (which has been heated by the filament circuit, not shown in the diagram). As a result, there is a small current of the order of milli amperes in the plate circuit. This current increases from zero to a maxm and then decreases to zero during +ve half cycle. During -ve half cycle, the plate becomes -ve and does not attract a ~~sigale~~ single electron and the plate current becomes zero.

A high resistance called load resistance (R_L) of the order kilo ohm up to Mega ohm is placed in the circuit. The output voltage can be derived from the two ends of the load resistance. The D.C output in the graph no-1 has been shown and we see that the output is undir continuous and fluctuating.

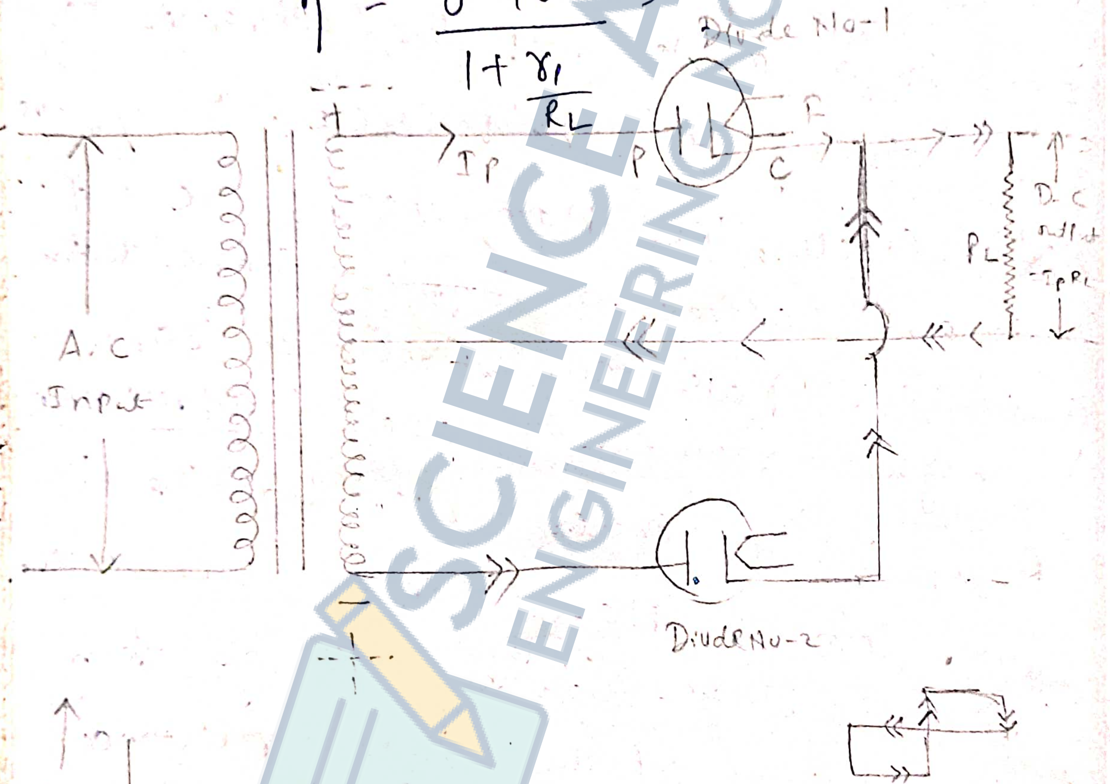


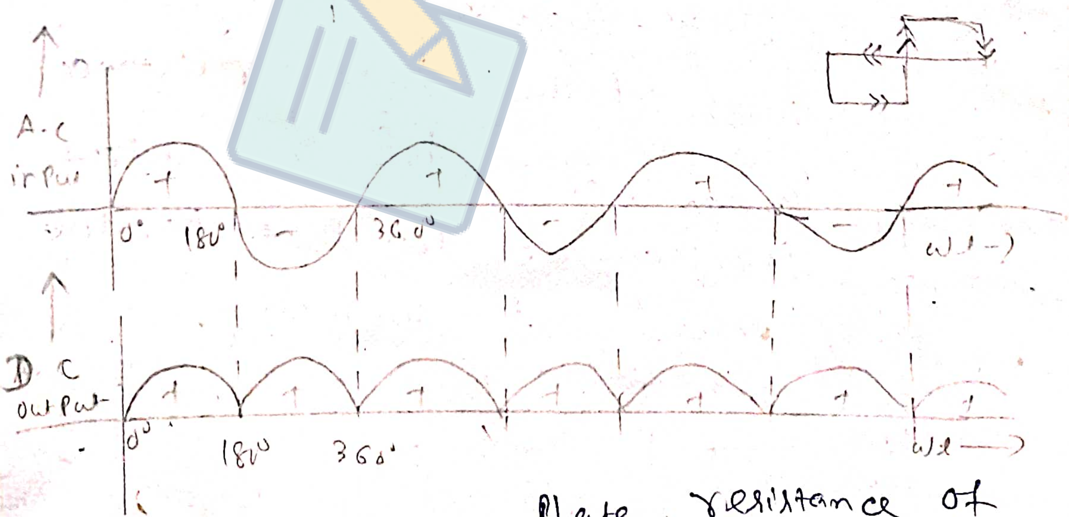
graph-1

Since there is a unidirectional flow of electrons from the cathode towards the plate, it is compared to a valve and called diode valve.

Efficiency of rectification is defined as the ratio of the d.c output power to the A.C input power. And it can be shown that

$$\eta = \frac{0.406}{1 + \frac{r_p}{R_L}}$$





where r_p = Plate resistance of the diode, obtained as the reciprocal of the slope of the (*)

linear portion of the characteristic curve of the diode.

Since $r_p << R_L$, we can neglect the ratio $\frac{r_p}{R_L}$ compared to one.

Then $\eta = 0.406 = 40.6\%$.

2. Diode as full wave rectifier

When the input voltage reaches diode no-1 as +ve, it receives electrons from the cathode. At that time diode No-2 remains inactive as its plate receives -ve voltage. Thus, during the first half cycle, diode no-1 only functions and produces a small fluctuating current of the order of few milli amperes. When this current flows over the load resistance, the voltage produced between its two ends can be tapped.

During the 2nd half cycle, diode no-2 becomes active where as diode No-1 becomes inactive. As shown in fig-2, the circuit has been prepared in such a manner that the direction of flow of current through the load resistance remains the same. And the output voltage is unidirectional, yet fluctuating but continuous.

Rectification efficiency

$$\eta = \frac{\text{D.C power output}}{\text{A.C Power input}}$$

$$= \frac{0.812}{1 + \frac{r_p}{R_L}}$$

Since $r_p << R_L$, the ratio of $\frac{r_p}{R_L}$ can be neglected and we get $\eta = 0.812 = 81.2\%$

Triode →

Introduction → It is a device having three electrodes namely cathode, plate and grid. The grid is a piece of wire wound round the cathode rather loosely and it is connected to -ve terminal of a battery so as to control the flow of electrons. In this regard it is more efficient than a Diode. Triode is used to amplify a smaller voltage and it is also used as an oscillator by which electromagnetic waves can be generated.

Construction →

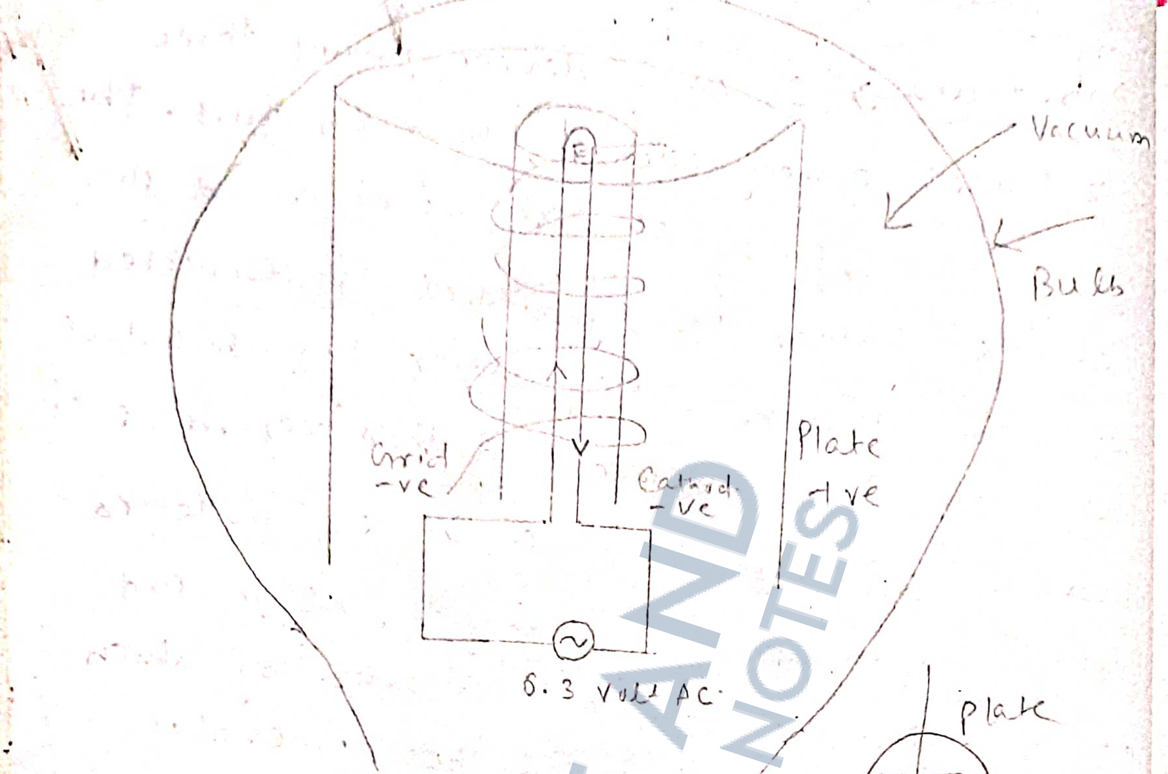
1) Filament
2) Cathode
3) Plate

} Same as diode (write in exam, of diode)

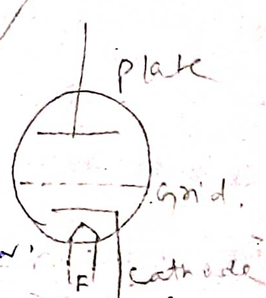
4) **Grid →** It is also called 'controlled grid' because it is nearer to the cathode and slight change in its -ve voltage makes a greater change in the plate current. The grid is more effective than the plate. If it will be connected to the +ve terminal of a battery then it will accept electron ~~and Ip~~ & Ip decrease & grid current developes. Grid current is undisirable because it causes power loss in grid circuit. ~~will decrease~~ Therefore, the grid is always connected to the -ve terminal of a battery.

All these are kept inside a hard glass bulb with the inside air pumped out.

Hence it is also called Vacuum triode.



Symbol of triod



Action (working) → See 2019 page Sample paper

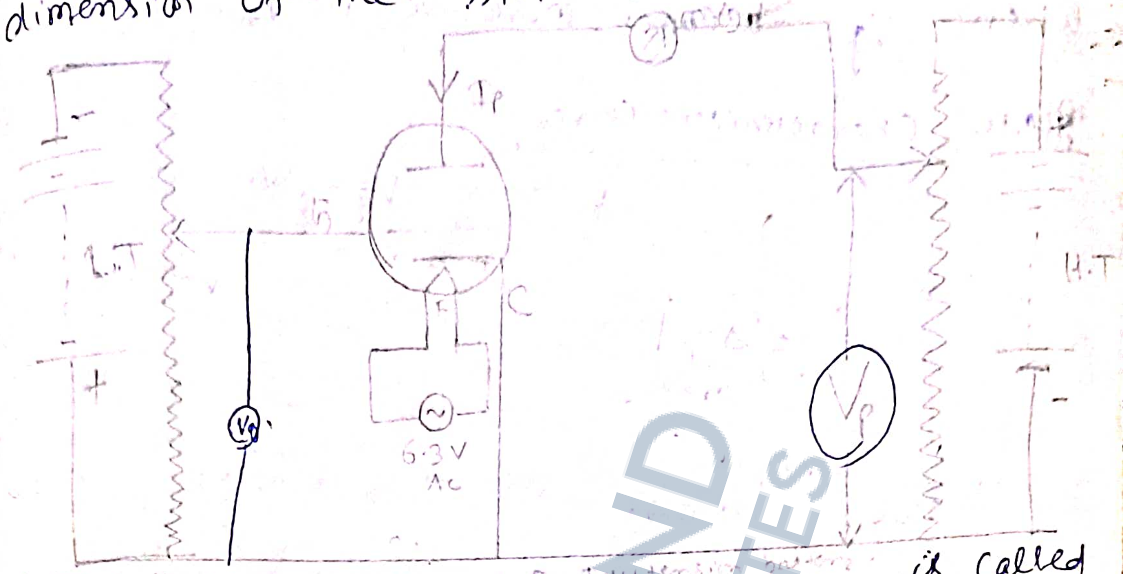
By using potentiometric arrangements for the plate voltage (Vp) and grid voltage (vg) one can get different values of I_p. Two sets of characteristics curves can be drawn.

① Plate current versus plate voltage when the grid voltage is kept constant.

② Plate current Vs grid voltage when plate voltage is kept constant.

Plate Characteristic curve →

with a particular value of grid voltage, the plate voltage is gradually increased. The plate current is found to increase also. Unlike the diode there is no saturation stage. The slope on any linear portion of any Curve Can be found Out. The dimension Of the slope is that Of Conductance.



H.T → high tension battery, L.T → low tension battery

The reciprocal of the slope is called plate resistance (r_p).

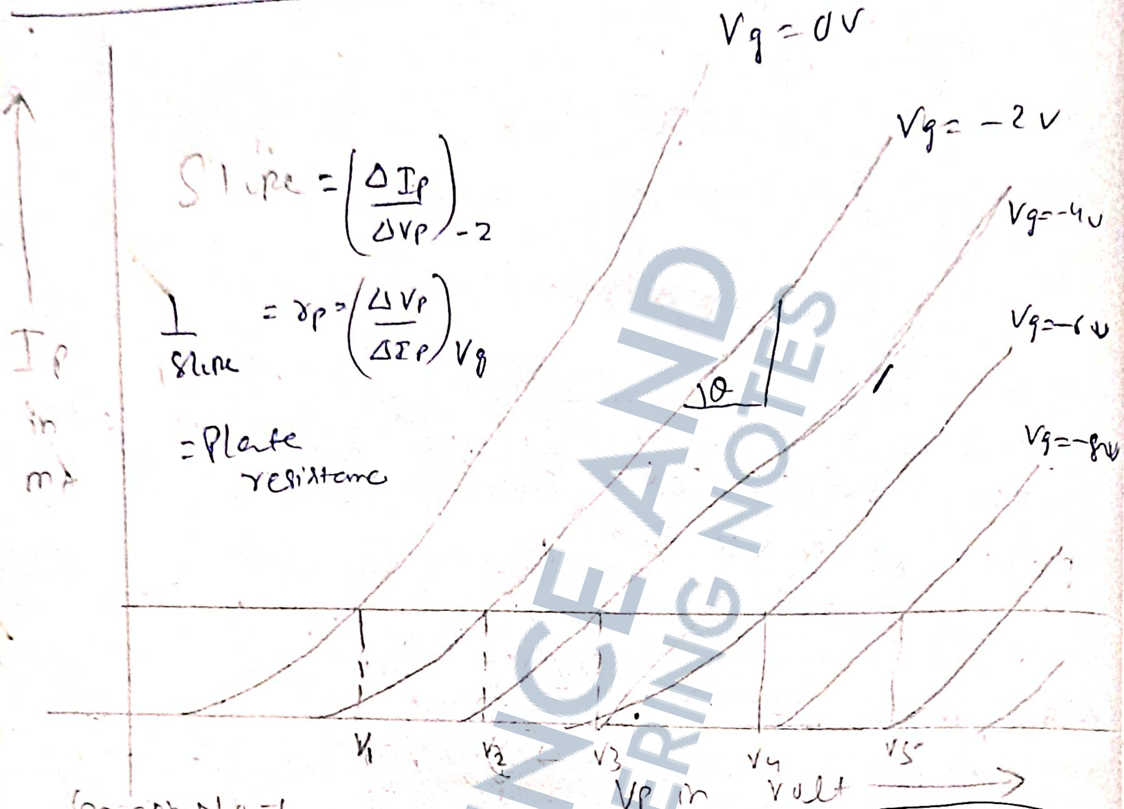
i.e. $r_p = \left(\frac{\Delta V_p}{\Delta I_p}\right)_{V_g}$

This shows that the plate resistance of the same triode changes with the operating voltage.

If the grid be made more −ve, the maxm value of the plate current reduces very much and a certain grid voltage called cut-off grid voltage or Critical grid voltage, the plate current will be zero, however great plate voltage is applied.

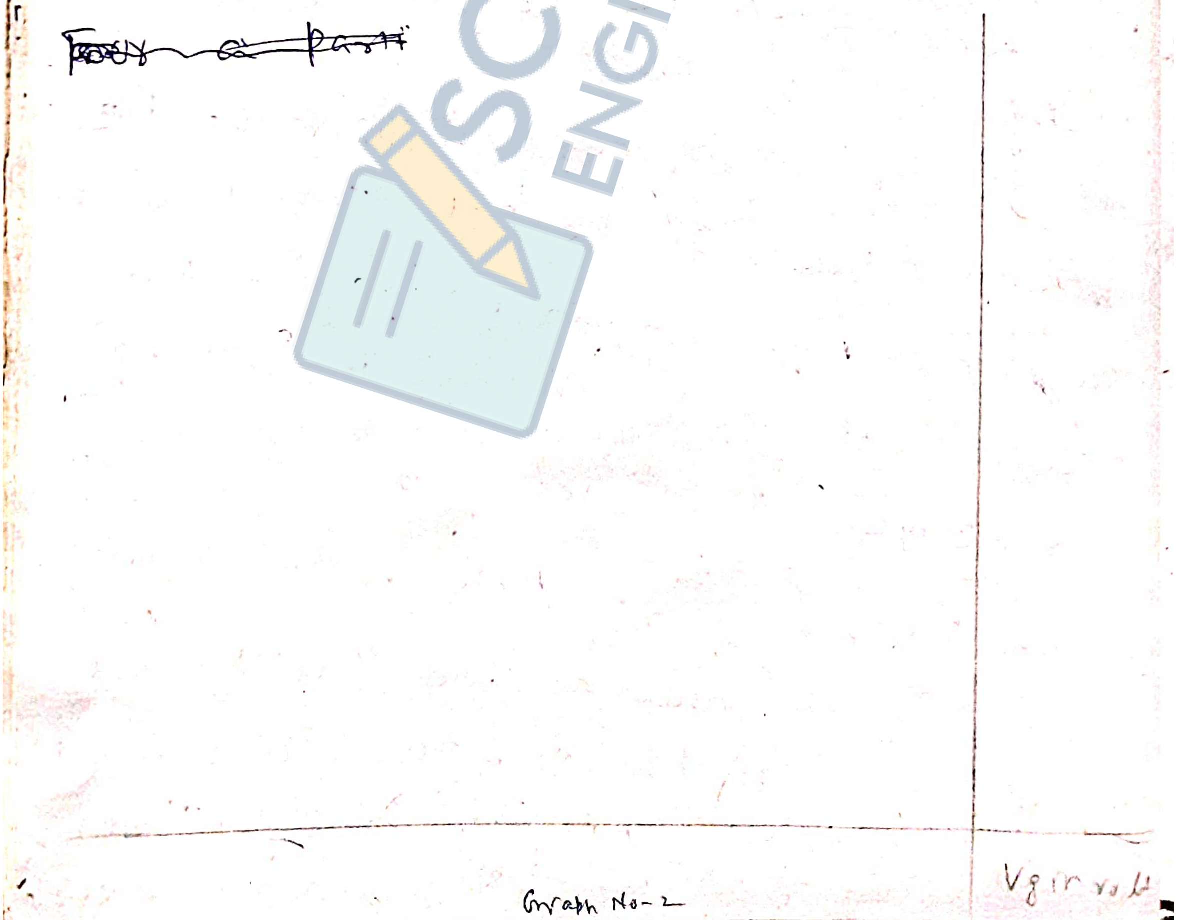
If we draw a line // to x-axis for $I_p = I_0$ (say), then it will cut different curves at different points. Dropping ⊥ lrs, we see that more plate voltage is necessar to get the same amount of plate current, when V_g becomes more -ve (i.e $V_4 > V_3 > V_2 > V_1$)

Plate characteristic curves



Graph No-1

Mutual characteristic curves

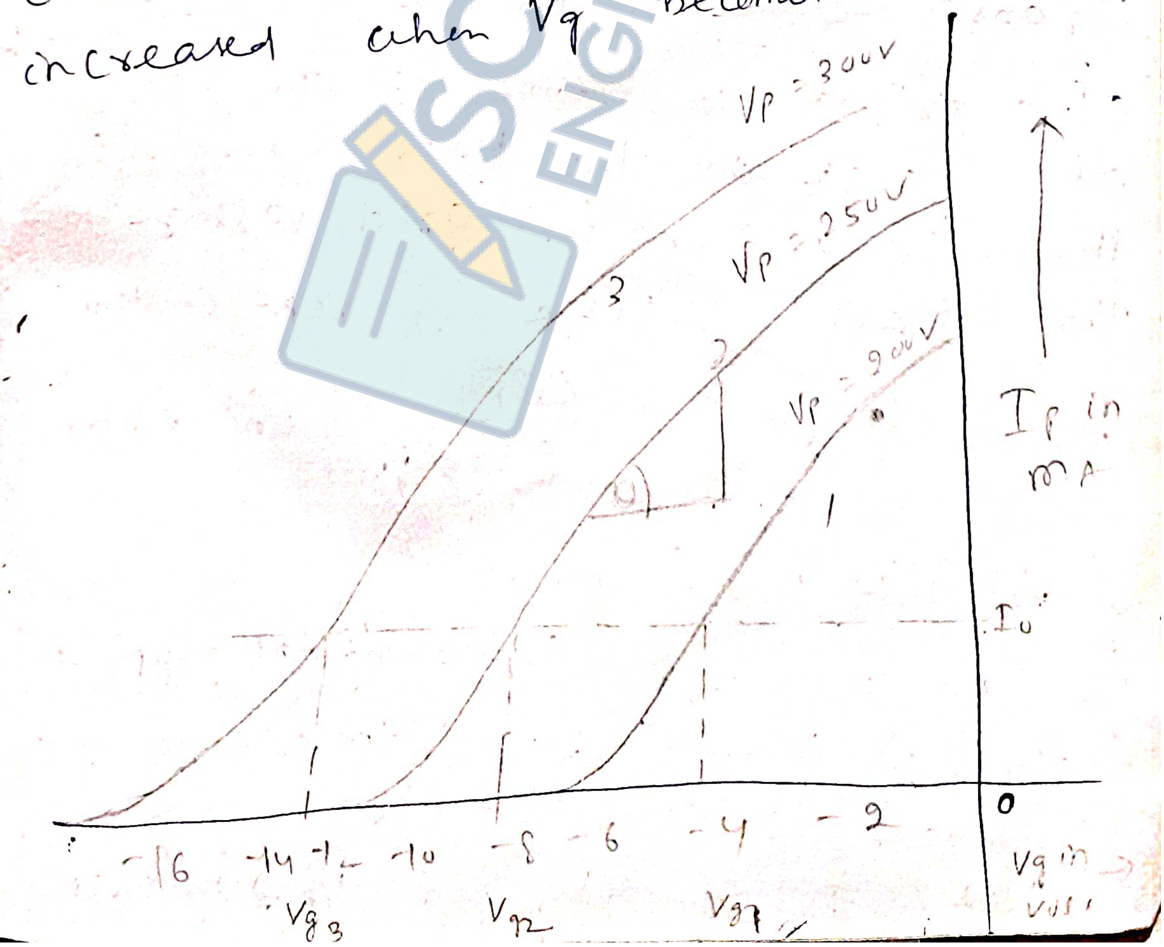


Graph No-2

For a particular plate voltage V_p the grid voltage be gradually made more -ve. Then the plate current I_p will decrease. In graph No-2, ~~the~~ three such curves have been shown. Slope on any curve can be found out from the linear portion. Its dimension is the same as that of conductance which we call as transconductance or mutual conductance (g_m).

$$\therefore \; g_m = \left(\frac{\Delta I_p}{\Delta V_g}\right)_{V_p}$$

If we draw a horizontal line parallel to x-axis, at a particular current I_0, we see V_p has to be increased when V_g becomes more -ve.



Valve Constants of a triode

A triode is characterised by 3 constants.

1. Plate resistance (r_p)
2. Trans Conductance (g_m)
3. Amplification factor (μ)

Plate resistance of the ~~triode~~ triode is defined as the ratio of the change in the plate voltage to the change in the plate current when grid voltage is kept constant.

$$r_p = \left(\frac{\Delta V_p}{\Delta I_p}\right)_{V_g}, \text{ Unit Ohm.}$$

Trans Conductance or mutual conductance of a triode is defined as the ratio of change in the plate current to the change in the grid voltage when the plate voltage is kept constant.

$$g_m = \left(\frac{\Delta I_p}{\Delta V_g}\right)_{V_p}, \text{ Unit mho.}$$

Amplification factor →

To understand the meaning of amplification factor of triode, let us take a numerical example.

Let $I_p = 100$ mA, when $V_p = 200$ volt

& $V_g = -6V$.

If ~~B~~ V_p be increased to 250 volt, with V_g kept constant at $-6V$, then I_p will increase from 100 mA to 125 mA. (say)

i.e $\Delta V_p = 50V$ has caused ~~catt~~ $\Delta I_p = 25 mA$

Keeping V_p at 250 volt, let V_g be made -8 volt, the plate current will decrease from 125 mA to 100 mA (say)

i.e $\Delta V_g = 2V$ has caused $\Delta I_p = 25 mA$.

This shows that ~~the~~ ~~cl~~ a change of 50V of the plate voltage is equally effective as a change of 2V of the grid voltage

Defn of μ → The ratio of change in the plate voltage to the change in the grid voltage to keep the plate current constant is called amplification factor.

i.e $\mu = \left(\frac{\Delta V_p}{\Delta V_g}\right)_{I_p} = 25$ in our example.

Relation among the valve constants

$$\mu = \frac{\Delta V_p}{\Delta V_g} = \frac{\Delta V_p}{\Delta I_p} \cdot \frac{\Delta I_p}{\Delta V_g} = r_p \cdot g_m$$

$\therefore$ $\boxed{\mu = r_p \cdot g_m}$

Triode as an amplifier →

Before deriving an expression for the voltage amplification by a triode, let us study fig-1. In this circuit, there is a fixed grid voltage & a fixed plate voltage. The grid voltage be −6V and the plate voltage be +200 V (say). A high resistance called load resistance (R_L) is also included in the plate circuit. From the two ends of R_L, output voltage can be derived, which is

$I_p \cdot R_L$ = Fixed.

If an alternating small voltage, called signal voltage, say $e = 6 \sin\omega t$ be included in the grid circuit as shown in fig(2), then the effective grid voltage will vary between 0 to −12 volt.

because

$$(V_g)_{max} = +6 + (-6) = 0\,V$$

$$(V_g)_{Min} = -6 + (-6) = -12 \text{ volt}$$

Accordingly, the plate current will change from I_p to $(I_p \pm \Delta I_p)$.

At any instant of time, let the grid voltage be −2V when plate current = $I_p + \delta I_p$ as shown in fig 3.

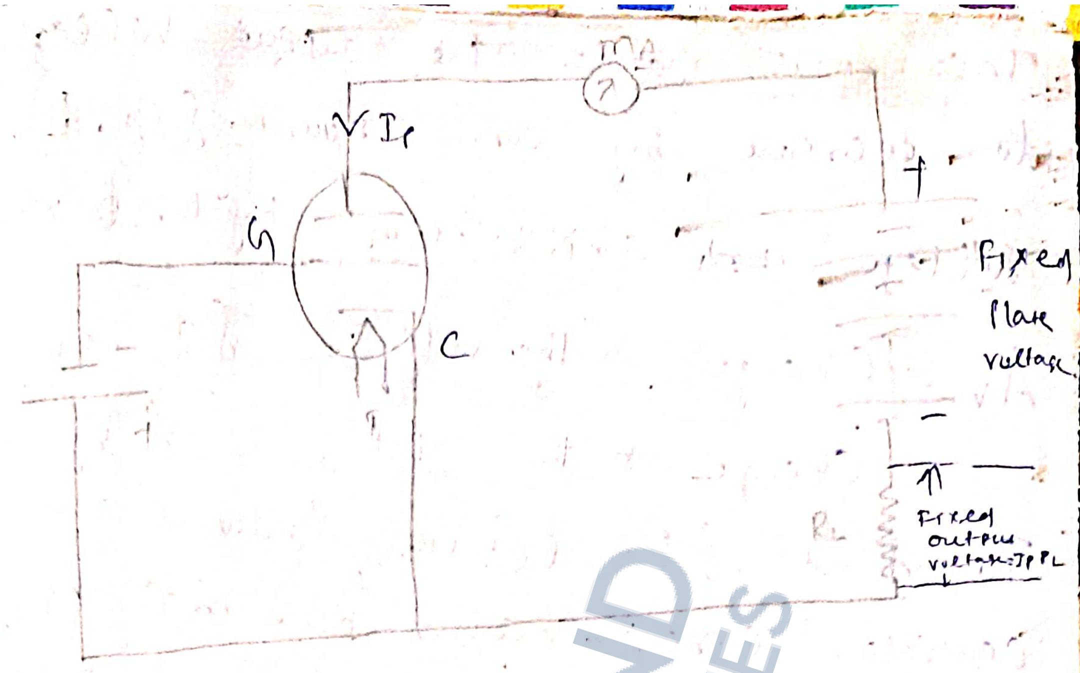
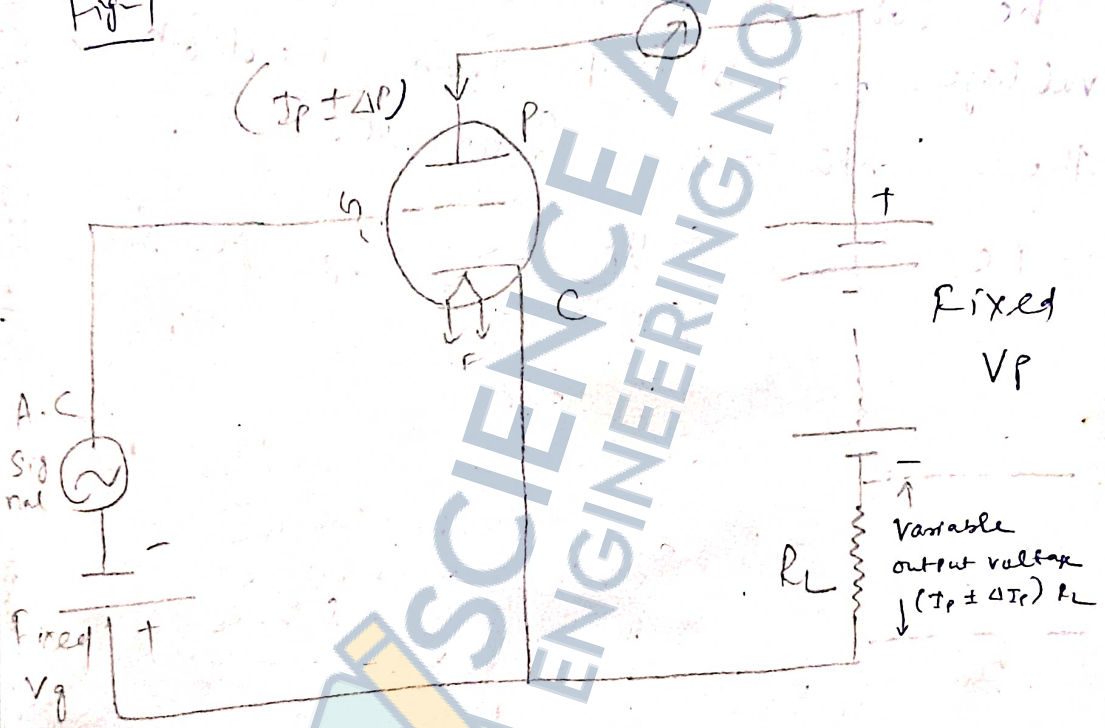
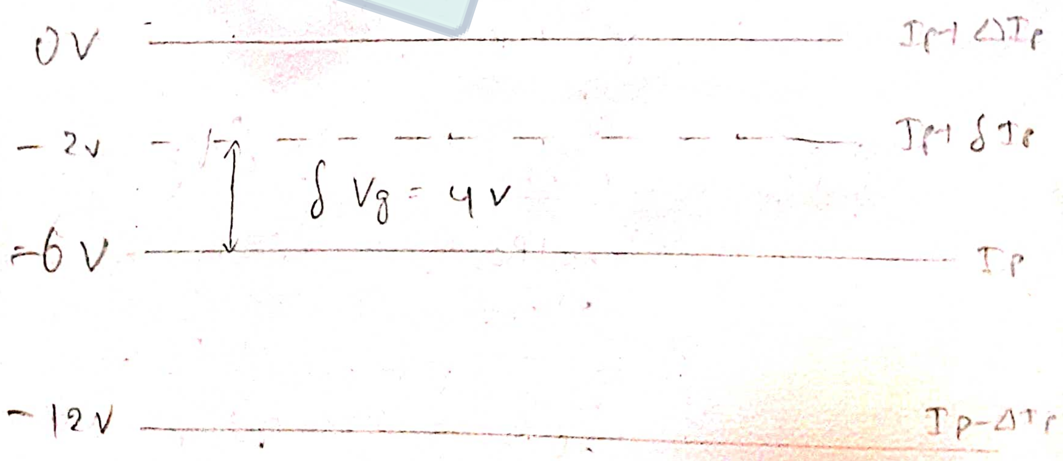

mA
Ip
G
C
Fixed Plate voltage
RL
Fixed output voltage = Ip RL

Fig-1


mA
(Ip ± ΔI)
P
G
C
Fixed Vp
A.C Signal
Fixed Vg
RL
Variable output voltage (Ip ± ΔIp) RL


0V
-2V
-6V
-12V
δ Vg = 4V
Ip + ΔIp
Ip + δ Ip
Ip
Ip - ΔIp

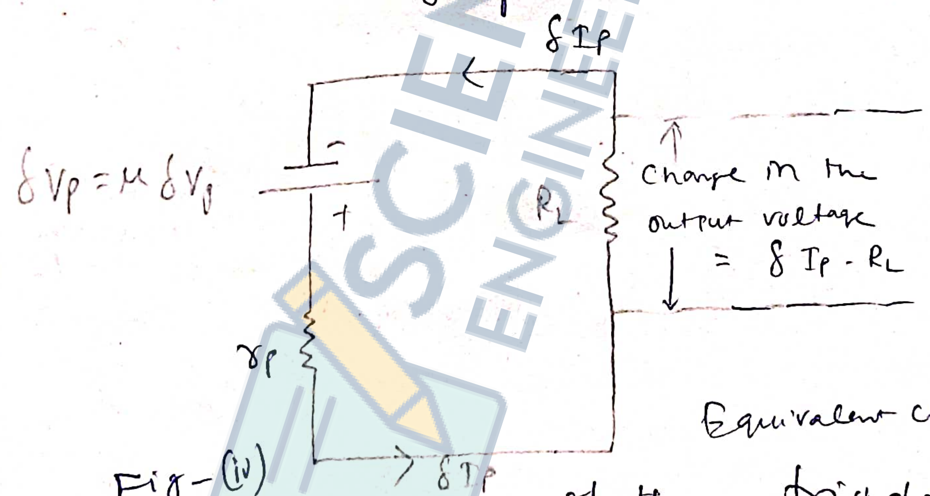
This will cause the output voltage to increase by an amount $\delta I_p \cdot R_L$.. by the triode voltage ~~amplification~~ amplification

$$A_v = \frac{\text{Change in the output}}{\text{Change in the input}} = \frac{\delta I_p \cdot R_L}{\delta V_g}$$

To find δI_p, let us draw an equivalent circuit as shown in fig (4).

The effective increase of the plate voltage is obtained from the defn of the amplification factor μ.

i.e $\mu = \frac{\delta V_p}{\delta V_g} \Rightarrow \delta V_p = \mu \cdot \delta V_g$



Equivalent circuit

Fig-(iv) of the triode circuit

Total resistance $= r_p + R_L$

$$\therefore \delta I_p = \frac{\delta V_p}{(r_p + R_L)} = \frac{\mu \, \delta V_g}{r_p + R_L}$$

$$\therefore A_v = \frac{\mu \cdot \left(\frac{\delta V_g}{(r_p+R_L)}\right) \cdot R_L}{\delta V_g} = \frac{\mu R_L}{r_p + R_L}$$

$$\therefore \boxed{A_V = \frac{\mu \cdot R_L}{r_p + R_L}}$$ No unit.

→ Ans for problems in the next page

(1) We know that in space charge limited region

$I_p^2 = K (V_P)^3$

$(100\ mA)^2 = K \cdot (120V)^3$

$x^2 = K (240V)^3$

$\Rightarrow \frac{10^4 \times mA^2}{x^2} = \left(\frac{1\ 120V}{2\ 240V}\right)^3 = \frac{1}{8}$

$\Rightarrow x^2 = 8 \times 10^4\ mA^2$

$\Rightarrow x = 2.83 \times 10^2\ mA$

$= 283\ mA$.

$(100 \times mA)^2 = K \times (120V)^3$

$x^2 = K \times (480)^3$

$\Rightarrow \frac{10^4 \times mA^2}{x^2} = \left(\frac{1}{4}\right)^3$

$\Rightarrow x^2 = 64 \times 10^4 \times mA^2$

$8 \times 10^2\ mA$

$\Rightarrow x = 800\ mA$

(2) $I_p = 10\ mA$, $V_P = 100$ volts, $(2I_p)$

$\frac{(10\ mA)^2}{(20\ mA)^2} = \frac{K (100\ volt)^3}{K\ x^3}$

~~$\Rightarrow x^3 = \frac{20\ mA \times 100\ V^3}{10\ (mA)}$~~

$\Rightarrow x = V = 200 \times V^3$

$$\frac{1}{4}\left(\frac{1}{2}x\right)^2 = \frac{100^3 \text{ volt}^3}{x^3}$$

$$\Rightarrow x^3 = 4 \times 100^3 \text{ volt}^3$$

$$\Rightarrow x = 4^{\frac{1}{3}} \times 100 \text{ volt}$$

Let $y = 4^{\frac{1}{3}}$

$\log y = \frac{1}{3}\log 4 = \frac{1}{3} \cdot 2\log 2 = \frac{1}{3} \times 2 \times .3010$

$\frac{2}{10} = \frac{1}{3} = .2$

$\Rightarrow y = \text{antilog}(.2) = 1.585$

$\therefore x = 1.585 \times 100 = 158.5$ volt

3. Efficiency = $\frac{\text{D.C output}}{\text{A.C input}} = \frac{0.406}{1+\frac{r_p}{R_L}} = \frac{0.406}{1+\frac{200}{800}}\frac{1}{4}$

$R_L = 800\,\Omega$

$r_p = 200\,\Omega$

$I_p \cdot R_L = 100$ volt.

$= .406 \times \frac{4}{5} \times 100\,\%$

$= 32.48\,\% \simeq 32.5\,\%$

.406
80
32.480

4.

5. $\mu = 30$, $R_L = 50\,k\Omega$, $r_p \cdot g_m = 30$

$\mu = 34$, $R_L = 85\,k\Omega$, $r_p \cdot g_m = 34$

25.11.2x

Problem

(4) The following readings were obtained from the linear portion of a vacuum triode. From that find.

(a) Plate resistance (b) Mutual Conductance

(c) amplification factor

Ans: 11.1 Kilo ohm, 4.666×10^{-3} mho., 52

V_p or E_b	150 V	150 V	100 V
I_p or I_b	12 mA	5 mA	7.5 mA
V_g or E_c	−1.5 V	−3 V	−1.5 V

r_p = Plate resistance $= \left(\dfrac{\Delta V_p}{\Delta I_p}\right)_{V_g}$

$= \dfrac{(150-100)\text{ volt}}{(12-7.5)\text{ mA}} = \dfrac{50 \times 10^3}{4.5}$ ohm

$= \dfrac{500}{45} = \dfrac{100}{9} = 11.11\text{---}$ K ohm.

g_m = Mutual Conductance

$= \left(\dfrac{\Delta I_p}{\Delta V_g}\right)_{V_p} = \dfrac{(12-5)\text{ mA}}{(-1.5+3)\text{ volt}}$

$= \dfrac{7 \times 10^{-3}}{1.5} = \dfrac{70}{15} \times 10^{-3} = 4.666 \times 10^{-3}$ mho

$= 4.666$ milli mho

μ = Amplification factor

$= r_p \, g_m$

$= \frac{100}{9} \times 10^3 \text{ ohm} \times \frac{14}{3} \times 10^{-3} \text{ mho}$

$= \frac{1400}{27} = 51.851 \simeq 52$ Ans

(5.) The voltage amplification factor is 30 with load resistance 50 K ohm and 34 with 85 Kilo ohm load resistance. Determine the value constants.

Ans: 20 Kilo ohm, 2.1 milli ohm, 42

~~volts~~

(3.) A half wave rectifier is used to supply 100 volts D.C from a load of 800 Ohms. The diode has a plate resistance of 200 Ohms. find the rectification efficiency.

Ans: 32.5%

(2). Plate current in a diode is 10 mA, when a plate voltage is 100 volt operating in space charge limited region. what is the plate voltage necessary to double the plate current?

Ans: 158.7 volt

(4) Under space charge limited condition, the plate current in a diode is 100 mA with a plate voltage of 120 volt. Find the plate currents with the

plate voltages of 240 and 480 volts.

Ans: 283 mA, 800 mA.

P-N Junction

A P-N Junction can be prepared out of a crystal of Ge or Si by doping with pentavalent impurity atoms at one end and trivalent impurity atoms at the other end. The action of such a device is understood by connecting it into 2 different ways

(i) Forward biasing.

(ii) Reverse biasing.

Forward biasing

A P-N junction is said to be forward biased when the +ve terminal of the battery is connected to the P end of the P-N junction and -ve terminal of the battery is connected to the N end of P-N Junction.

The +ve plate repells the holes towards the junction layer whereas the -ve plate repels the electrons towards the same layer. As a result, the electrons occupy the holes and leave behind holes in the N-region.

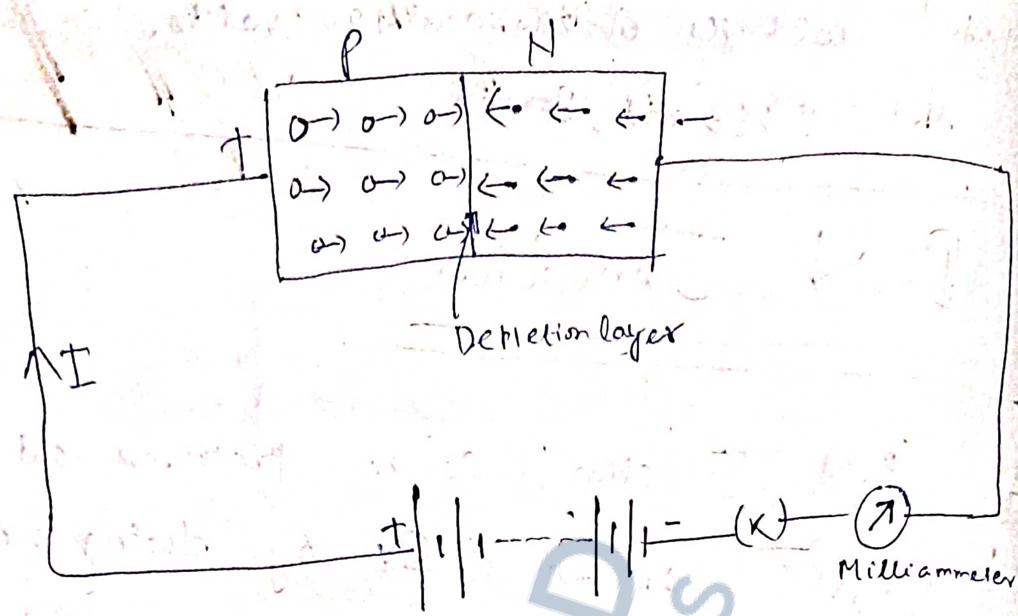


Fig-I

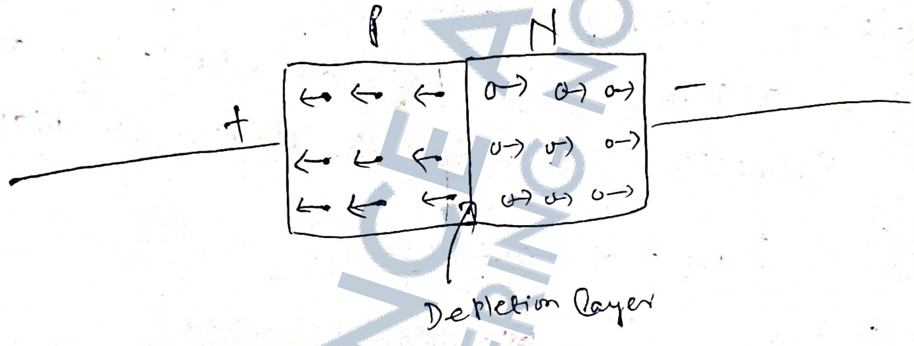


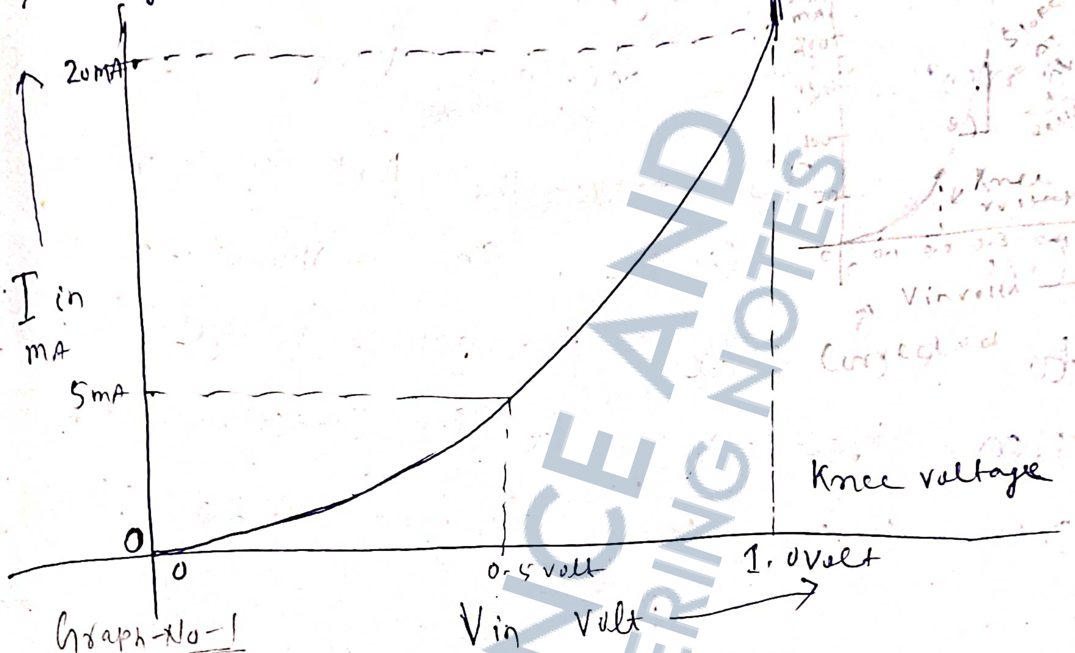
Fig-II Intermediate stage

This has been shown in fig (ii).

Ultimately the electrons are absorbed by the +ve Plate & holes are ~~ga~~ again left behind in the P-region. This is just the situation shown in fig (i). These ~~abso~~ absorbed electrons move to the battery and then towards the N-region where they occupy the places of the holes.

Again the process is repeated.

A small current of the ~~or~~ order of mA is produced. This current is small but very sensitive towards the small change of applied voltage. This is indicate in graph no 1. The voltage at which the current increases very sharply is called Knee voltage.

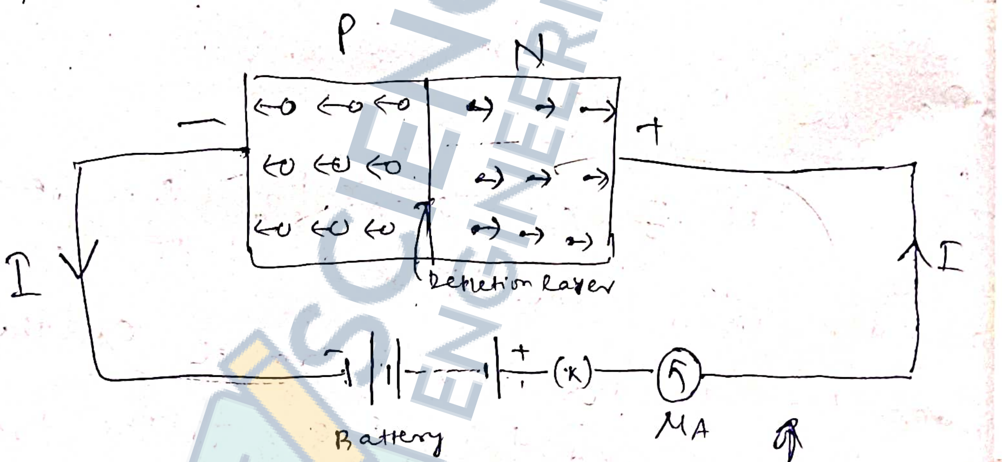


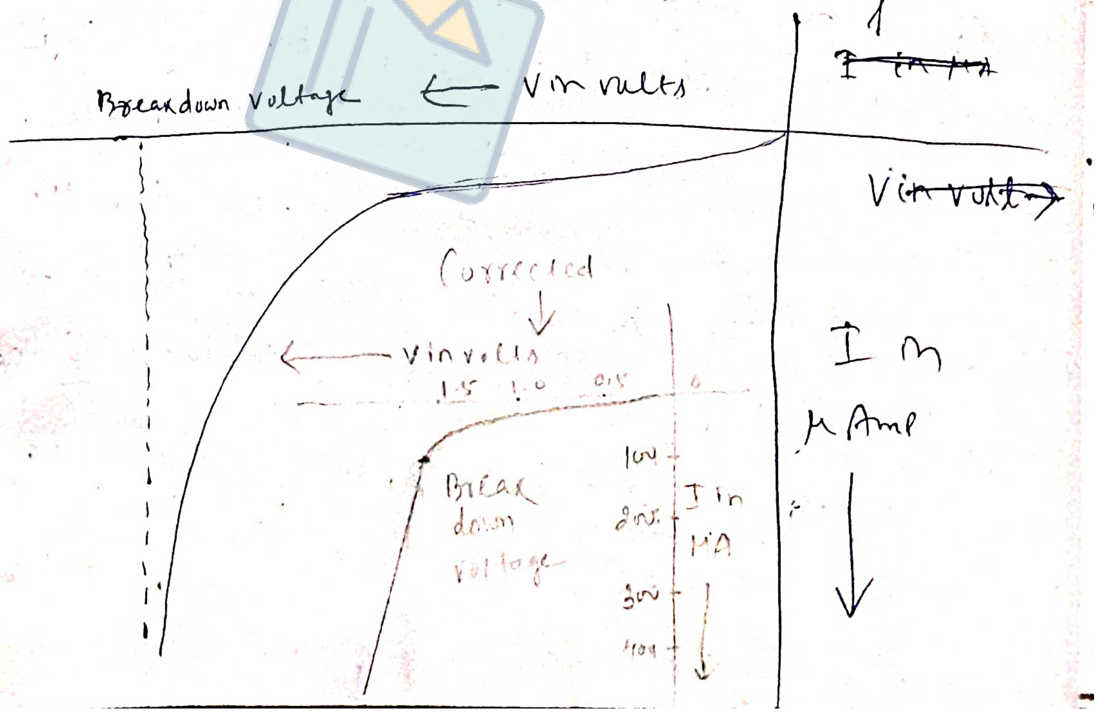
Graph-No-1

Reverse Biasing

The P-N Junction is said to be reverse biased when the P end of it is connected to the -ve terminal of the battery and the N end to the +ve terminal of the same battery. Due to the attraction of the -ve plate for the holes and +ve plates for the electrons, the holes and electrons are found to move away from one another. Since the electrons and holes have not combined, the flow is almost stopped. Only a very small current of the order of microamperes flows due to some ~~stra~~ stray electrons and holes (minority charge carrier) formed in the specimen. A current of a few μA flows till a voltage called <u>breakdown voltage</u> is reached. Beyond (further) this voltage, the current again increases very fast.

To make the P-N Junction act like a diode, care should be taken to see that the applied voltage is low. Then, practically the P-N Junction conducts only when it is forward biased ($\because I_{MAX}$ 1mA)





From the above discussion, we see that the P-N Junction conducts only when it is forward biased, provided the applied voltage is low. This is similar to that of a vacuum diode valve. For this reason, the P-N Junctions have almost replaced the vacuum diodes.

The advantages are

① P-N junction is very small in size

② It is much cheaper compared to vacuum diodes.

③ Operating voltage necessary for P-N junction is very small. Even a torch battery can do the work. (V = 1.5 V)

④ Unlike the vacuum diodes no extra heating device is necessary

P-N Junction as a half wave rectifier

We know that alternating voltage changes its sign twice during a complete cycle. When the voltage supplied to the P-N junction is +ve i.e the P end is connected to the +ve terminal of the battery & N-end is connected to the -ve terminal of the battery then the

+ve P end repels the holes and the -ve N end repels the electrons towards the junction layer. As a result, the electrons occupy the holes and they are absorbed by the +ve plate and a small current of the order of a few mAmperes is developed in the circuit. This current increases from 0 to a max^m and then decreases to zero during the +ve half cycle. During the -ve half cycle the P end becomes -ve and attracts the holes and N ends becomes +ve attracts the electrons. As a result holes & electrons do not combine and thus the current produced is of the order of a few μAmperes which can not be easily detected. A high resistance called Load resistance (R_L) of the order of Kilo ohm up to mega ohm is placed in the circuit. The output voltage can be derived from the two ends of this load resistance. In the graph no (1) the d.c output has been shown & we see that the output is discontinuous and fluctuating. Since there is unidirectional flow of electrons from the P-end towards the N-end, it is compared to a valve.

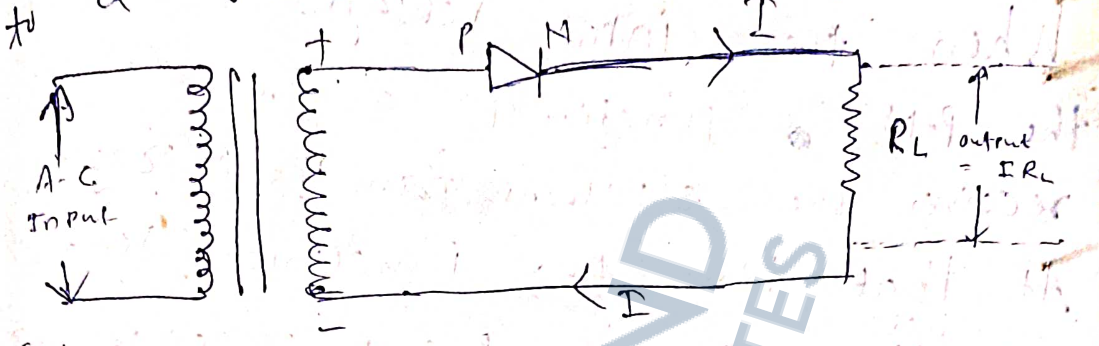
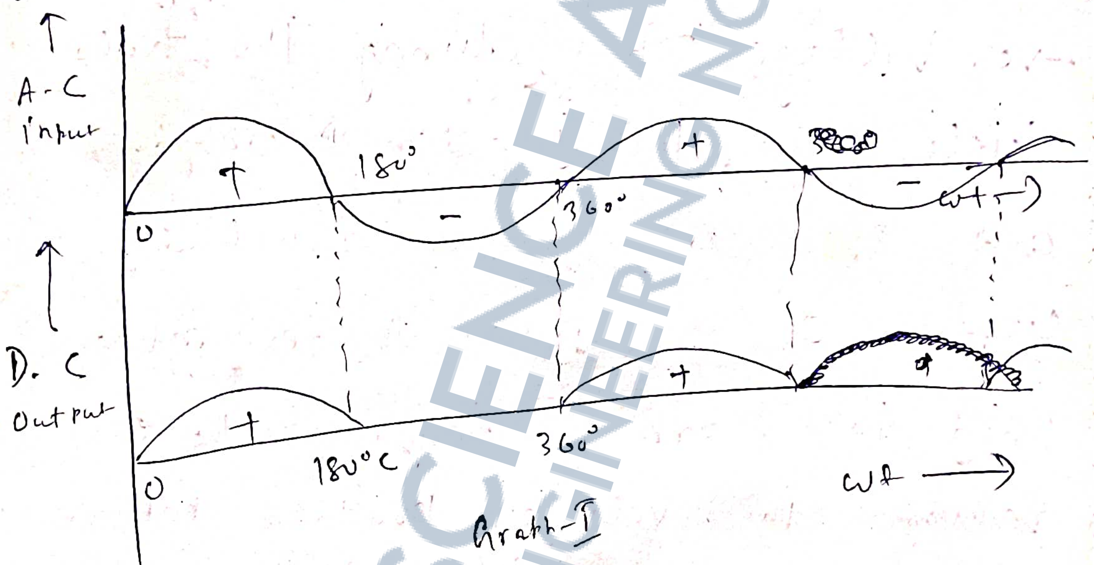


fig 1



Graph-I

Efficiency of rectification is defined as the ratio of d.c output power to the a.c input power and is shown at

$$\eta = \frac{0.406}{1 + \frac{r_p}{R_L}}$$

where r_p = Resistance of the p-n junction obtained as the reciprocal of the slope of the graph no 1. of the action of P-N junction

Since $r_p << R_L$, we can neglect the ratio $\frac{r_p}{R_L}$ compared to 1. Then

η = Efficiency = 0.406 = 40.6%

P-N junction as full wave rectifier

When the input voltage reaches the P-N junction (1) as +ve, it receives the electrons from the N-region. At that time P-N junction (2) remains inactive as its P-end receives -ve voltage. Thus, during the first half-cycle the P-N junction (1) only functions and produces a small fluctuating current of the order of few mAmperes. When this current flows over the load resistance, the voltage produced between the two ends can be tapped.

During the second half cycle, the P-N junction (2) becomes active whereas the P-N junction (1) remains inactive. As shown in fig (ii), the circuit has been prepared in such a manner that the direction of flow of current through the load resistance remains the same. And the output voltage is unidirectional yet fluctuating : But is Continuous.

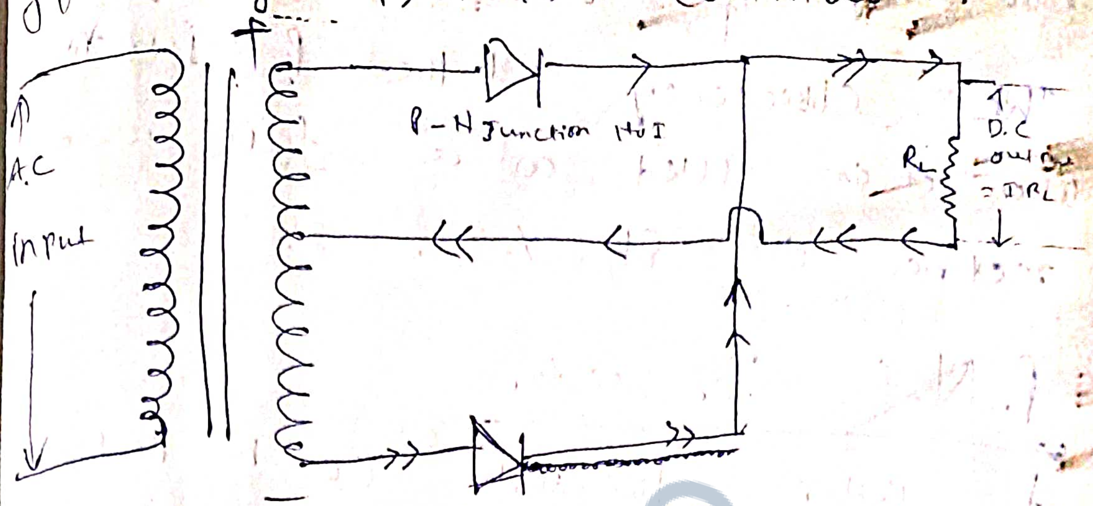


Fig (i)

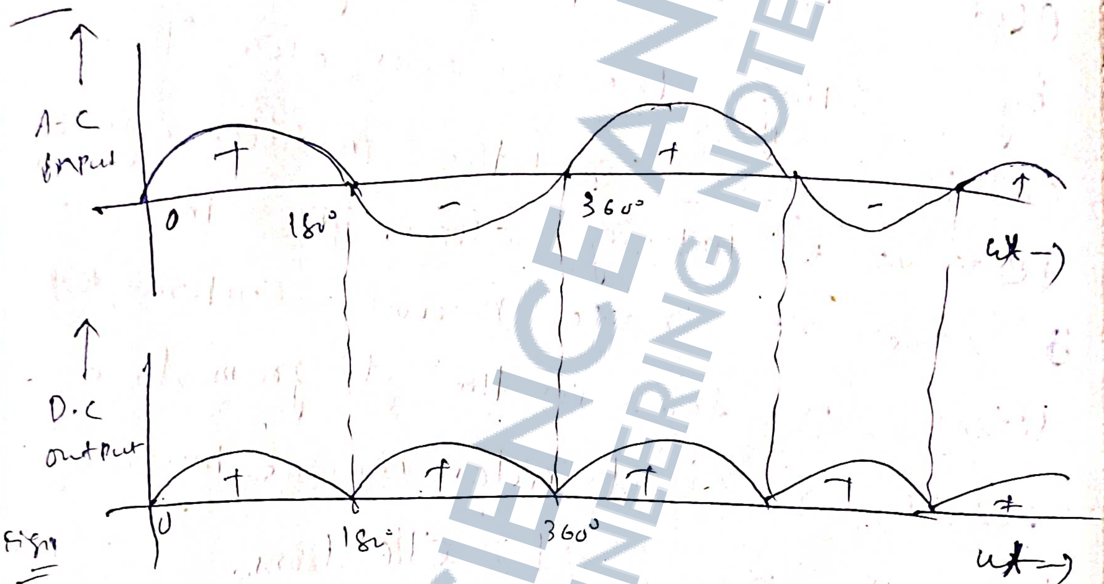


Fig (ii)

Rectification efficiency is defined as the ratio of d.c output power to the a.c input power and is shown as $\eta =$

$$\text{Efficiency} = \frac{0.812}{1 + \frac{r_p}{R_L}}$$

where r_p = Resistance of the P-N junction

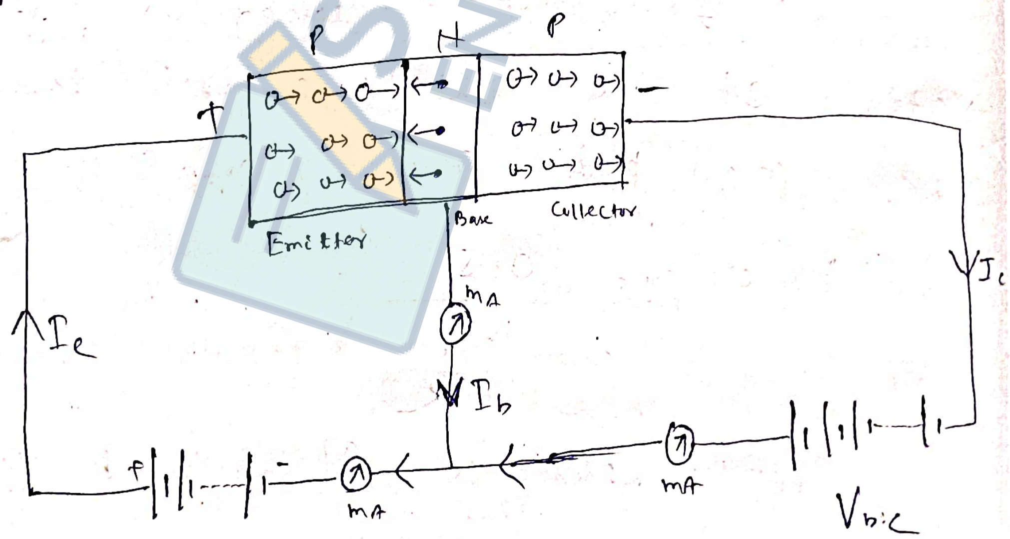
R_L = Load resistance.

Since $r_p << R_L$, then we can the ratio of $\frac{r_p}{R_L}$ as compared to 1, Then the

Efficiency, $\eta = 0.812$ i.e. 81.2%. Thus the efficiency of the P-N junction when it is used as a full wave rectifier is 81.2%.

P.N.P Transistor

A P-N-P transistor can be prepared out of a pure crystal of Ge or Si by doping the 2 ends with trivalent impurity atoms and the middle region by penta valent impurity atoms. The middle zone is made narrow compared to the 2 sides as shown in the diagram. As a result, no. of holes become much higher than the no. of electrons.

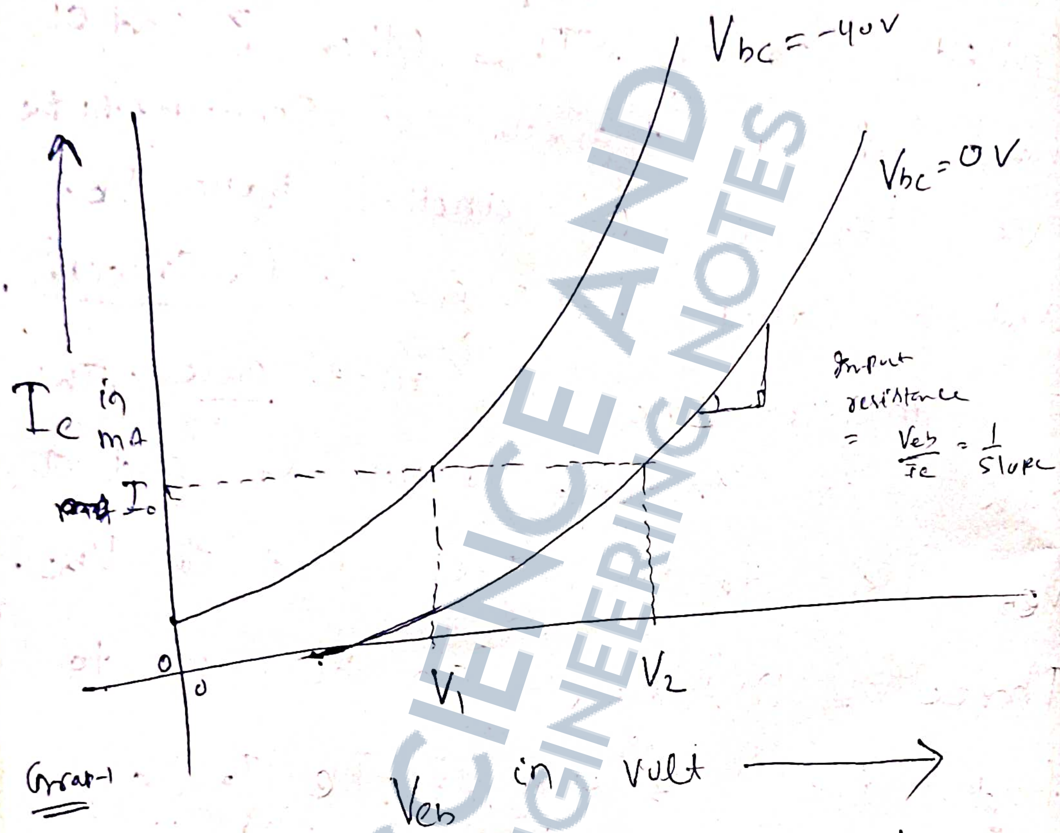


$$I_e = I_b + I_c$$

A P-N-P transistor thus formed can be regarded as a P-N junction connected in series with an N-P junction. To study the action of the P-NP transistor the P-end of the P-N Junction is Connected to the +ve terminal of a battery V_{eb}. i.e this P-N junction is forward biased and this P end is Called <u>emitter</u>. The other P end of the P-N-P transistor is Connected to the -ve terminal of another batter V_{bc} and we Called that P-end as the <u>Collector</u>. The middle zone is Called <u>base</u>. This base is Connected to the -ve end of V_{eb} and to the +ve end of V_{bc}. Three mili Ammeters Can be used to find the 3 Currents. I_e, I_b, I_c

Emitter is heavily doped to provide large number of charge carrier, base is lightly doped & thin it passes most of the emitter injected carriers to the collector. Collector is moderately doped.

<u>Action</u> → Since the emitter is Connected to the +ve terminal of a battery, the ~~what~~ holes of that end are pushed towards the base. The electrons of the base region are attracted towards the emitter. Hence they Combine, but no. of electrons is less Compared to the no of holes. Majority of the holes cross over ch to the Collector zone. The ~~less~~ electrons ~~back~~ reach the +ve end and get absorbed by the +ve plate. They move through the conducting wire upto the junction point, and some of them go towards the base while the others go towards the collector zone. These electrons will occupy the holes present in the base & collector zones.



Graph-1

Due to the flow of electrons through the conductors a current like I_b is produced on the base circuit and I_c along the collector circuit such that their sum equals to that of the emitter current I_e.

$$\therefore I_e = I_b + I_c$$. Obviously $I_c < I_e$

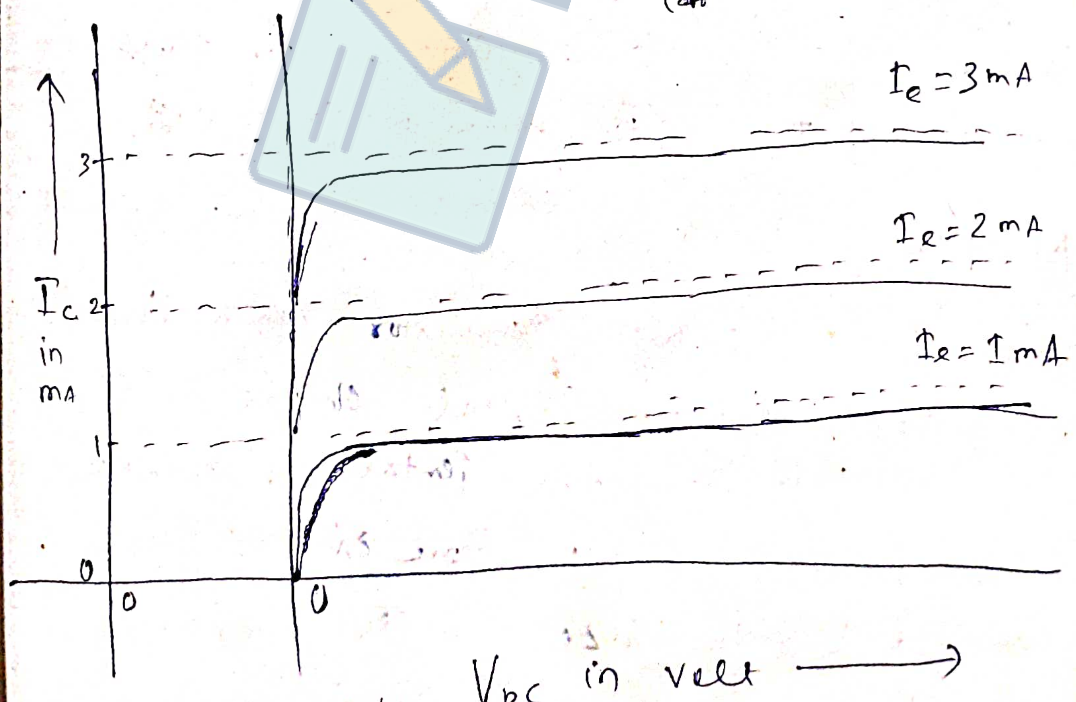
To sets of characteristic curves can be drawn for P-N-P and N-P-N transistors.

(i) I_e versus V_{eb} when V_{bc} is kept constant. or (I_c is kept constant)

(Input Characteristic Curves)

(ii) I_c verses V_{bc} when V_{eb} or I_e is kept Constant. (Output Characteristic Curves.)

As shown in graph no (i), the emitter current increases slowly with the increase of emitter base voltage (V_{eb}) when V_{bc} is made 0. On the other hand when V_{bc} is made... the emitter current increases very quickey with the change or V_{eb} when $V_{bc} = -40V$ (Say). If we draw a horizontal line // to x-axis for a constant current I_o, then it cuts the 2-curves at 2 different points. It indicates that voltage necessary to have I_o for $V_{bc} = -40$ volt is V_1 which is less than V_2 (at



Graph-2

(Voltage necessary for have same current I_E when $V_{bc} = 0$)

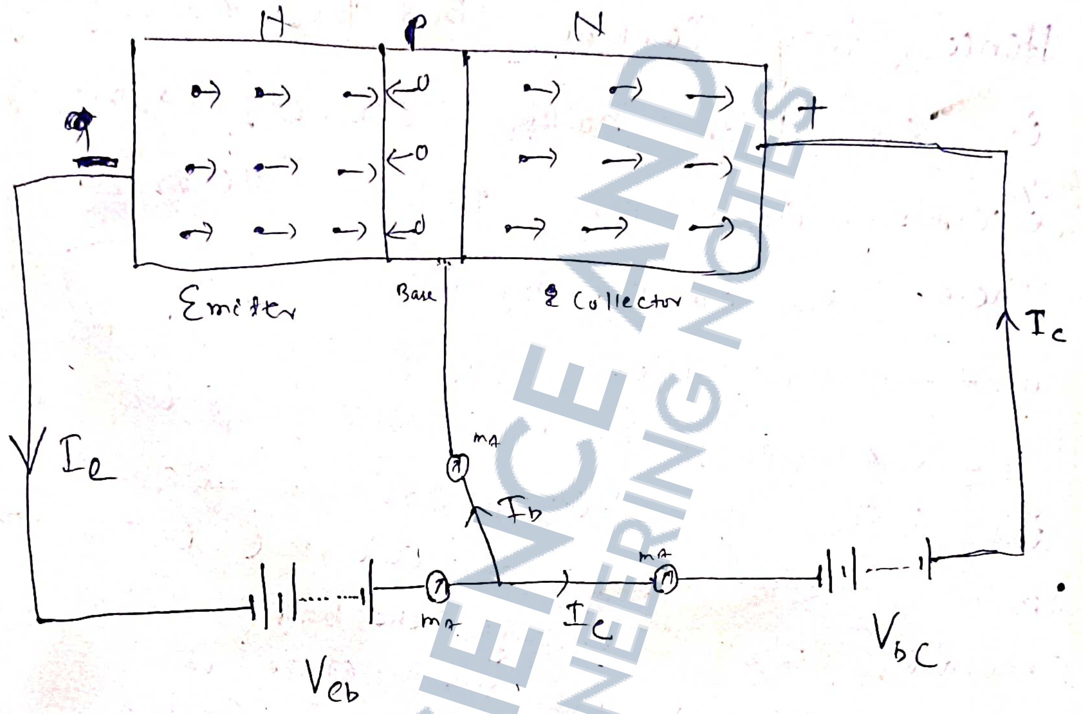
Input resistance can be found out as the ~~rat~~ reciprocal of the slope from the linear portion of the curves.

With the emitter current kept fixed the base collector voltage is to be gradually changed so that different collector currents are obtained. When this current plotted ~~...~~ along y-axis & V_{bc} along x-axis, a curve is obtained which ~~curve~~ is similar to the static characteristic curve of a diode value. Saturation stage is quickly raised. A set or similar curves are obtained for different values of I_e as shown in graph no(1).

N-P-N transistor

~~...~~ A N-P-N transistor can be prepared out of a pure crystal of Ge or Si by dopping the 2ends with pentavalent impurities atoms and the middle zone is made narrow compared to the size as shown in fig. As a result, no. of electrons becomes much higher them no of holes.

A N-P-N transistor thus formed can be regarded as a N-P junction connected in series with PN junction. To study the action of the N-P-N transistor the N end of the the N-P junction is



$I_e = I_b + I_c$

connected to the -ve terminal of a battery V_{eb}. i.e this N-P junction is forward biased. & this N end is called emitter.

The other N end of N-P-N transistor is connected to the +ve terminal of another battery V_{bc} and we called that N-end as collector. The middle zone is called base.

This base is connected to the -ve end of V_{bc} & +ve end of V_{eb}. Three ~~millimeters~~ milliammeters can be used to find the 3 currents I_e, I_b & I_c.

Action → Since the emitter is connected to the -ve terminal of the battery, the electrons of that end are pushed towards the base. The holes of the base are attracted towards the emitter. Hence they combine, but the no of holes is less than no of electrons. Majority (95%) electrons cross over to the collector zone. These are absorbed by the +ve plate. ~~They move through the conducting wire upto the junction point & some of them go towards the base while others go towards emitter.~~

About 5% electrons diverted to the external circuit through the base. The majority electrons come out of the -ve terminal of V_{CB} which moves towards emitter region. Then the process is repeated. Thus, current through the transistor is due to the motion of electrons from ~~collector to emitter~~ emitter to collector while conducting ~~which~~ current in the external circuit is due to motion of electrons from collector to emitter.

Form fig, we see that

~~Sum of~~ emitter current = Sum of base & collector current.

$$I_E = I_B + I_C$$

The characteristic curves are similar to p-n-p transistor.

30.11.21

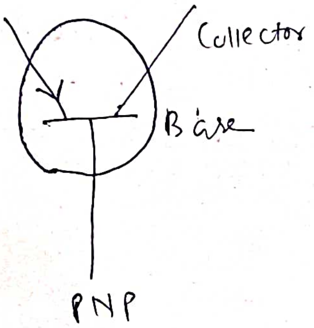
Types of transistor Connections

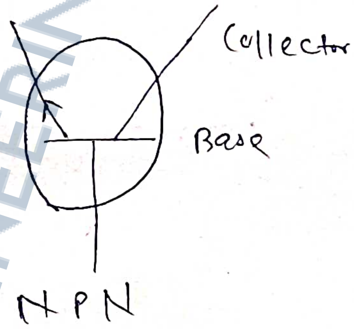
A transistor can be connected in 3 different ways.

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

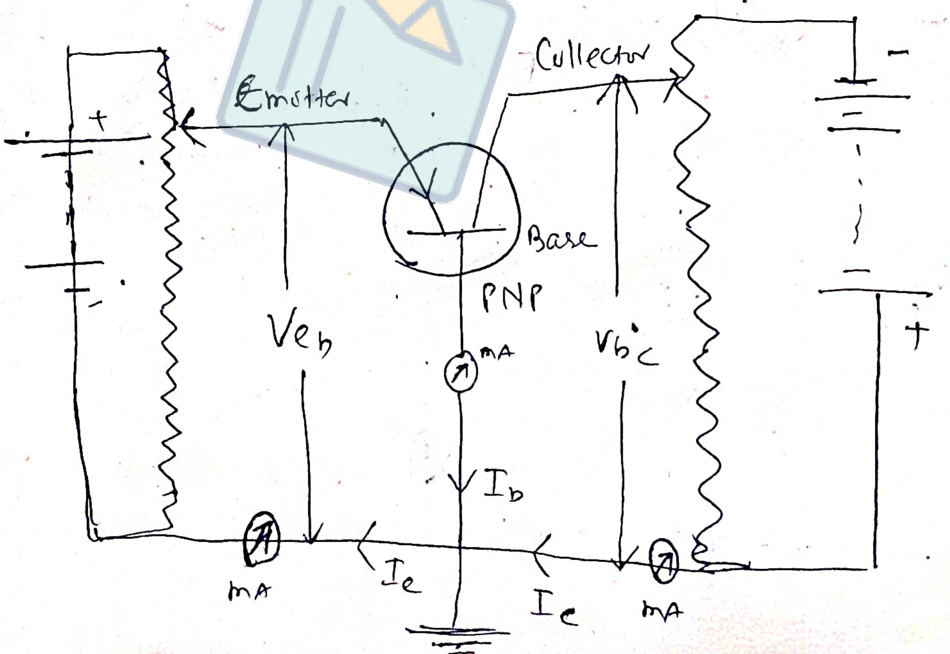
In all such connections, the emitter must be forward biased & collector must be reverse biased.

Symbols of transistors

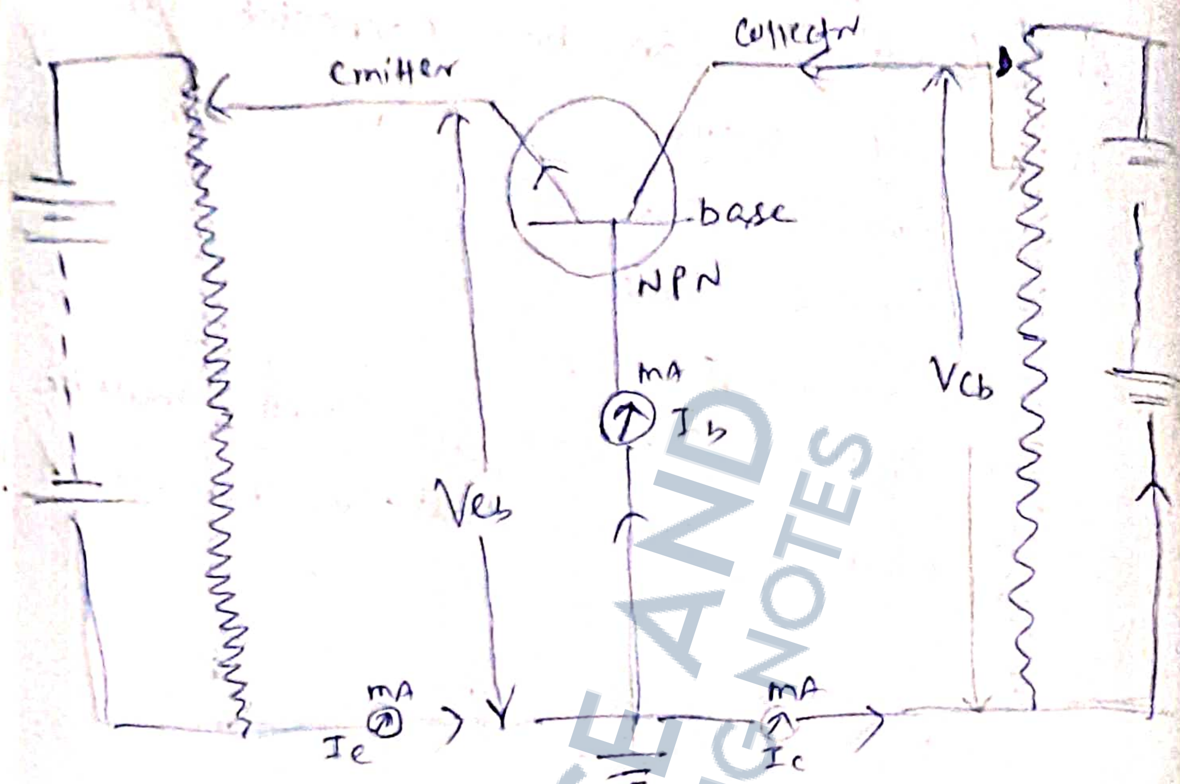




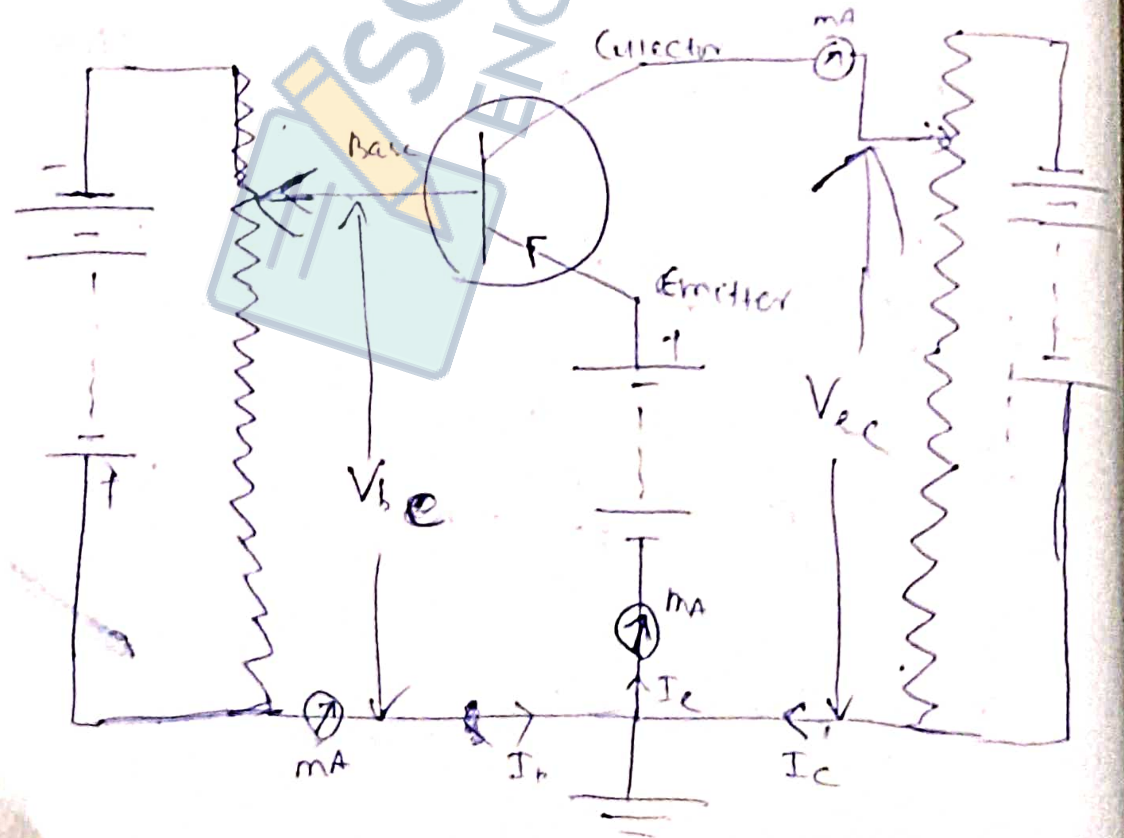
1(a) Common base PNP transistor connection



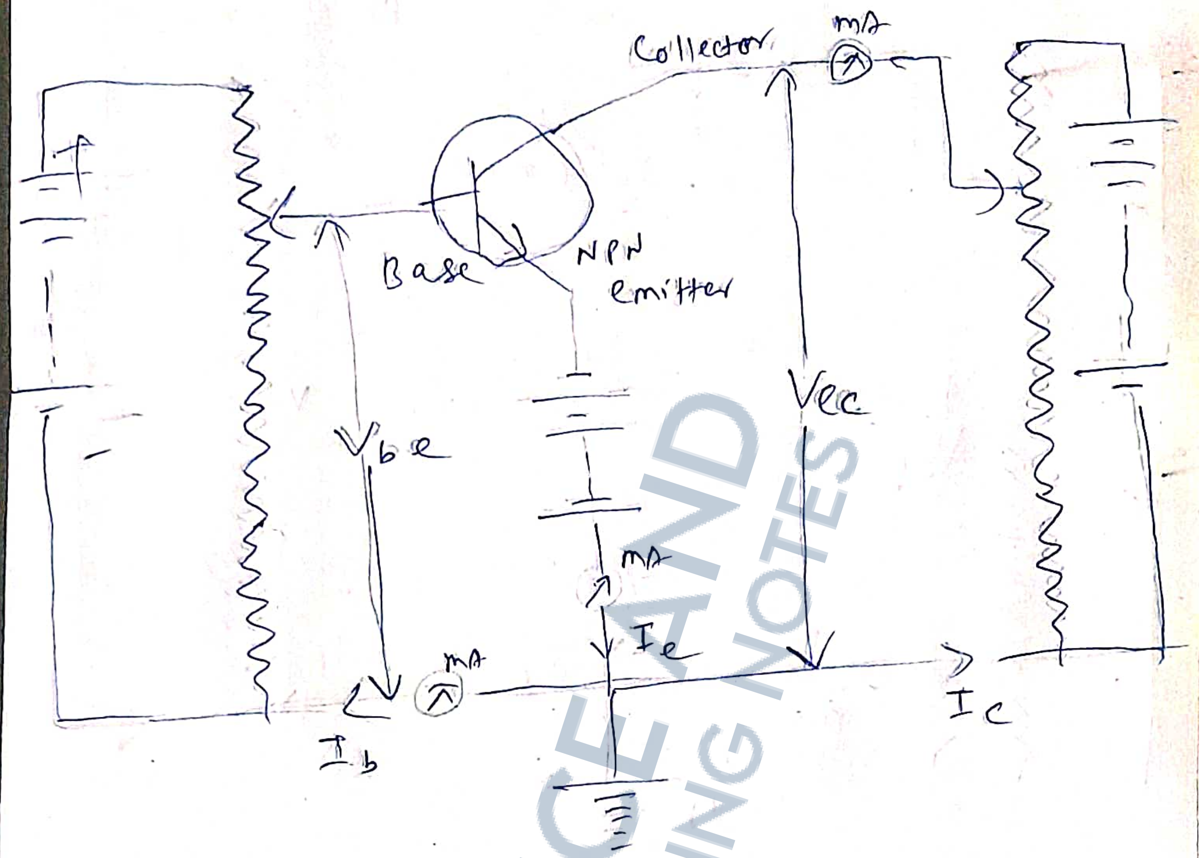
1 (b) Common base NPN transistor connection



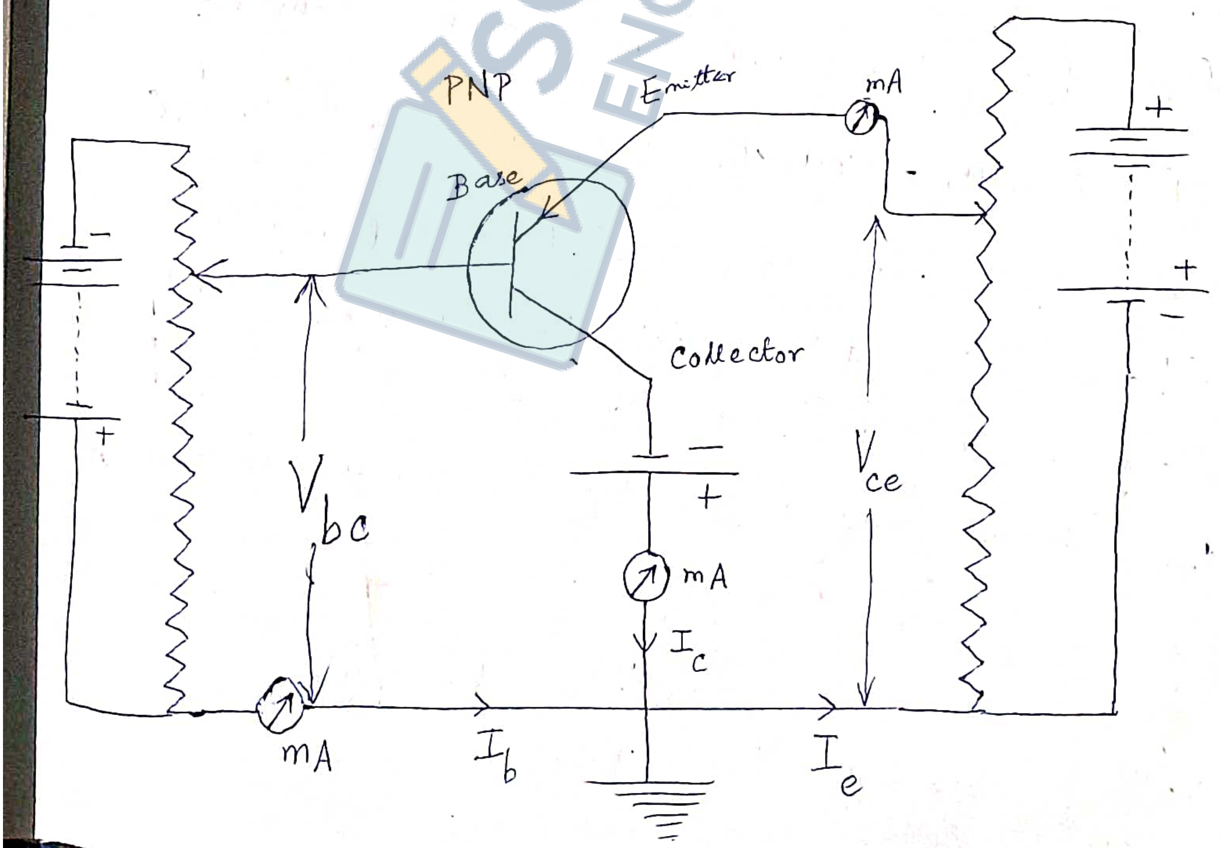
2 (a) Common emitter PNP transistor connection



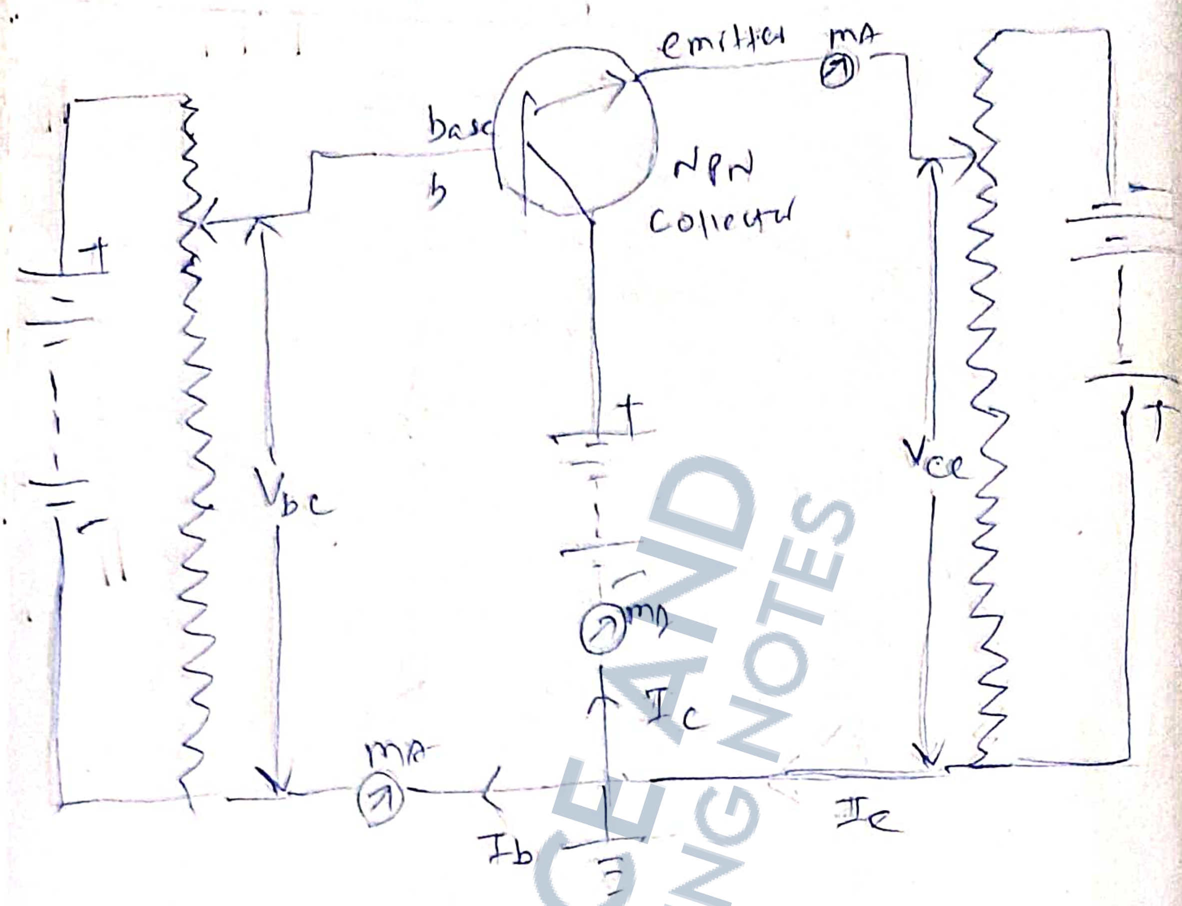
2(b) Common emitter NPN transistor Connection



3(a) Common Collector PNP transistor Connection



3 (b) Common collector NPN Connection.



Transistor Parameters

There are 3 different ways of connecting the transistors and accordingly 3 constants for the same transistor can be defined.

① Emitter - Collector Current gain factor (α)

It is defined as the ratio between the change in the collector current to the change in the emitter current when the base collector voltage is kept constant.

$$\therefore \alpha = \left(\frac{\Delta I_c}{\Delta I_e}\right)_{V_{bc}}$$

It is obtained from the common base type of transistor connection.

Its value ranges from 0.9 to 0.99.

(2) Base - Collector ~~Con~~ Current gain factor (β)

It is defined as the ratio between the change in collector current to the change in base current, ~~taken~~

$$\therefore \beta = \left(\frac{\Delta I_c}{\Delta I_b}\right)_{Vce}$$

It is obtained from the common emitter type of transistor connection. Its value ranges from ~~22~~ 20 to 500.

(3) Base - emitter current gain factor (γ)

It is defined as the ratio between the change in emitter current to the change in base current

$$\therefore \gamma = \frac{\Delta I_e}{\Delta I_b}$$

It is obtained from the common collector type of transistor connection.

Relation between α & β

For all types of transistor connections, we know that $I_e = I_b + I_c$

$$\Rightarrow \Delta I_e = \Delta I_b + \Delta I_c$$

Dividing both the sides of the above eqn by ΔI_e, we get

$$\Rightarrow 1 = \frac{\Delta I_b}{\Delta I_e} + \frac{\Delta I_c}{\Delta I_e} \quad \text{—(i)}$$

$$= \frac{\Delta I_b}{\Delta I_c} \cdot \frac{\Delta I_c}{\Delta I_e} + \alpha$$

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

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

Relation between α & γ

From eqn (i), we get

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

$$\Rightarrow 1 - \alpha = \frac{1}{\gamma}$$

$$\Rightarrow \gamma = \frac{1}{1-\alpha}$$

Relation Among α, β, γ

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

$$\Rightarrow \boxed{\beta = \alpha\gamma}$$

Problems

1. In a common base connection, $I_e = 1.5$ mA. Find I_b & I_c when the current amplification factor is 0.94.

Sol^n : Given $\alpha = 0.94$

$$\alpha = \frac{\Delta I_c}{\Delta I_e} = 0.94$$

$$\Rightarrow \frac{I_c - 0}{I_e - 0} = 0.94$$

$$\Rightarrow \frac{I_c}{1.5} = .94$$

$$\Rightarrow I_c = (1.5 \times .94)$$

$$= ~~2.31~~$$

$$= 1.41 \text{ mA}$$

$$I_b = I_e - I_c = 1.5 - 1.41 = 0.09 \text{ mA}$$

225 6
2310
.94 1.5 225 6
221 0
135

2. Find I_e when $\beta = 40$ & $I_b = 10\mu A$

$$\beta = \frac{\Delta I_c}{\Delta I_b}$$

$$\Rightarrow \beta = \frac{I_c - 0}{I_b - 0} = \frac{I_c}{10\mu A}$$

$$\Rightarrow 40 = \frac{I_c}{10\mu A}$$

$$\Rightarrow I_c = 400\mu A$$

$$I_e = I_b + I_c = 10 + 400 = 410 \mu A$$

(3) Find the value α β & γ when

(i) $\alpha = 0.9$

(ii) $\alpha = 0.98$

(iii) $\alpha = 0.99$

Ans ÷ (9, 10), (49, 50) (99, 100)

1) (i) $\beta = \frac{\alpha}{1-\alpha} = \frac{.9}{1-.9} = \frac{.9}{.1} = 9$

$\gamma = \frac{\beta}{\alpha} = \frac{9}{.9} = 10$

(ii) $\beta = \frac{\alpha}{1-\alpha} = \frac{.98}{1-.98} = \frac{.98}{.02} = 49$

$\gamma = \frac{\beta}{\alpha} = \frac{49}{.98} = 50$

(iii) $\beta = \frac{\alpha}{1-\alpha} = \frac{.99}{1-.99} = \frac{.99}{.01} = 99$

$\gamma = \frac{\beta}{\alpha} = \frac{99}{.99} = 100$.

(4) For a transistor in C-emitter connection the voltage drop across a collector load is 1.5 volt. The value of 1 KΩ of $\alpha = 0.96$. Find the value β, I_c, I_b & I_e.

Ans: 24, 1.5 mA, 0.06 mA, 1.56 mA

Ans: In common emitter connection

Voltage = 1.5 volt

$R_L = 1 k\Omega$

$$I_C = \frac{V}{R} = \frac{1.5}{1 \times 10^3} = 1.5 \times 10^{-3} = 1.5 \text{ mA (Ans)}$$

$\alpha = 0.96$

$$\Rightarrow \frac{\Delta I_c}{\Delta I_e} = 0.96$$

$$\Rightarrow \frac{I_c - 0}{I_e - 0} = 0.96$$

$$\Rightarrow \frac{1.5}{I_e} = 0.96$$

$$\Rightarrow I_e = \frac{1.5}{.96} = \frac{150}{96} = 1.56 \text{ mA (Ans)}$$

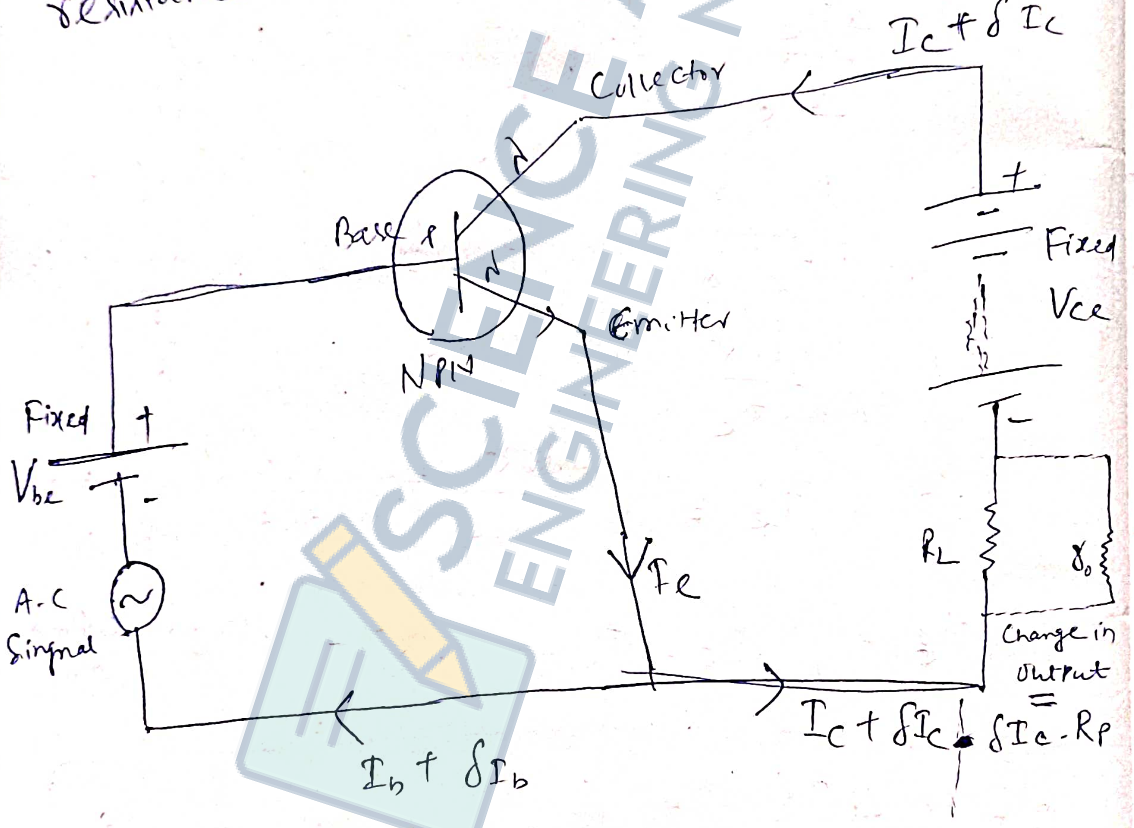
$$I_b = I_e - I_c = 1.56 - 1.5 = .06 \text{ mA (Ans)}$$

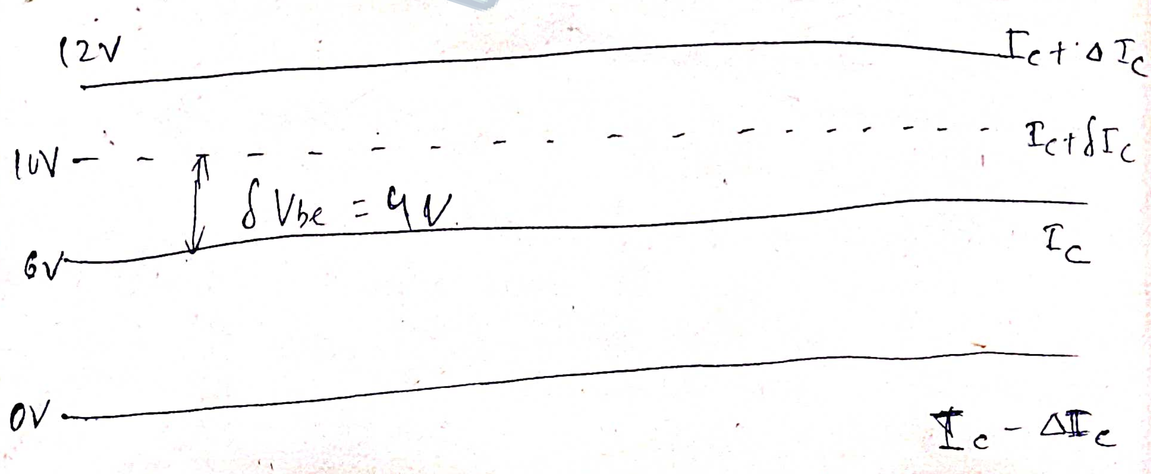
$$\beta = \frac{\Delta I_c}{\Delta I_b} = \frac{I_c - 0}{I_b - 0} = \frac{1.5}{.06} = \frac{150}{6} = 24$$

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.96}{1-.96} = \frac{.96}{.04} = 24 \text{ (Ans)}$$

Transistor as Amplifier

Lets take the case of an NPN transistor connected as common emitter in the circuit. Suppose, there is no A.C signal in the circuit. Due to fixed V_{be} & fixed V_{ce}, the currents in different branches will be fixed. Hence the output voltage derived from the 2 ends of the load resistance will be fixed like $I_c \cdot R_p$





where R_P = Equivalent resistance between R_L & r_0.

r_0 = Resistance of the output circuit.

$$\frac{1}{R_P} = \frac{1}{R_L} + \frac{1}{r_0}$$

$$\Rightarrow R_P = \frac{R_L r_0}{R_L + r_0}$$

Due to the introduction of the alternating small voltage (signal) represented by ~~e = Es~~ $e = 6 \sin\omega t$ (say), the net voltage between the base and emitter will change. To maintain the base at some +ve voltage, we must have a fixed V_{be} = 6 volt (Min^m Value)

At any instant of time, suppose the net voltage between the base and the emitter be 10 Volt.

$$\Rightarrow \delta V_{be} = 4 \text{ volt}$$

Due to δV_{be}, there will be a change in the base current as well as the collector current.

If δI_c be the change in the collector current, then the change in the output

$= \delta I_c \cdot R_r$

A_v = Voltage Amplification by the transistor

$= \frac{\text{Change in the output}}{\text{Change in the input}}$

$= \frac{\delta I_c \cdot R_r}{\delta I_b \cdot r_1}$

where δV_{be} = Change in the input voltage

$= \delta I_b \cdot r_1$

r_1 = Total resistance between the base & emitter.

$$\therefore A_v = \left(\frac{\delta I_c}{\delta I_b}\right) \cdot \left(\frac{R_L r_o}{R_L + r_o}\right) \cdot \frac{1}{r_1}$$

$$= \beta \cdot \left(\frac{R_L r_o}{R_L + r_o}\right) \cdot \frac{1}{r_1}$$

where β = ~~Bottom~~ Base - Collector Current gain factor

$= \frac{\Delta I_c}{\Delta I_b}$

$$\therefore A_v = \frac{\beta \cdot r_o}{r_1} \cdot \left(\frac{R_L}{r_o + R_L}\right)$$

$$A_v = \beta' \cdot \frac{R_L}{r_0 + R_L}$$

where $\beta' = \frac{\beta \cdot r_0}{r_i}$ = Dimensionless quantity.

This expression for the voltage amplification is very much similar to the corresponding expression due to a triode as an amplifier.

$$\left(A_v = \frac{\mu R_L}{r_p + R_L} \right)$$

In multistage amplifiers the output voltage from one amplifier is used as the signal voltage for the other amplifier. As a result the amplification becomes very large. We can write

$$(A_v)_{net} = (A_v)_1 \times (A_v)_2 \times (A_v)_3 \text{------}$$

Problems

In a common-emitter amplifier circuit $\beta = 60$, input resistance = 500 Ω & output resistance = 5000 Ω. What is the voltage gain (A_v) if $R_L = 10\,k\Omega$

(Ans = 400)

Ans:

$$A_V = \frac{\beta_0 r_0}{r_1}\left(\frac{R_L}{r_0 + R_L}\right)$$

$$= \frac{60 \times \cancel{5000}\,10}{\cancel{5000}}\left(\frac{10\times10^3}{5000 + 10\times10^3}\right)$$

$$= 600\left(\frac{\cancel{10^3}}{\cancel{10^3}}\left(\frac{10}{5+10}\right)\right)$$

$$= \cancel{600}^{40} \times \frac{10}{\cancel{15}}$$

$$= 400$$

Binding in solids

Compared to gaseous and liquid states, the atoms and molecules in a solid are more closely packed and they are held together by strong forces of attraction. These interatomic forces are basically electrostatic in nature. When atoms come closer and finally unite to form molecules, their electrons rearrange themselves in such a way as to achieve stable configuration. This rearrangement of electrons gives rise to different types of bonds which hold the atoms together in a solid state. The ~~principle~~ principal types of bonds in solid are,

1. Ionic or Electrovalent bonds
   Ex: NaCl, MgO, CaF_2
2. Covalent ~~bonds~~ or Homopolar bonds
   Ex: C, Si, Ge

3. Metallic bonds

Ex: Na, Al, Cu, Ag

4. Molecular bonds due to Vander-waal's force Ex → Solid Argon, solid Kr and solid Xe.

(1) Ionic bonds

This type of bonds are mainly formed in inorganic compounds like NaCl, KOH etc and never in pure elements. This type of bonds are very strong and develop between two atoms out of which one gives out an electron and other accepts it. i.e There is complete transfer of electrons from one atom to the other.

For example, let us discuss the formation of NaCl molecule. The electronic configuration of Na atom is $1s^2 2s^2 2p^6 3s^1$. It can lose one electron to become Na^+ ion. The electron configuration of Cl is $1s^2 2s^2 2p^6 3s^2 3p^5$. Hence Cl can accept the electron donated by Na and it will become Cl^- ion.

Now Na^+ and Cl^- will attract each other by strong electrostatic force of attraction (due to Colombs law)

Properties of Ionic solids →

Solids having ionic bonds have the following characteristic properties.

1. Crystal structure :- X-ray diffraction study has revealed that such solids have well defined crystalline structure. They are hard and brittle.

2. Melting & boiling points → Since, powerful electrostatic forces exist between the ions, considerable energy is required to overcome these forces. Hence ionic solids have high melting & boiling points.

3. Electrical Conductivity → Since free electrons are not available, ionic solids are insulator. However, in the fused state, some of the ions move and conductivity increases with the increase of temp.

4. Solubility →
Ionic solids are readily soluble in solvents like water & liquid Ammonia.

5. Ionic reaction → Ionic reactions are practically instantaneous. For ex, when $AgNO_3$ soln is added to NaCl or $BaCl_2$ etc, white ppt of AgCl is immediately formed.

Covalant bond →

A Covalant bond is formed when two similar or dissimilar atoms achieve stability by sharing valance electrons between themselves. The shared electrons become the common electrons of both the atoms. By this, the atoms achieve the noble gas configuration.

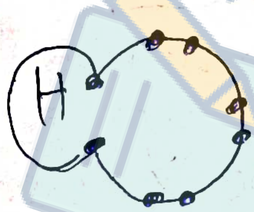
Ex :- 1 H_2 molecule formation.

H ×• H

or

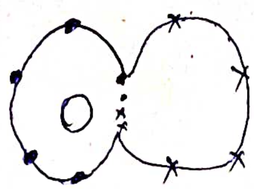
H—H

Ex-2 →



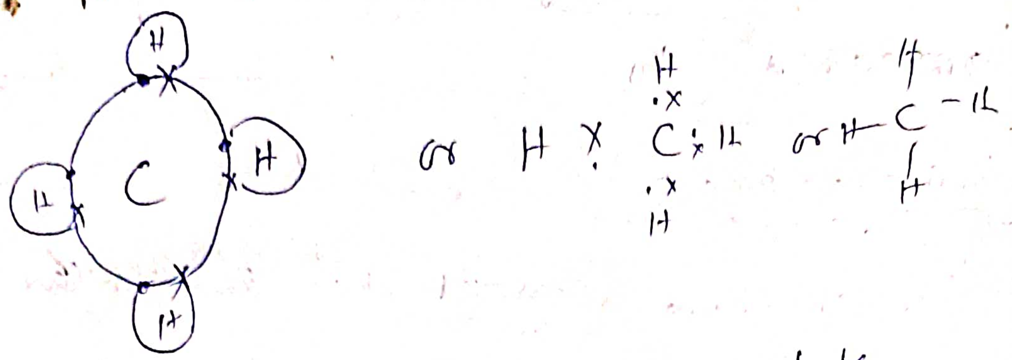
or H ×• Cl (with ×× electron pairs) or H—Cl

Ex- 2 O_2 molecule formation



or Ö :× Ö (with ×× electron pairs) or O = O

Ex-4 CH_4 molecule formation



The following additional points are to be noted.

1. Attainment of noble gas configuration is not essential.
2. The two electrons forming a pair must have opposite spin.
3. A covalent bond may be either polar or non polar depending on the fact whether the electron pair is shared unequally or equally between two atoms.

Properties of covalent bond

The characteristic properties are discussed below.

(1) **Physical state** → Covalent compounds may be solids, or gases. For ex → Cl_2 is gas, Br_2 is liquid & I_2 is solid at normal temp & pressure.

(2) **Crystal structures** → The following three types of covalent compounds are found.

(a) Covalent solids like sulphur and

Iodine possess molecules or atoms that are held together by weak forces. Hence they are soft & easily fusible.

(b) In the case of Diamond, the atoms are found to form giant molecules. Each 'C' atom forms 4 covalent bonds with four neighbouring atoms and these bonds from the corners of a regular tetrahedron. ($\theta = 109.5^0$ = Angle between two bonds)

(c) In the case of graphite, the 'C' atoms forms regular hexagons & layers of atoms ~~are found~~ between are found with weak forces adjacent layers. This is the cause of softness and lubricating action of graphite.

③ Melting & boiling points →

Since covalent bonds are ~~not~~ not that strong as the ionic bonds, covalent compounds have comparatively low M.P & B.P.

④ Electrical conductivity →

All covalent solids are basically insulators because free electrons are not available for conduction process. However, metals like Ge & Si are semiconductors & their conductivity increases with the increase of temp & introduction of impurity

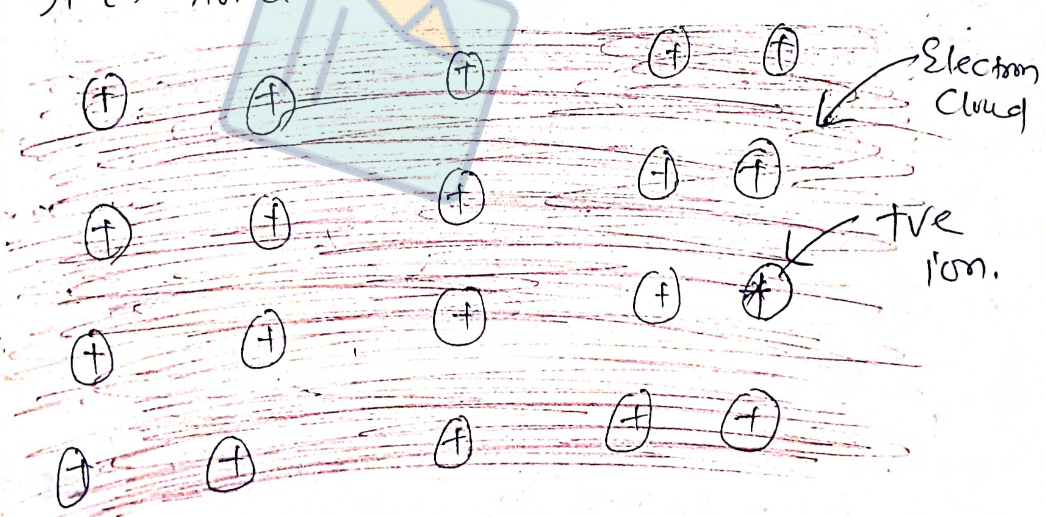
Atoms :

(5) Solubility →

Covalent compounds are soluble in non polar solvents like Benzene & CCl_4.

(3) Metallic bond →

When atoms or molecules unite to form a metal, the outermost electron of each atom or molecule gets detached from the parent atom and these electrons forms cloud of -ve charge called sea of electron. The ions are found at regular lattice points. The electron cloud present in between two +ve ions is ~~attached~~ attracted equally by the ions. The metallic bond is comparatively weaker than the ionic and covalent bonds. It is sometimes called unsaturated covalent bond.



Properties of Metal →

(1) They have crystalline structure.

(2) Since free electrons are available in plenty, the electrical conductivity is extremely high even at low temp.

(3) Since the metallic bonds are not very strong, metals have moderate to high melting temperatures

(4) Metals have high thermal conductivity due to electrons taking part in the conduction process.

(5) Since free electrons in a metal absorb light energy; all metals are opaque to light.

(4) Molecular bonds →

This type of bonds occure in those elements or compounds which have noble gas configuration.
Due to vanderwaal's forces, the ~~molecular~~ molecules attract each other with a weak force.
Only at very low temp, such solids are formed. Two such molecules have many attractive & repulsive forces, yet calculation shows that the net force is attractive (as shown by vanderwaal.)

Properties of molecular solids →

(1) Molecular structures can be both crystalline and non crystalline.

(2) These solids have low densities.

(3). Because of weak molecular bonds, such solids have low melting points.

4. Since free electrons are not available they are good insulators.

(5) They are usually transparent in nature

(6) They are soluble in both polar & nonpolar ~~solve~~ liquids.

26. 12. 2K

Crystal Structure

Solids are mainly of two types

1. Crystalline
2. Amorphous

X-ray diffraction by some solids Clearly shows that ~~three~~ there is ~~Perio~~ periodic arrangement of atoms or molecules & these are called Crystals.

Crystal Structure = Lattice + Basis

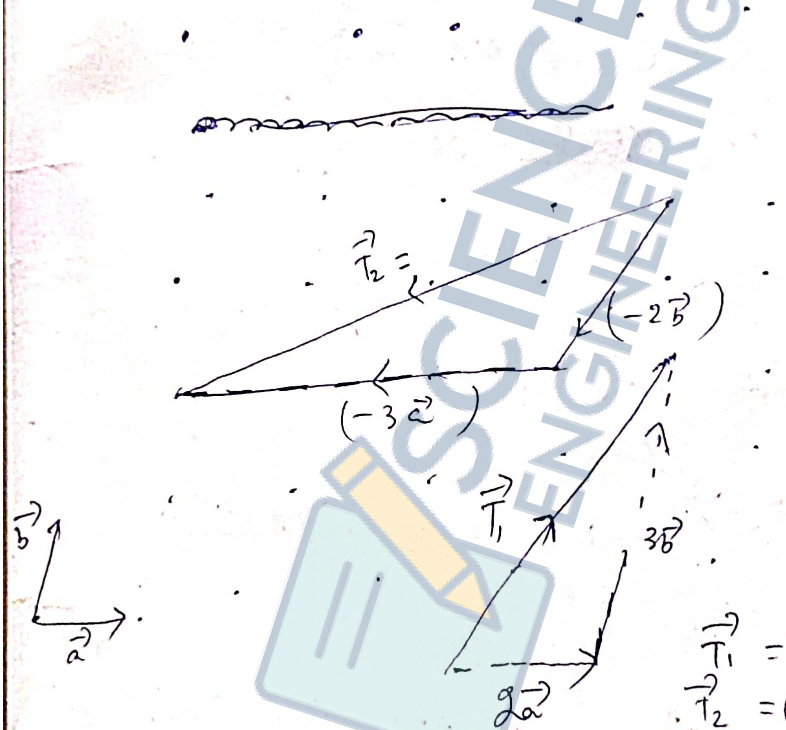
The internal design or arrangement scheme is called lattice. Where as the atom or groups of atoms placed at the regular lattice points is called basis.

EX → The NaCl molecule is found at the Corner of a Cube & also at the 6 face centres of NaCl Crystal.

In the case of amorphous solids there is no such orderliness found as in the case of crystals.

Ex-) Glass.

In this regard liquids can be compared with amorphous solids. But they (liquids) differ in having a definite boiling point & freezing point whereas amorphous solids donot possess such temperatures.



$$\vec{T_1} = 2\vec{a} + 3\vec{b}$$
$$\vec{T_2} = (-3)\vec{a} + (-2)\vec{b}.$$

Primitive translation vectors

In three ~~dimensional~~ dimension, there are three primitive translation vectors $\vec{a}, \vec{b}, \vec{c}$. Crystal structure is confirmed. It the vector joining any lattice point to another lattice point, called translation vector is of the form

$\vec{T} = n_1 \vec{a} + n_2 \vec{b} + n_3 \vec{c}$

where n_1, n_2, n_3 are integers (both +ve & -ve). In the diagram two dimensional translation vector have been shown.

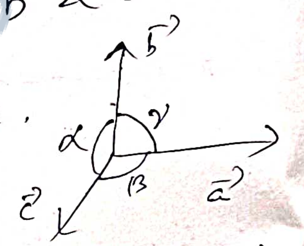
Types of Crystal Structures

Mainly there are seven types of crystal structures.

① **Cubic**, $a = b = c$, $\alpha = \beta, \gamma = 90^\circ$

where α = angle between $\vec{b}$ & $\vec{c}$,

Ex → NaCl, CaF_2 etc.



② **MonoClinic** → $a \neq b \neq c$, $\alpha = \beta = 90^\circ \neq \gamma$

Ex: $FeSO_4$, Na_2SO_4

③ **TriClinic** → $a \neq b \neq c$, $\alpha \neq \beta \neq \gamma = 90^\circ$

Ex → $CuSO_4$, $K_2Cr_2O_7$

④ **Tetragonal** → $a = b \neq c$, $\alpha = \beta = \gamma = 90^\circ$

Ex → $NiSO_4$, SnO_2

⑤ **Orthorhombic** → $a \neq b \neq c$, $\alpha = \beta = \gamma = 90^\circ$

Ex: $BaSO_4$, $MgSO_4$

⑥ **Trigonal** $a = b = c$, $\alpha = \beta = \gamma \neq 90^\circ$

Ex: $CuSO_4$

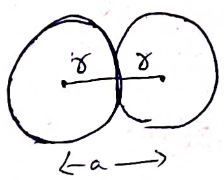
7. Hexagonal :- $a = b \neq c$, $\alpha = \beta = 90°$, $\gamma = 120°$

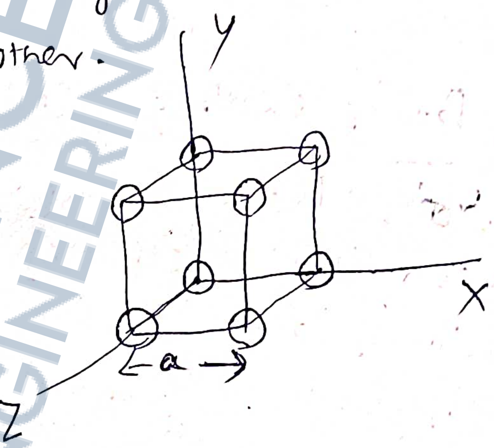
Ex → SiO_2, AgI

Cubic Structure →

There are 8 atoms at the 8 corner points of a unit cube of side length 'a'. But each atom is shared by 8 such cubes. Hence effectively there is only one atom in the unit cell. It is called Simple cubic structure.

For close packing of spheres, they should touch each other.





∴ atomic radius $= r = \frac{a}{2}$

Packing fraction is defined as the ratio of the volume actually occupied by atom or atoms present in a unit cell to the volume of the unit cell.

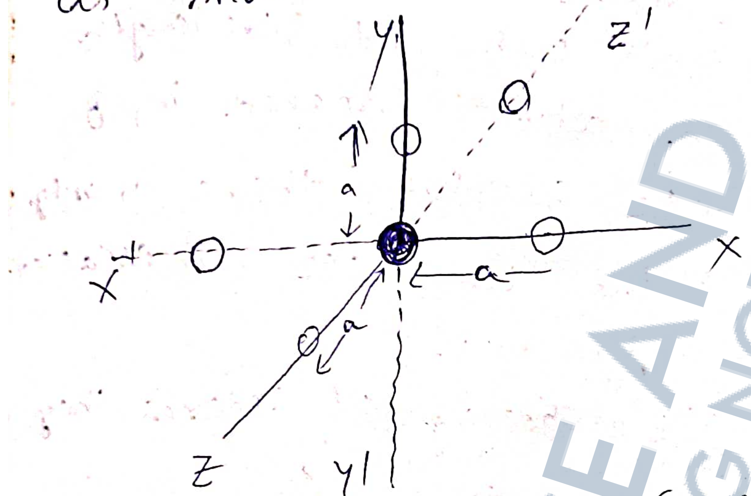
For S.C structure, $f = \frac{\frac{4}{3}\pi r^3}{a^3}$

$$= \frac{\frac{4}{3} \cdot \frac{22}{7} \cdot \left(\frac{a}{2}\right)^3}{a^3} = \frac{88}{21} \times \frac{1}{8} = \frac{11}{21} = 0.523$$

$= 52.3\%$. This shows that a lot

of empty space exist inside the solid.

Co-ordination Number is defined as the number of nearest neighbours of an atom. It is 6 for SC Structure as shown below.



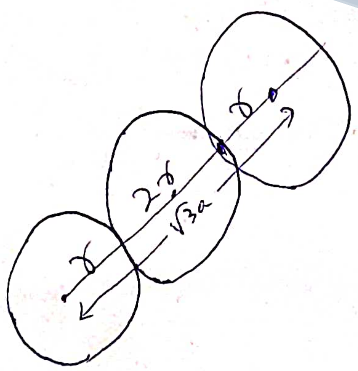
Body Centred Cubic (BCC)

If there is one atom at the centre of each unit cell in addition to the 8 atoms at the 8 corners points, a BCC Crystal is formed.

Number of atoms in a unit cell

$= \left(\frac{1}{8} \times 8\right) + 1 = 2$

For closest packing of spheres, they must touch along the diagonal.



packing fraction

$= f = \frac{\text{Volume of two atoms in the unit cell}}{\text{Volume of the unit cell}}$.

$$= \frac{2 \cdot \frac{4}{3}\pi r^3}{a^3} = \frac{\frac{2}{3} \cdot \frac{4}{3} \cdot \pi \cdot \left(\frac{\sqrt{3}a}{4}\right)^3}{a^3}$$

$$= \frac{\frac{8}{3} \cdot \pi \frac{3\sqrt{3}\,a^3}{4 \times 16}}{a^3} = \frac{2 \times \frac{22}{7} \times 1.732}{16}$$

$$= .6804 = 68.04\%.$$

Co-ordination number → (8) Because the body centres are nearest to the atom at any corner point ($\sqrt{3}\frac{a}{2} = 0.866a < a$)

Face centred cubic (FCC) →

In addition to the 8 atoms at the 8 corner points, there are 6 atoms present at the 6 face centres.

Hence no of atoms in the unit cell

$$= \left(\frac{1}{8} \cdot 8\right) + \left(\frac{1}{2} \cdot 6\right) = 1+3 = 4$$

For closest packing of spheres, they must touch along the face diagonal.

$$\therefore 4r = \sqrt{2}\,a$$

$\therefore$ atomic radius $= r = \frac{\sqrt{2}}{4}a$

Packing fraction $= \frac{\text{Volume occupied by 4 atoms in the unit cell}}{\text{Volume of unit cell}}$

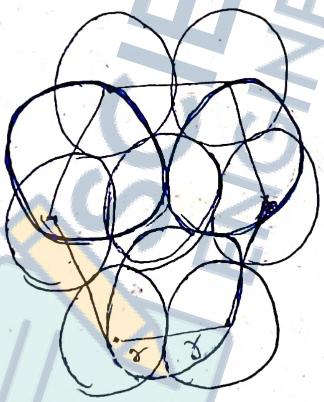
$$= \frac{4 \times \frac{4}{3}\pi r^3}{a^3} = \frac{4 \times \frac{4}{3}\pi \left(\frac{\sqrt{2}a}{4}\right)^3}{a^3}$$

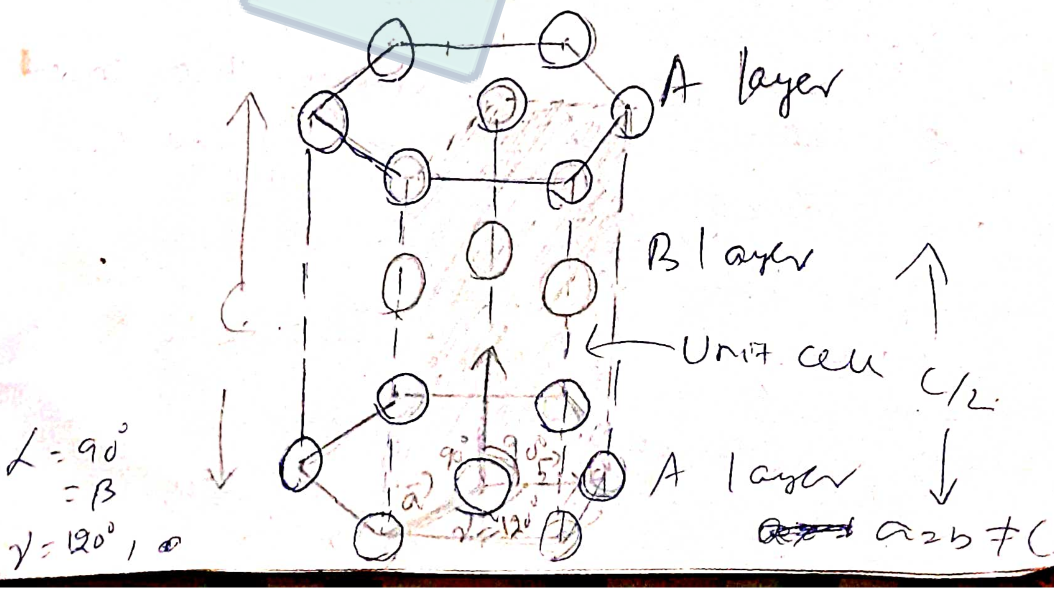
$$= \frac{11 \times 1.414}{21} = .7406 = 74.06\ \%$$

Co-ordination no = 12 (Because the face centred atoms are the nearest neighbours)

Hexagonal Close packed structure (HCP)

Here the arrangement of atoms is like AB, AB, AB ---- . The unit cell (where repetition gives the crystal structure) is a rhombus as shown in the 2nd diagram.





Atomic radius $= r = \frac{a}{2}$

Volume of the unit cell = Base area × Height

$= \left(\frac{\sqrt{3}}{4} a^2 - a\right) \cdot c$

$= \frac{\sqrt{3}}{2} a^2 c$

Number of atoms in the unit cell

$= \left(\frac{1}{8} \times 8\right) + 1 = 1+1 = 2$

∴ packing fraction = f = Volume of two atoms in the unit cell / Volume of the unit cell

$= \frac{\frac{4}{3}\pi r^3 \times 2}{\frac{\sqrt{3}}{2} a^2 c} = \frac{\frac{4}{3}\pi\left(\frac{a}{2}\right)^3 \cdot 2}{\left(\frac{\sqrt{3}}{2}\right) a^2 c}$

$= \frac{\frac{8}{3} \cdot \frac{11}{7} \cdot \frac{a^3}{8}}{\frac{\sqrt{3}}{2} a^2 c} = \frac{44a}{21} \times \frac{1}{\sqrt{3}\, c} = \frac{44}{21\sqrt{3}} \times \frac{a}{c}$

But $\frac{c}{a}$ ratio $= \frac{2\sqrt{2}}{\sqrt{3}}$

∴ f = packing fraction $= \frac{44}{21\sqrt{3}} \times \frac{\sqrt{3}}{2\sqrt{2}}$

$= \frac{22\sqrt{2}}{21 \times 2} = \frac{11 \times 1.414}{21}$ (11, 0.202, 3)

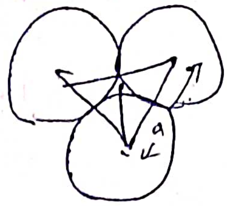
$= 0.7406 = 74.06\%$

Problems →

1. Prove that $\frac{c}{a} = \frac{2\sqrt{2}}{\sqrt{3}}$ for hcp structure.

Ans. Height of the triangle h

$= \frac{\sqrt{3}}{2} a$



$x = \frac{2}{3} h = \frac{2}{3} \cdot \frac{\sqrt{3}}{2} a = \frac{a}{\sqrt{3}}$

Since B layer of atoms touch the A- layer on the sides, we can apply pythagoras theorem.

$a^2 = \left(\frac{c}{2}\right)^2 + x^2$

$\Rightarrow a^2 = \frac{c^2}{4} + \left(\frac{a}{\sqrt{3}}\right)^2$

$\Rightarrow a^2 = \frac{c^2}{4} + \frac{a^2}{3}$

$\Rightarrow a^2 - \frac{a^2}{3} = \frac{c^2}{4}$

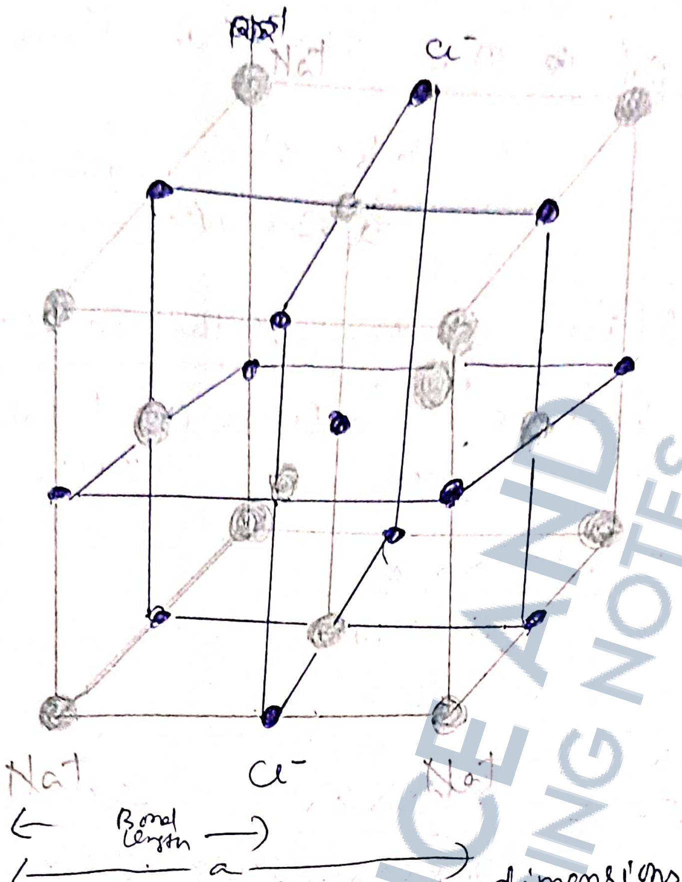
$\Rightarrow \frac{2a^2}{3} = \frac{c^2}{4}$

$\Rightarrow \frac{\sqrt{2}\, a}{\sqrt{3}} = \frac{c}{2}$

$\Rightarrow \frac{c}{a} = \frac{2\sqrt{2}}{\sqrt{3}} = \frac{2 \times 1.414}{1.732} = 1.632a$

~~$\Rightarrow \frac{a}{c} = \frac{\sqrt{3}}{2\sqrt{2}}$~~

NaCl Structure →



Calculation of the dimensions of a unit cell →

The dimension of the unit cell or the interatomic distance in a crystal lattice can be calculated from the knowledge of molecular weight (M) or atomic weight (A), Avogadro Number (N_0), density of the material (ρ) and number of atoms or molecules in the unit cell (n)

Ex → 1 BCC Crystal

In the α - iron crystal, there are two atoms of iron in the unit cell. Atomic weight = A = 55.85, density of iron = 7.86 gm/c.c

Number of atoms of iron present in

55.85 gm = N_0 = 6.023×10^{23}

∴ Mass of one atom of Iron

$$= \frac{55.85}{6.023 \times 10^{23}} \text{ gm}$$

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{\text{Mass of the unit cell}}{\text{Volume of the unit cell}}$$

$$7.86 = \frac{\frac{2 \times 55.85}{6.023 \times 10^{23}}}{a^3}$$

$$\Rightarrow a^3 = \frac{2 \times 55.85}{7.86 \times 6.023 \times 10^{23}} = \left(\frac{20 \times 55.85}{7.86 \times 6.023}\right) \times 10^{-24} \text{ c.c}$$

$$\Rightarrow a = \left(\frac{20 \times 55.85}{7.86 \times 6.023}\right)^{\frac{1}{3}} \times 10^{-8} \text{ cm.}$$

∴ $a = 2.87 \times 10^{-8}$ cm = 2.87 A°

Formula

$$\rho = \frac{\frac{n \cdot A}{N_0}}{a^3}$$

$$\Rightarrow \boxed{a^3 \rho = \frac{nA}{N_0}}$$

Example → 2

Molecular weight of NaCl = 23 + 35.5 = 58.5

Number of molecule in the unit cell

n = 4

Density $= \rho = 2.18$ gm/c.c

Number of molecules of NaCl present in 58.5 gm $= 6.023 \times 10^{23}$

Mass of one molecule of NaCl

$$= \frac{58.5}{6.023 \times 10^{23}} \text{ gm.}$$

Density

$$= \frac{\text{Mass}}{\text{Volume}} = \frac{\text{Mass of the unit cell}}{\text{Volume of the unit cell.}}$$

$$2.18 = \frac{4 \times \frac{58.5}{6.023 \times 10^{23}}}{a^3}$$

$$\Rightarrow a^3 = \frac{4 \times 58.5}{2.18 \times 6.023 \times 10^{23}} = \left(\frac{40 \times 58.5}{2.18 \times 6.023}\right) \times 10^{-27} \text{ c.c}$$

$$\Rightarrow a = \left(\frac{40 \times 58.5}{2.18 \times 6.023}\right)^{\frac{1}{3}} \times 10^{-8}$$

$$= 5.63 \times 10^{-8} \text{ cm}$$

$$= 5.63 \text{ A}^{\circ}$$

$\therefore$ Bond length $= \frac{a}{2} = \frac{5.63}{2} = 2.815 \text{ A}^{\circ}$.

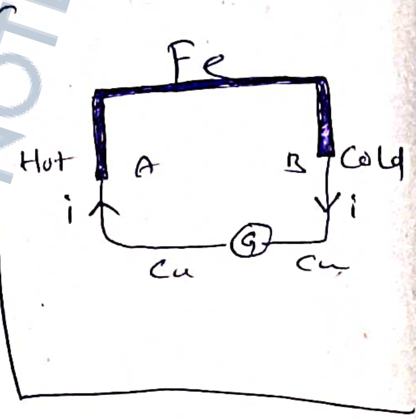
Formula

$$\rho = \frac{nM}{N_0} / a^3 \Rightarrow a^3 \rho = \frac{nM}{N_0}$$

See-beck effect

A thermo-couple is constituted by a pair of metals (copper-iron, bismuth-antimony, etc) with their ends fused into one another. The soldered ends are called junctions of the thermo-couple.

Consider two rods, one of iron and another of copper, having common junction A & B. A Galvanometer G is also connected in the circuit (As shown in figure). Since there is no source of emf in the circuit, therefore the Galvanometer shows no deflection.



Now if one of the junctions is heated keeping the other cold, the galvanometer gives deflection indicating an electric current starts flowing through the circuit. This current is called

Thermo electric current.

The phenomenon by virtue of which a thermo electric current is generated in the circuit comprising of two different metals, when two junctions are maintained at a difference of temp. is known as **seebeck effect** or thermo electric effect.

The e.m.f generated is known as - thermo e.m.f hot Copper → At the hot junction, current flows from → Copper to Fe

In Cold junction current from → Fe to Cu.

In Bi and Sb.

In hot junction → Bismuth to Sb

In Cold junction → antimony to Bismuth.

Bi - Sb thermo ~~couple~~ emf > Cu - Fe thermo emf