UNIT-I

INTRODUCTION.

Introduction:

* Poor lighting results in dangerous effects like eye strain, headaches, accidents due to insufficient lighting or to glare.

* In past human beings passed most of their time out of doors and their lighting needs were provided by nature.

* Today most of time spend in buildings where artificial lighting plays an important role.

* Good lighting reduces accidents increases the production in factories, improves the health of the community due to reduction of eye strain.

* Everywork which can be done in day-light can equally be done during night time with same efficiency.

* Too bright lights may not be confused as good illumination because it may caus

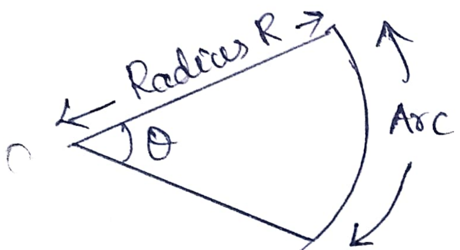
Definitions:

1. Plane Angle:

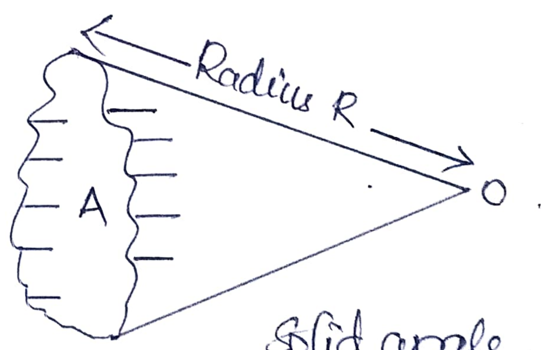
A plane angle is subtended at a point and is enclosed by two straight lines lying in the same plane.

* It is denoted by the greek letter θ.
* It is measured in degrees or radians.

$$\text{plane angle } (\theta) = \frac{\text{arc}}{\text{radius}}$$



Plane angle



Solid angle.

2. Solid angle:

Solid angle is the angle subtended at a point in space by an area i.e. the angle enclosed in the volume formed by numerous lines lying on the surface and meeting at the point.

$$\text{Solid angle } (\omega) = \frac{\text{area}}{(\text{radius})^2}$$

Eg: Largest solid angle subtended at the centre of sphere.

$$\omega = \frac{\text{area of sphere}}{(\text{radius})^2} = \frac{4\pi r^2}{R^2} = 4\pi$$

$$= 4\pi. \text{ steradians.}$$

Relation between plane angle & Solid angle:

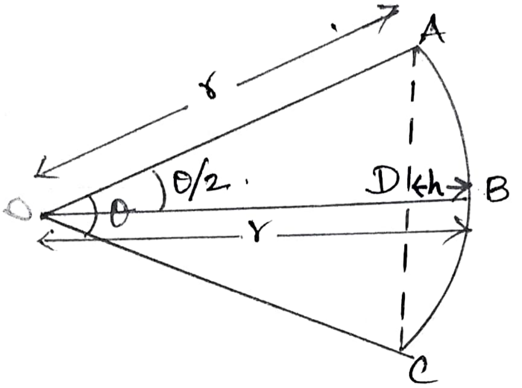


Fig (1).

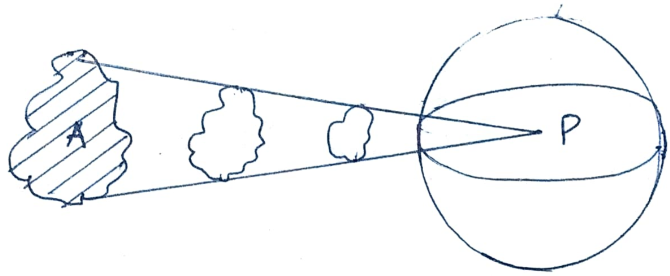
In fig (2)
Consider an area A relative to a point P. If all points on the boundary of the area A are joined to P, a cone like shape is formed at P. and the angle subtended by the area A at P is known as the solid angle.

Let P represent the centre of sphere. There will be a boundary of intersection where the solid angle subtended by area A passes through the sphere.

$$\text{Solid angle subtended by area 'A'} = \frac{\text{Area of intersection at sphere surface}}{(\text{Radius of sphere})^2}$$

$$= \frac{4\pi r^2}{r^2}$$

$$= 4\pi.$$



Let the segment ABC subtend a solid angle of ω and the lines OA and OC subtend a plane angle θ at the centre 'O' of the circle.

$$\omega = \frac{\text{Surface area of segment ABC.}}{r^2}$$

$$= \frac{2\pi r h}{r^2}$$

$$= \frac{2\pi h}{r}.$$

From fig (1).

From Δ ODA, $OD = r\cos\theta/2.$

$\left[\cos\theta = \frac{adj}{hyp}\right]$

$\left(\cos\theta/2 = \frac{OD}{r}\right)$

$$OD = r - h$$

$$\therefore \quad r - h = r\cos\theta/2$$

$$\frac{r-h}{r} = \cos\theta/2.$$

$$r(1-\cos\theta/2) = h.$$

Subs ( ) in ( )

$$\omega = \frac{2\pi r(1-\cos\theta/2)}{r}$$

$$\omega = 2\pi\left(1-\cos\frac{\theta}{2}\right).$$

Luminous Intensity: (I)

Luminous intensity in a given direction is defined as the luminous flux emitted by the source per unit solid angle.

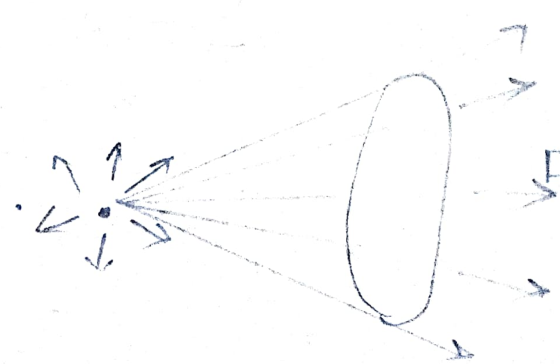
Measured in candela.

$$\boxed{I = \frac{\phi}{\omega}}$$ (lumen/steradian) or Candela.

Luminous flux: (ϕ)

It is the rate of energy radiation in the form of light waves.

$$\boxed{\phi = \frac{Q}{t}}$$



* Unit is lumen.

Lumen:

One lumen is defined as the

luminous flux emitted by a source of one candle power in a unit solid angle.

Lumen = candle power of source × solid angle.

Candle Power: (CP)

It is defined as the no. of lumens emitted by that source per unit solid angle in a given direction.

$$CP = \frac{lumen}{\omega}$$ [lumen/steradian or candela.]

Illumination:

Illumination is defined as the luminous flux received by the surface per unit area.

$$E = \frac{\text{Luminous flux}}{\text{area}}.$$

$$E = \frac{\phi}{A} = \frac{CP \times \omega}{A}.$$

Units:

1. lux.
2. lumen/m^2.
3. meter candle.
4. foot candle.

Lux or meter candle:

It is defined as the illumination of the inside of a sphere of radius 1m and a source of 1 CP is fitted at the centre of sphere.

Foot candle:

It is the unit of illumination and is defined as the illumination of the inside of a sphere of radius 1 foot, and a source of 1CP is fitted at the centre of it.

1 lux = 1 foot candle = 1 lumen/(ft)^2.

$$1 \text{ foot candle} = \frac{\text{lumen}}{\left(\frac{1}{3.28}\right)^2 m^2} = 10.76 \text{ lux (or) m-candle.}$$

1 foot candle = 10.76 lux.

Brightness: (L) (or) Luminance.

Brightness of any surface is defined as the luminous intensity per unit surface area of the projected surface in the given direction.

$$\boxed{L = \frac{I}{A\cos\theta}}$$

Mean horizontal candle Power (MHCP)

Mean of candle power of source in all directions in horizontal plane.

Mean spherical candle power (MSCP)

Mean of Candle power of source in all directions in all planes.

Mean hemispherical candle power (MHSCP)

Mean of candle power of source in all directions above or below the horizontal plane.

Lamp efficiency:

$$\text{Lamp efficiency} = \frac{\text{luminous flux o/p}}{\text{power input}}$$

Unit : lumen/W.

* Ratio of total luminous flux emitting from the source (o/p) to its electrical input in watts.

Coefficient of Utilization: (or) Utilization factor:

$$UT = \frac{\text{total lumens reaching the working plane}}{\text{total lumens emitting from source}}$$

Maintenance Factor:

$$MF = \frac{\text{Illumination under normal working Cond}^n}{\text{illumination under everything is clean.}}$$

* Always less than one. & around 0.8.

Depreciation Factor:

$$D.F = \frac{1}{\text{maintenance factor}}$$

* Always more than one.

Reflection Factor: (R.F)

$$R.F = \frac{\text{reflected light}}{\text{incident light}}.$$

Beam Factor:

$$B.F = \frac{\text{lumen in the beam of a projector}}{\text{lumens given out by lamps}}.$$

Absorbtion factor:

$$\text{Absorbtion factor} = \frac{\text{total lumens available after absorbtion}}{\text{total lumens given out by lamp}}$$

1. A 200V lamp takes a current of 1.2A, it produces a total flux of 2,860 lumens. Calculate.

(i) the MSCP of the lamp.

(ii) efficiency of the lamp.

i) $MSCP = \frac{\text{total flux}}{4\pi} = \frac{2860}{4\pi} = 227.59.$

ii) $\text{Lamp efficiency}(\eta) = \frac{\text{total flux output}}{\text{electrical input}}.$

$$= \frac{\text{lumen}}{VI\cos\phi} \quad [\cos\phi = 1].$$

$$= \frac{2860}{200 \times 1.2 \times 1}$$

$$= 11.9 \text{ (lumens/W)}$$

2. A room with an area of 6x9m is illustrated by ten 80W lamps. The luminous efficiency of the lamp is 80 lumens/W and the co-efficient of utilization is 0.65. Find the average illumination.

Room area = 6×9

$= 54 m^2$.

Total wattage $= 80 \times 10$ (W × no. of lamps)

$= 800$ W.

Total flux emitted by 10 lamps = Power × η

$= 800 \times 80$.

$= 64,000$ (lumens)

Flux reaching working plane = Flux (lumens) × UF.

$= 64000 \times 0.65$.

$= 41,600$ lumens.

Illumination, $E = \frac{\Phi}{A}$

$= \frac{41,600}{54}$

$= 770.37$ lux.

3. The luminous intensity of a lamp is 600 CP. Find the flux given out. Also find the flux on the hemisphere containing the source of light and zero above the horizontal.

WKT,

Intensity, $I = \frac{\phi}{\omega}$.

$\therefore \phi = I \times \omega$

$= 600 \times 2\pi$

$= 3769.911$ lumens.

Waste light Factor:

* when a surface is illuminated by several no. of sources of light, there is certain amount of wastage due to overlapping of light waves.

* For rectangular area : 1.2.

* irregular area : 1.5

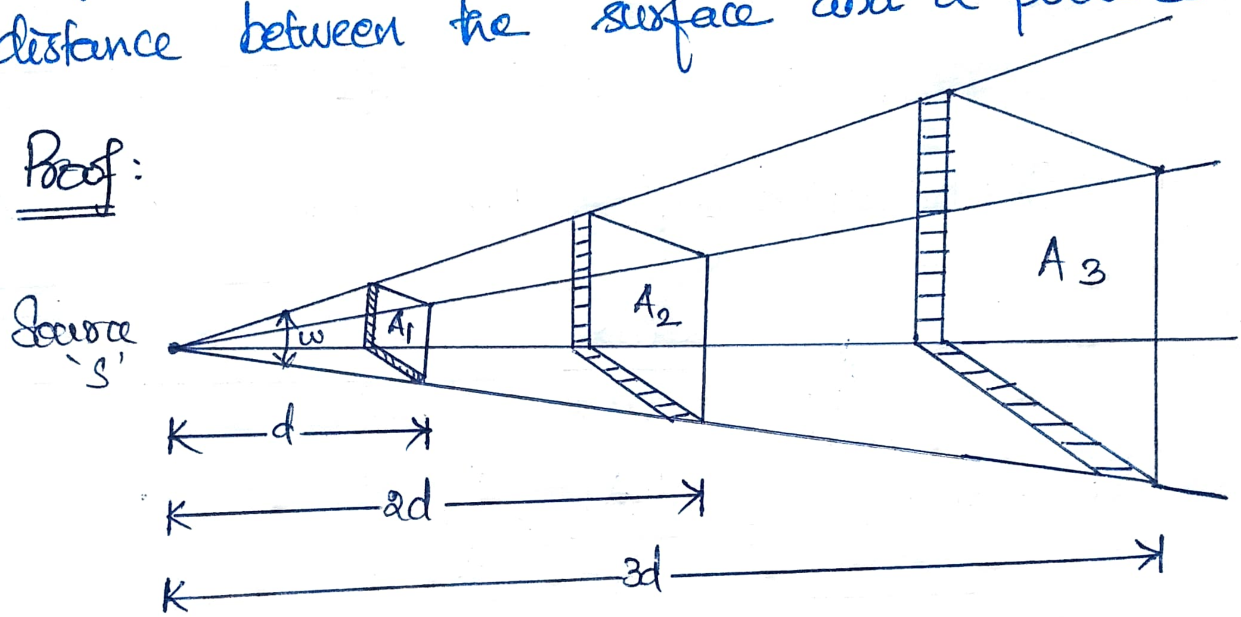
1. Inverse Square law.

2. Lambert's cosine law.

Inverse Square Law:

This law states that the illumination of a surface is inversely proportional to the square of distance between the surface and a point source.

Proof:



* Let 'S' be a point source of luminous intensity 'I' candela, the luminous flux emitting from source crossing '3' parallel plates having areas A_1, A_2, A_3 square metres, which are separated by a distance of d, 2d and 3d from the point source respectively.

For area A_1, solid angle, $\omega = \frac{A_1}{d^2}$ ——— (1)

WKT, $I = \frac{\phi}{\omega}$

$\therefore$ Luminous Intensity = $\dfrac{\text{Luminous flux}}{\text{Solid angle}}$.

$\therefore$ Luminous flux reaching area A_1 = Luminous Intensity × Solid angle.

$$\phi = I \times \omega \quad \text{——— (2)}$$

Sub. (1) in (2)

$$\phi = I \times \frac{A_1}{d^2} \quad \text{——— (3)}$$

Illumination 'E_1' on the surface area 'A_1' is,

$$E_1 = \frac{\text{flux}}{\text{area}} \quad \text{——— (4)}$$

Subs (3) in (4)

$$= \frac{I A_1}{d^2} \Big/ A_1 .$$

$$E_1 = \frac{I}{d^2} \text{ (lux)} \quad \text{——— (5)}$$

Similarly E_2 can be written as,

$$E_2 = \frac{I}{(2d)^2} \text{ (lux)} \quad \text{——— (6)}$$

Similarly E_3 can be written as,

$$E_3 = \frac{I}{(3d)^2} \text{ (lux)} \quad \text{——— (7)}$$

from 5, 6, 7, eq^n s

$$E_1 : E_2 : E_3 = \frac{1}{d^2} : \frac{1}{(2d)^2} : \frac{1}{(3d)^2} \quad \text{—— (8)}$$

Hence from eq^n (6.8) illumination on any surface is inversely proportional to the square of distance between the surface and the source.

Lambert's Cosine Law:

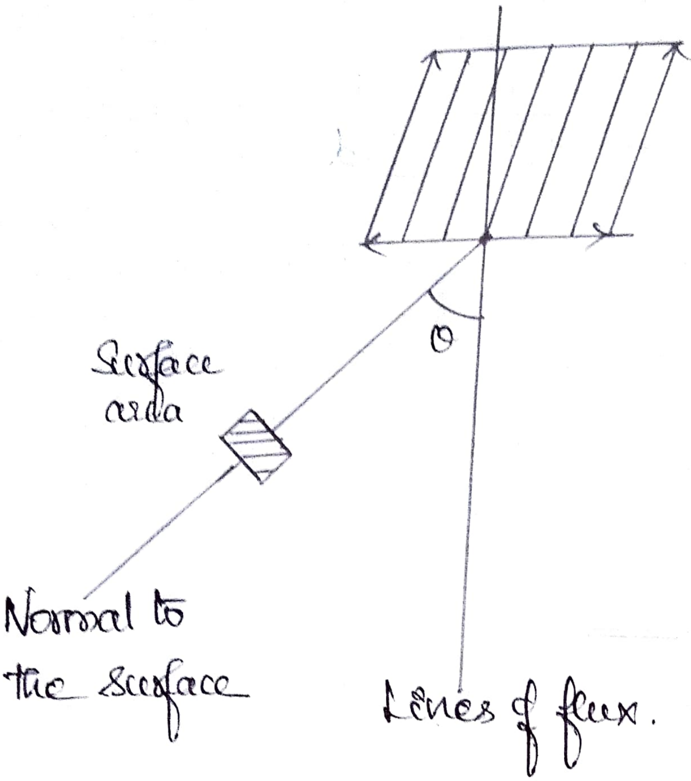
This law state's that illumination E at any point on a surface is directly proportional to the cosine of the angle between the normal at that point and the line of flux.

Proof:-

For Lambert's cosine law, assume that the surface is inclined at an angle 'θ' to the lines of flux.

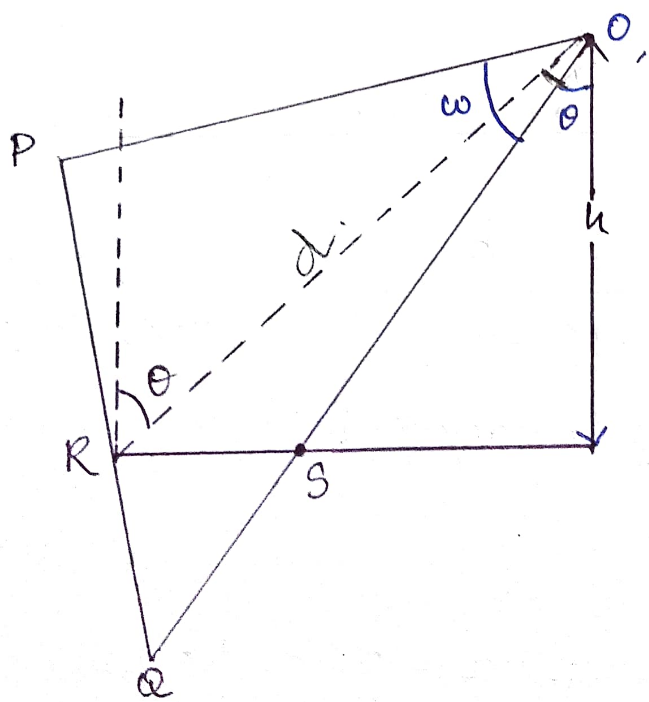
PQ = The surface area normal to the source and inclined at 'θ' to the vertical axis.

RS = The surface area normal to the vertical axis and inclined at an angle θ the source 'O'.



d: distance b/w Source & surface, m.

h: height of source from surface, m.



$\cos\theta = \frac{PQ}{RS}$.

The illumination of the surface PQ,

$$E_{PQ} = \frac{\text{flux}}{\text{area of PQ}} \quad \text{———— (1)}$$

$$= \frac{I \times \omega}{[illegible]} \quad \text{———— (2)}$$

where, $\omega = \dfrac{\text{area of } PQ}{d^2}$.

$$\therefore E_{PQ} = \frac{I}{\text{area of } PQ} \times \frac{\text{area of } PQ}{d^2}.$$

$$E_{PQ} = \frac{I}{d^2} \quad \text{--------- (3)}.$$

The illumination of the surface RS,

$$E_{RS} = \frac{\text{flux}}{\text{area of } RS} \quad \text{--------- (4)}$$

WKT

$$PQ = RS\cos\theta \quad \text{--------- (5)}.$$

$$\text{area of } RS = \frac{\text{area of } PQ}{\cos\theta} \quad \text{--------- (6)}$$

Subs. (6) in (4).

$$E_{RS} = \frac{\text{flux}}{\text{area of } PQ/\cos\theta}$$

Similar to previous derivation,

$$E_{RS} = \frac{I}{d^2}\cos\theta \quad [\text{||}^{\text{ly}} \text{ eq}^{\text{n}}: (3)] \text{ --- (}$$

From fig. (6).

$$\cos\theta = \frac{h}{d} \; ; \; h = d\cos\theta \quad \text{--------- (7.1}$$

$$d = \frac{h}{\cos\theta} \quad \text{--------- (8)}$$

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subs (8) in (7)

$$E_{RS} = \frac{I}{(h/\cos\theta)^2} \cos\theta .$$

$$= \frac{I \cos^3\theta}{h^2} \quad \text{———— (9)}$$

also subs. (7.1) in (9).

$\therefore h = d\cos\theta .$

$$E_{RS} = \frac{I \cos^{3}\theta}{d^2 \cos^2\theta}$$

$$= \frac{I}{d^2} \cos\theta \quad \text{———— (10)} .$$

So,

$$\boxed{E_{RS} = \frac{I \cos^3\theta}{h^2} = \frac{I}{d^2} \cos\theta .}$$

* Above law is called "Cosine cube law." ($\cos^3$)

Statement:

Illumination at any point on the surface is dependant on the cube of cosine of the angle b/w line of flux and normal at that point.

Types of lamps :

1. Electric arc lamps : Ionization of air present b/w the electrodes produces an arc.

2. Incandescent lamps : when the filaments of these lamps are heated to high temperature, emits light.

3. Gaseous discharge lamps : when an electric current is made to pass through a gas or metal vapor, it produces visible radiation by discharge take place in gas vapor.

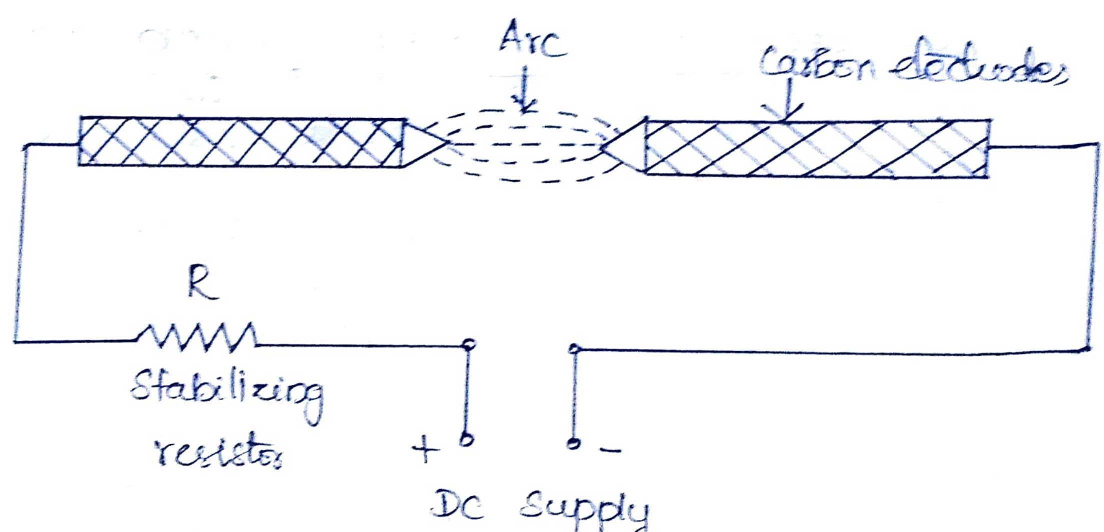
4. Fluorescent lamps : Certain materials like phosphor powder exposed to ultraviolet rays emit the absorbed energy into visible radiations fall in the visible range of wavelength.

Arc Lamps:

Types of arc lamp are,

1. Carbon arc lamp.
2. Flame arc lamp.
3. Magnetic arc lamp.

Carbon arc lamp:



* The two hard rod type electrodes madeup of carbon.
* Two electrodes are placed end to end and are connected to the DC supply.
* The DC supply across the two electrodes must not be less than 45V.
* When electric current passes through the electrodes

are in contact and then withdrawn apart, about 2-3 mm an arc is established between the two rods.

* The two edges of the rods become incandescence due to high resistance offered by rods, by transfer of carbon particles from one rod to the other.

* It is observed that carbon particles transfer from positive rod to negative.

* Positive electrode gets consumed earlier, hence positive electrode is of twice the diameter than negative electrode.

* A resistance 'R' is connected in series with the electrode for stabilizing the arc.

* As current increases, the vapourizing rate of carbon increases, which decreases the resistance so much, then voltage drop across the arc decreases.

* To maintain the arc b/w the two electrod

series resistance should be necessarily connected.

* For maintaining the arc, the necessary voltage required is :

$$V = (39 + 2.8l)V,$$

l : length of the arc.

Voltage drop = 60V.

Temperature = 3,500 – 4200°C. (+ve electrode)

" = 2500 °C (–ve electrode)

luminous efficiency = 9-12 (lumens/W)

*This low 'η' is due to service resistance provided in DC supply while in case of AC supply, an inductor is used in place of resistor.

Flame arc Lamp:

* The electrodes used in flame arc lamp are made up of 85% of carbon + 15% of Fluoride.

* Fluoride is also known as flame material.

* It has efficient property that radiates light energy from high heated arc stream.

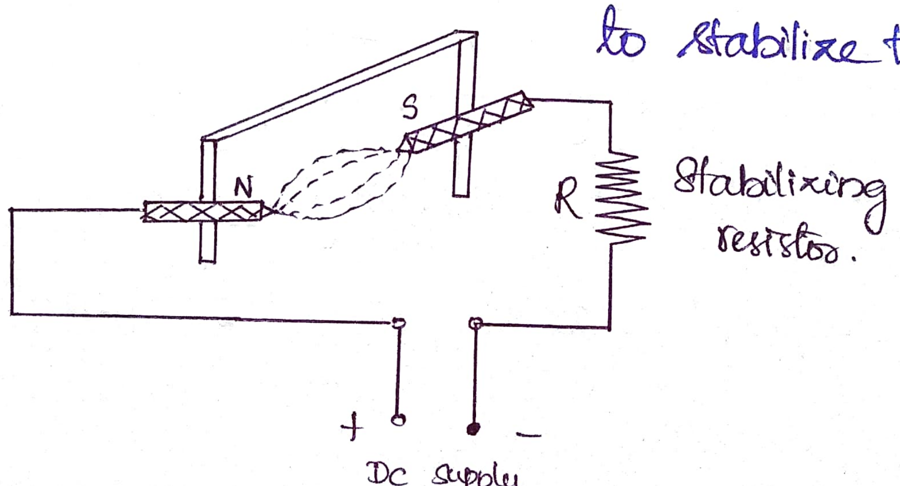
* Generally, core type electrodes are used and the cavities are filled with fluoride.

* Principle:- when arc is established b/w the electrodes, both fluoride and carbon get vaporized and give out very high luminous intensities.

* The colour of of flame arc lamps depends upon the flame materials.

* luminous efficiency = 8 lumens/W.

* Resistance is connected in service with the electrodes to stabilize the arc.



Magnetic Arc Lamp:

*This lamp consists of positive electrode that is made up of copper and negative electrode (Fe_3O_4) that is made up of magnetic oxide of iron.

* Light energy radiated out when the arc is struck b/w the '2' electrodes. These are rarely used lamps.

Incandescent Lamp:

* These lamps are temperature dependant sources.

* Principle: when electric current is made to flow thro' a fine metallic wire which is known as filament, its temperature increases. At low temperature it emits only heat energy. ~~but at~~ Very high temperature, the metallic wire emits both heat and light energy.

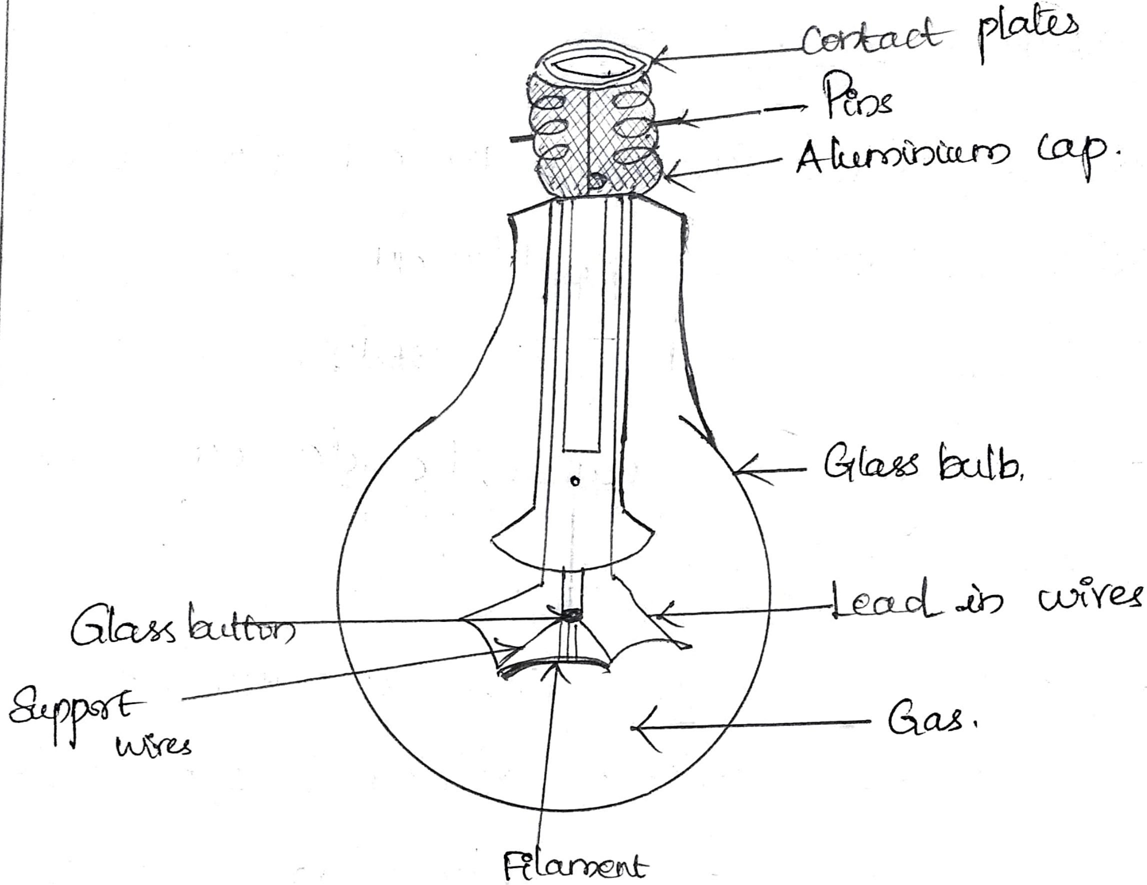
* The materials commonly used as filament for incandescent lamps are carbon, tantalum, tungsten and osmium.

Tungsten Lamp:

* The chemically pure tungsten is Very

strong & fragile. ([illegible])

* Construction:



* It consists of an evacuated glass bulb and an aluminium or brass cap is provided with two pins to insert the bulb into the socket.

* The inner side consists of tungsten filament and the support wires are made of molybdenum to hold the filament in proper position.

* A glass button is provided in which the

support wires are inserted.

* A stem tube forms an air-tight seal around the filament whenever the glass is melted.

Operation:

* When electric current is made to flow through the fine metallic tungsten filament, its temperature increases.

* At very high temperature, the filament emits both heat & light radiations.

* The maximum temperature at which the filament can be worked without oxidation is 2,000°C. beyond this temperature, the tungsten filament blackens the inside of bulb.

* The tungsten filament lamps can be operated efficiently beyond 2000°C, it can be attained by inserting a small quantity of inert gas nitrogen with small quantity of argon.

* But if gas is inserted instead of vacuum in the inner side, heat of lamp is conducted

away and it reduces the efficiency.

* To reduce this heat loss, filament should be wound that it takes very little space.

* Hence single coil instead of straight wire is used in vaccum bulbs upto 25W & gas filled bulbs from 300 to 1000W.

* Usually tungsten filament lamp suffers from ageing effect, the output of the light an incandescent lamp decreases as the lamp ages.

* The o/p reduces due to ② reasons.

⇒ At very high temperature, the vaporization of filament decrease the coil diameter so that resistance of the filament increases and hence it draws less current from the supply, so the temperature of the filament and the light o/p of the bulb decrease.

⇒ The current drawn from the mains and the power consumed by the filament decrease, which decrease the efficiency of the lamp with the passage of time. In addition, the evaporation of the filament at high temperature blackens the inside of bulb.

Advantages of incandescent lamp:

* These lamps are available in various shapes and sizes.
* These are operating at unity power factor.
* Not affected by surrounding air temperature.

Disadvantages

* Low efficiency.
* Colored light can be obtained by using different colored glass enclosures only.

Discharge Lamps:

Principle: An electric current is made to pass through a gas or vapour which produces its illuminance.

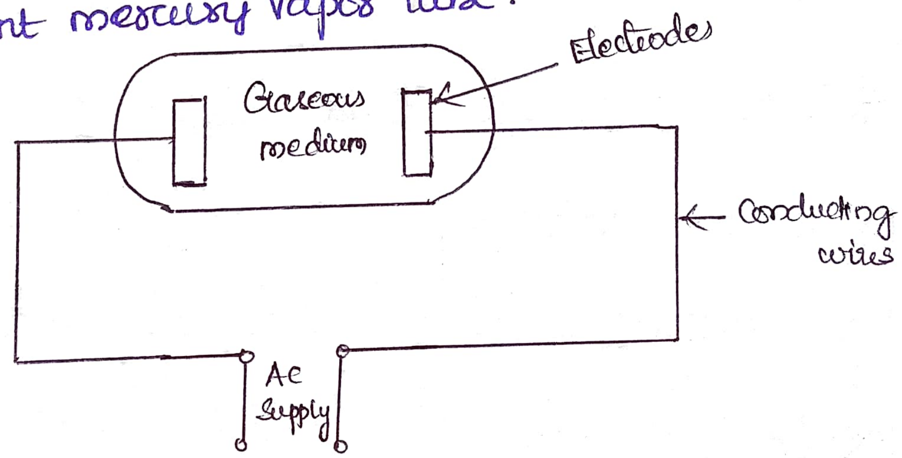
Choke: A choke or ballast is provided to limit high currents to a safe value.

Functions of choke :-

* It provides ignition voltage initially.
* Limits high currents.

Types of Discharge Lamps:

1. Neon gas.
2. Sodium vapor Lamp.
3. Mercury vapor Lamp.
4. Fluorescent mercury vapor tube.

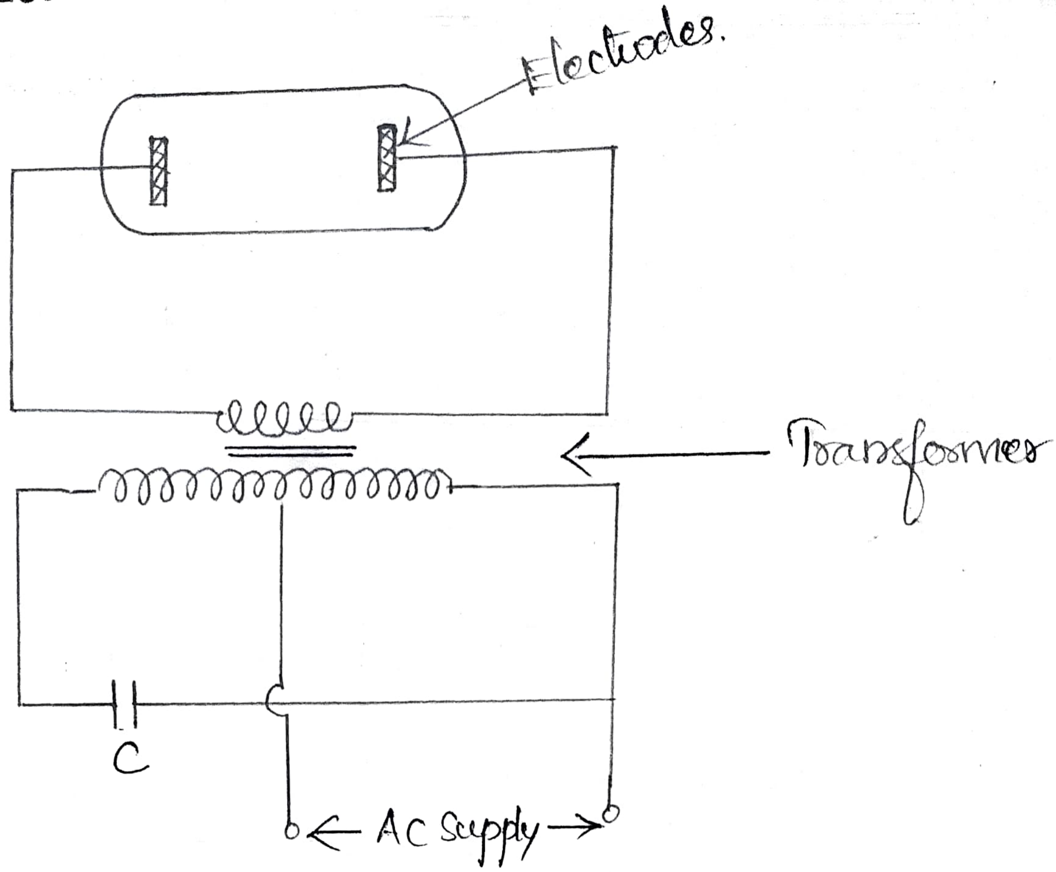


Discharge Lamps

Neon Discharge Lamp:

* This is a cold cathode lamp, in which no filament is used to heat the electrode for starting.
* Two electrodes placed at two ends of long

discharge tube.



* The discharge tube is filled with neon gas.
* A low voltage of 150V on DC or 110V on AC is impressed across the two electrodes.
* The discharge takes place through the neon gas that emits light or electromagnetic radiation reddish in color.
* Neon lamp electric circuit consists of a transformer with high leakage reactance in order to stabilize the arc.
* Capacitor is used to improve the power factor.

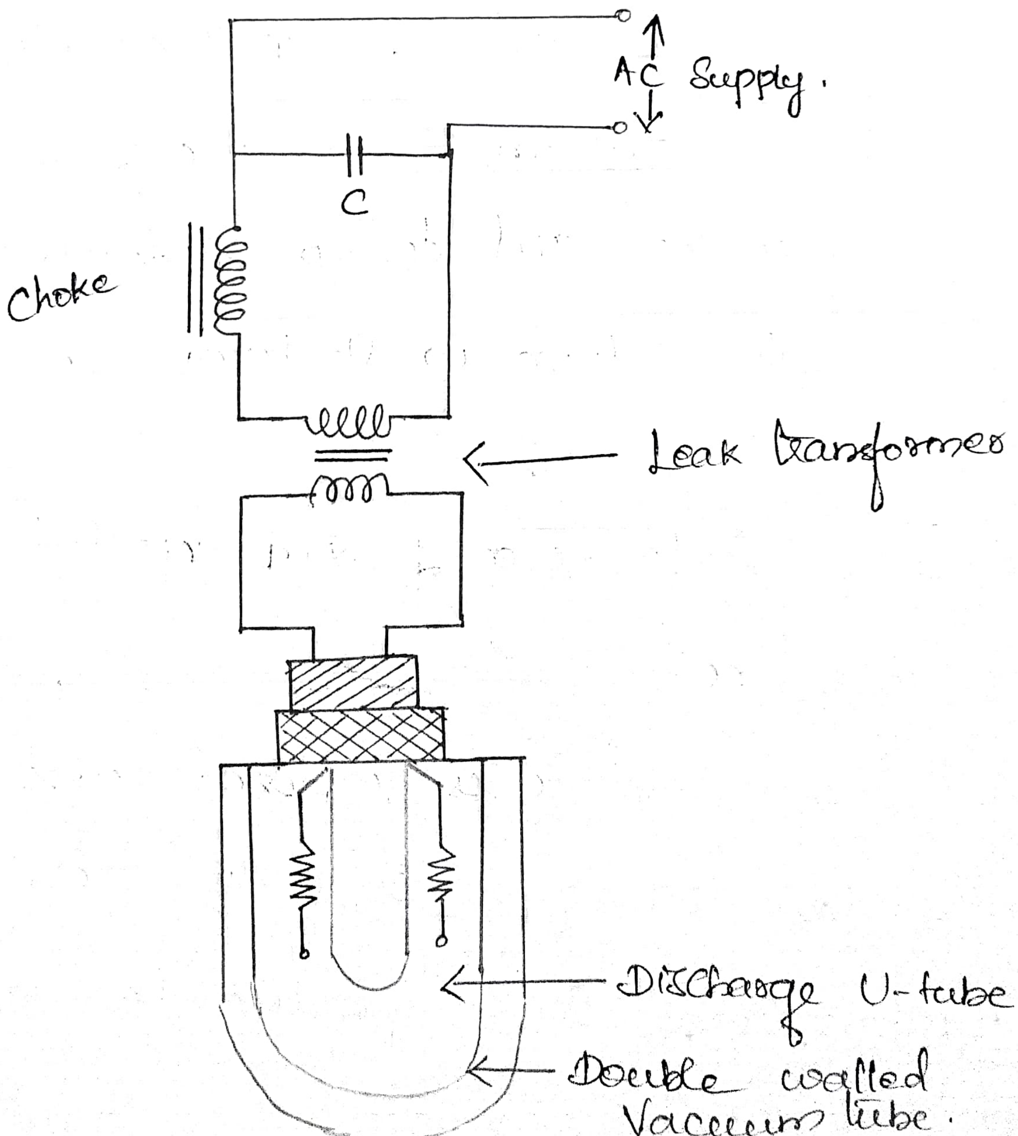
* Neon lamp efficiency is approximately 15 – 40 lumens/W.

* The power consumption of the neon lamp is 5W.

* If helium is used instead of neon, pinkish white light is obtained.

* These lamps are used as night lamps and as indicator lamps, used for the determination of the polarity of DC mains & for advertising purpose.

Sodium Vapour Lamp:



* It is a cold cathode and low pressure lamp.

* It consists of a U-shaped tube enclosed in a double walled Vaccum flask, to keep the temperature within working region.

* The inner U-tube consists of '2' oxide coated electrodes, with sealed ends.

Principle:

The 'U'-tube consists of small amount of neon gas and metallic sodium. At the time of start, the neon gas vaporizes and develops sufficient heat to vaporize metallic sodium in U-shaped tube.

Working:

* Sodium is in the form of solid deposited on the walls of inner tube.

* when sufficient voltage is impressed across the electrodes, the discharge starts in the inert gas, i.e. neon. It operates as low-pressure neon lamp with pink color.

* The temperature of the lamp increases gradually and metallic sodium vaporizes and then ionizes thereby producing the monochromatic yellow light.
* It takes 10-15 mins to give its full light output.
* Inorder to start the lamp, 380-450V of striking voltage required for 40 and 100W lamps.
* These voltages can be obtained from a high reactance transformer or an auto transformer.
* Power factor of lamp is very poor, so capacitor is placed to improve the power factor to above 0.8.
* The average life of Sodium Vapour lamp is 3000hr. and such bulbs are not affected by voltage variations

η : 40 - 50 lumens/W.

P : 45W, 60W, 85W, 140W. ratings.

T : 300°C.

Applications:

* Highway + street lighting.
* Parks, railway yards, general outdoor lighting etc

High Pressure Mercury Vapour Lamp:

* It depends mainly on pressure, Voltage, temperature

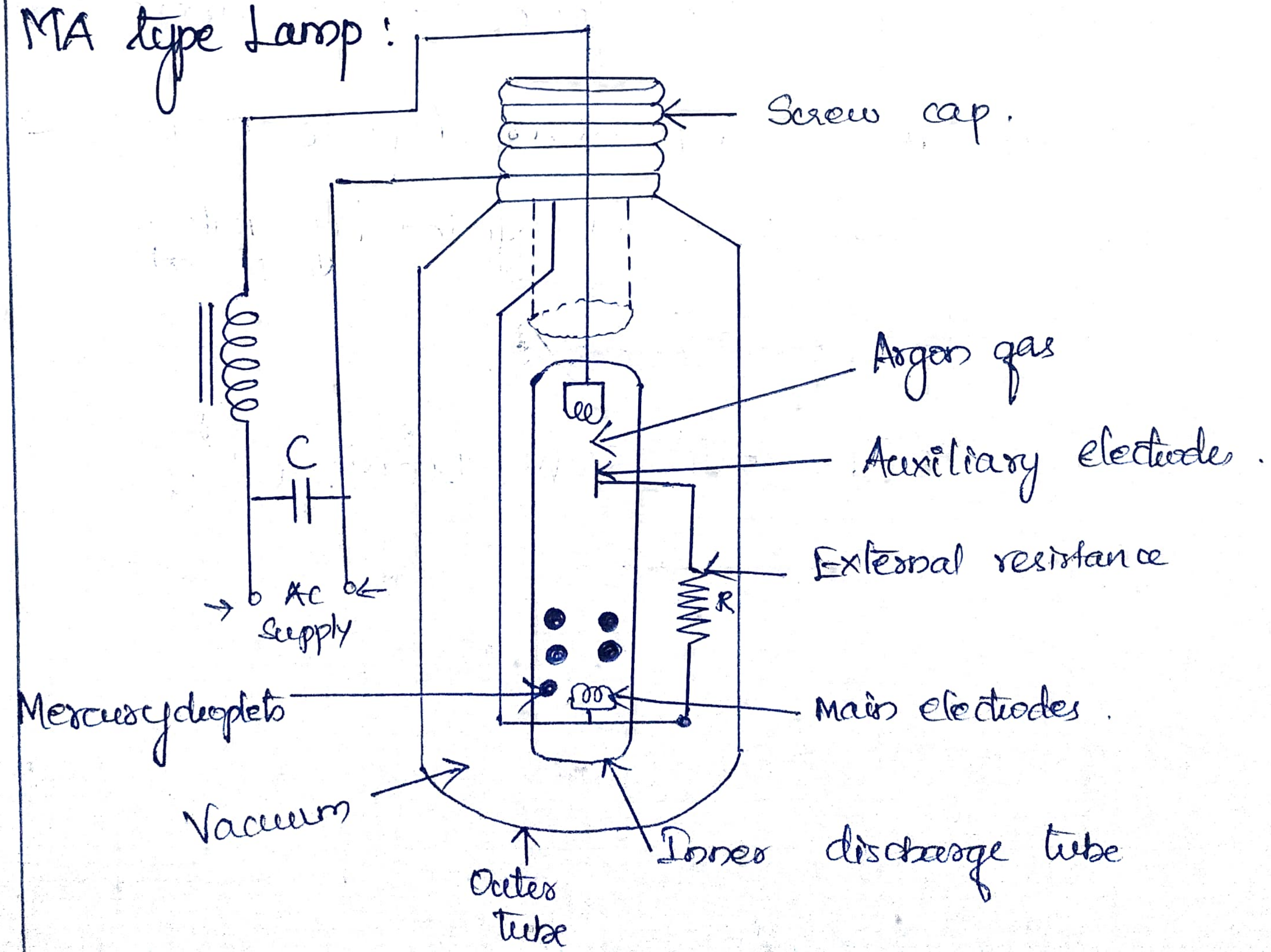
3 types:-

1. MA type : preferred for 250W & 400W rating bulbs on 200 – 250V AC supply.

2. MAT type : Preferred for 300W & 500W rating bulbs on 200-250 V AC supply.

3. MB type : Preferred for 80W & 1250W rating bulbs & high pressures.

MA type Lamp :



* Its construction is similar to Sodium Vapour lamp.

Construction:

* It consists of a long discharge tube in 'U' shape and is made of hard glass or quartz.

* This discharge tube is enclosed in an outer tube of ordinary glass.

* To prevent the heat loss from the inner bulb, by convection, the gas b/w the 2 tubes is completely evacuated.

* The inner tube contains 2 main electrodes and an auxiliary starting electrode, which is connected through a high resistance of about 50kΩ.

* It also contains a small quantity of argon gas and mercury.

* The two main electrodes are tungsten coils coated with electron emitting material (such as thorium metal).

Working:

* Initially, the tube is cold & hence the mercury

is in condensed form.

* Initially when supply is given to the lamp, argon gas present b/w the main & auxiliary electrodes gets ionized. and an arc is established. and then discharge takes place through argon for few minutes b/w the main & auxiliary electrodes.

* As a result discharge takes place through argon for few minutes in b/w main & auxiliary electrodes.

* After few minutes, the argon gas gets ionized b/w 2 main electrodes. Hence discharge shifts from auxiliary electrode to two main electrodes.

* During discharge process, heat is produced and this heat is sufficient to vapourize the mercury.

* Hence pressure becomes high & voltage drop increase from 20 to 150V.

* After 5-7 min, the lamp starts & give full output.

* Initially the discharge thro' argon is pale blue glow and the discharge thro' the mercury vapor is greenish blue light.

* choke is provided to limit high currents and capacitor is to improve the power factor of lamp.

* If the supply is interrupted, the lamp must cool down and the vapour pressure be reduced before start. It takes 3-4 min.

* Operating temperature : 600°C.

* η : 30 – 40 lumens/W.

* Power : 250, 400 W.

* Voltage : 200 - 250V / AC

Applications :

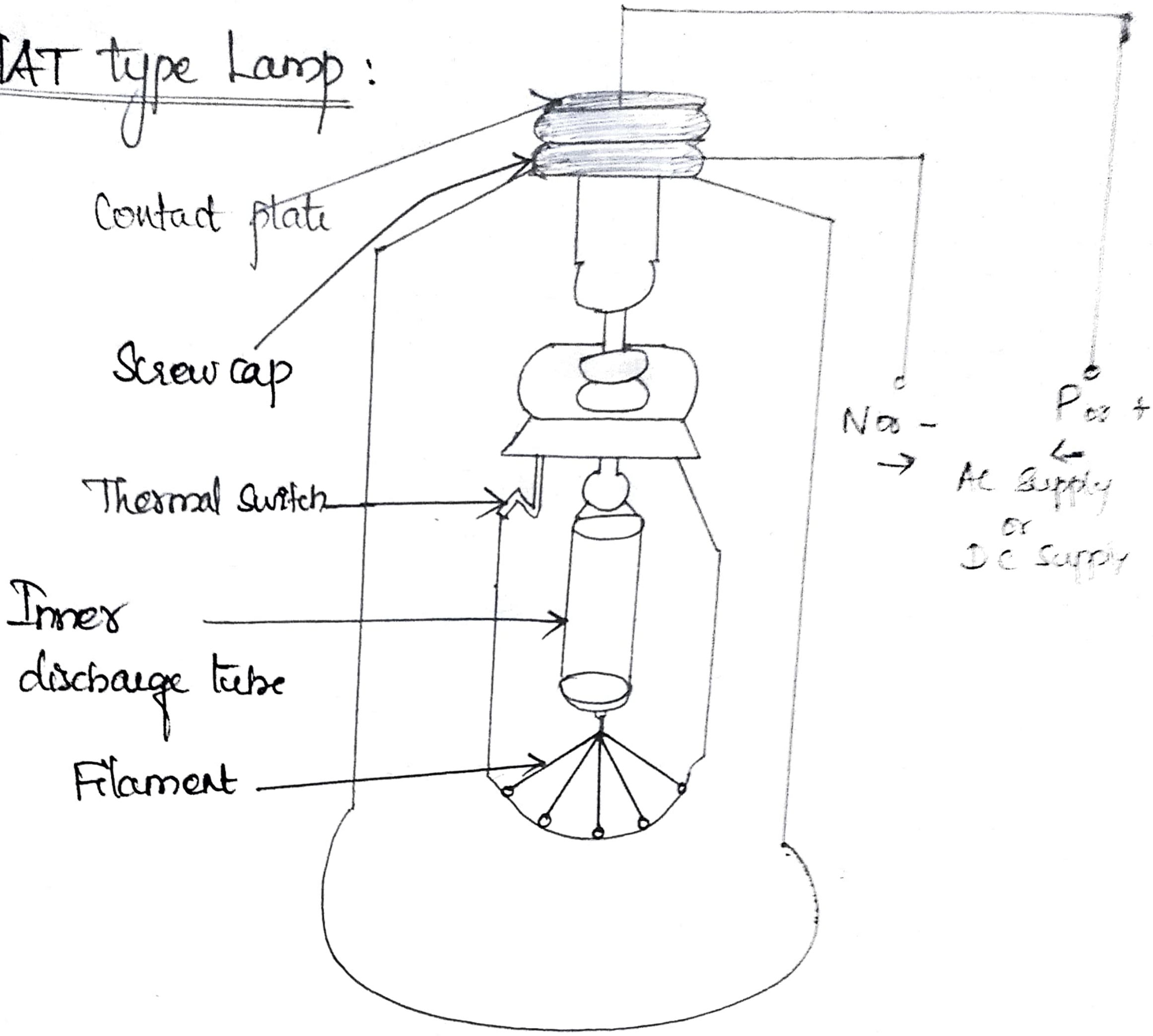
* General industrial lighting.

* Ports

* Shopping centre.

* railway yards.

MAT type Lamp :



* This lamp is manufactured in 300 and 500W rating for AC and DC.

* It consists of tungsten filament so that at the time of starting, it works as a tungsten filament lamp.

* Here the filament itself acts as choke to limit high currents.

* When the supply is switched ON, it works as a tungsten filament lamp, its full o/p is

given by the outer tube.

* At this time the temperature of inner discharge tube increases gradually, the argon gas present in it start ionizing in the discharge tube.

* At some particular temperature, is attained, the thermal switch gets opened, filament part is detached and voltage across the discharge tube increases.

* Now discharge takes place thro' mercury Vapour.

* Useful color effect canbe obtained by this lamp, because of combination of light emitted from the filament and blue radiations from discharge tube.

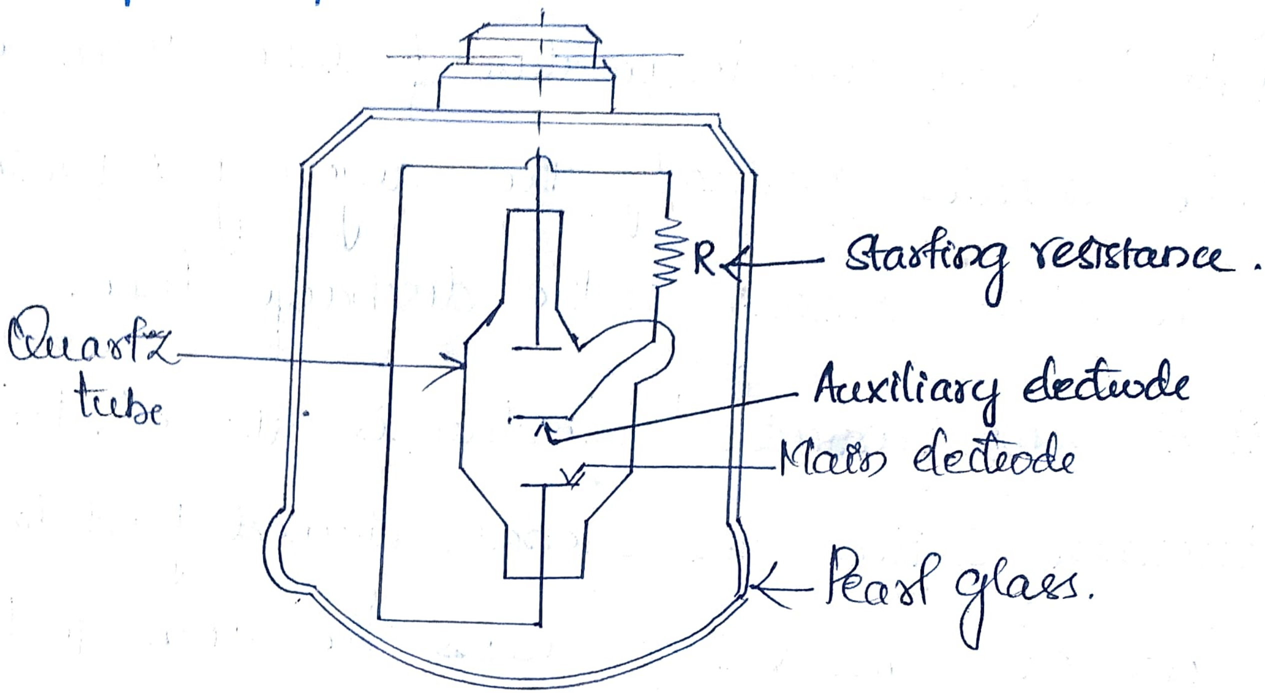
MB type Lamp:

* The inner discharge tube for the MB type lamp is about 5cm long and is made up of quartz.

* It has 3 electrodes - 2 main, 1 auxiliary.

* So high pressure is maintained inside the discharge tube, about 5-10 times greater than

atmospheric pressure.



* The outer tube is made with pearl glass material, so as to withstand high temperatures.

* Working similar to MA type.

* 300W and 500W for AC & DC.

* It consists of bayonet cap with three pins.

Flourescent Lamp (Low Pressure Mercury Vapor Lamp)

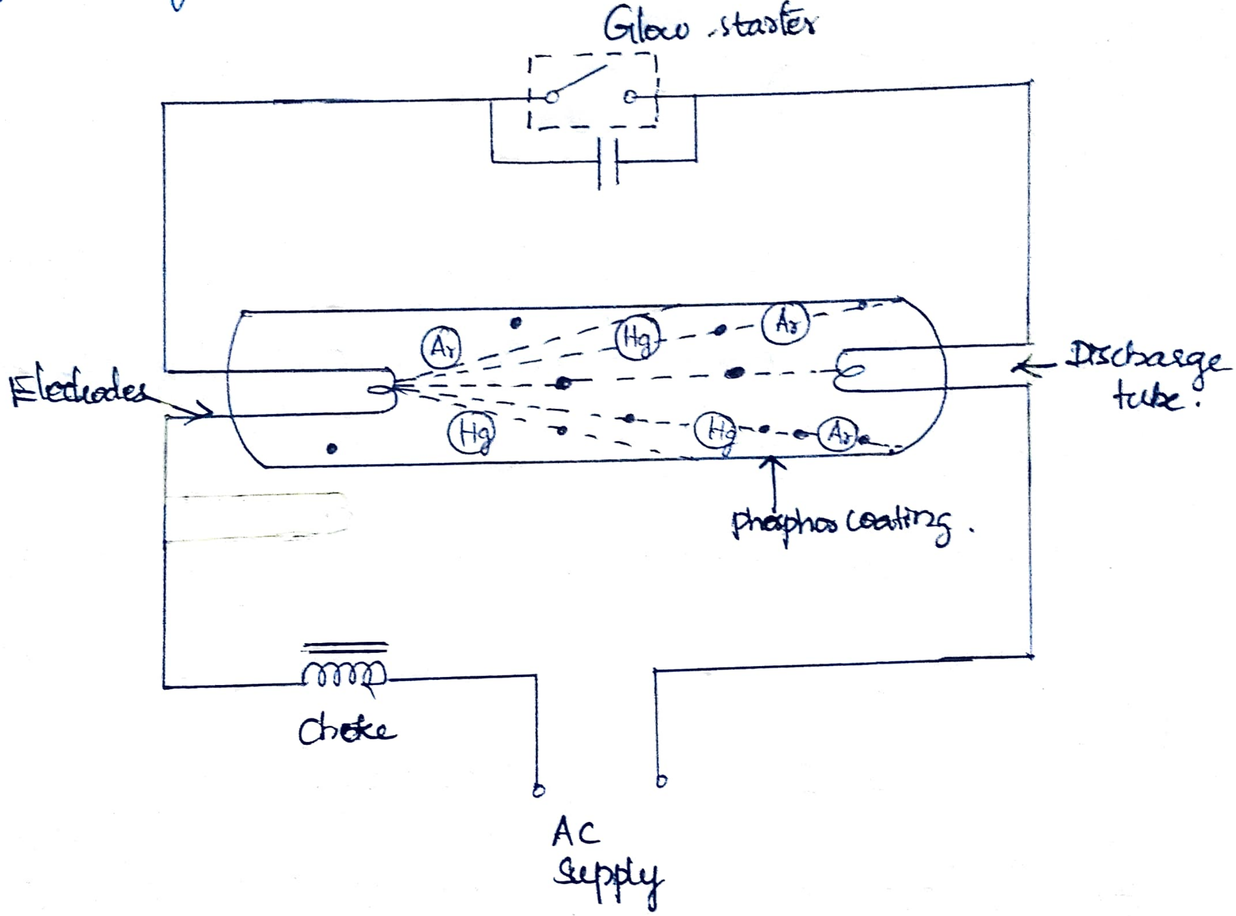
* Fluorescent lamp is a hot cathode low-pressure mercury vapour lamp.

Construction :

* It consists of a long horizontal tube, due to low pressure.
* The tube consists of 2 spiral tungsten electrode coated with electron emissive material placed at 2 edges of long tube.
* The tube contains small quantity of argon gas and certain amount of mercury at a pressure of 2.5mm of mercury.
* The low efficiency problem is overcome by coating the inside of tube with fluorescent powders in the form of solids known as phosphors.
* A glow starter switch contains small quantity of argon gas, having a small cathode glow lamp with bimetallic strip is connected in series with electrodes, which puts the electrodes directly across the supply, at the time of starting.

* A choke is connected in series thats acts as ballast, when the lamp is running.

* A capacitor of 4μF is connected to improve power factor.



Working

* At the time of starting, when both the lamp and the glow starters are cold, the mercury is in the form of globules.

* When supply is switched ON, the glow starter

terminals are open circuited and full supply Voltage appeared across these terminals, due to low resistance of electrodes and choke coil.

* The small quantity of argon gas gets ionised, which establishes an arc with a starting glow.

* This glow warms up the bimetallic strip thus glow starts get short circuited.

* Hence, the two electrodes come in series and are connected across the supply voltage.

* The two electrodes get heated and start emitting electrons due to the flow of current through them

* These electrons collide with the argon atoms present in the long discharge tube.

* In the beginning, the lamp starts conduction with argon gas as the temperature increases, the mercury changes into vapor form and takes over the conduction of current.

* In the mean time, the starter potential

reaches to zero, and the bimetallic strip gets cooling down.

* As a result the starter terminals will open. This results breaking of the series circuit.

* A very high voltage across around 1000V is induced, because of the sudden opening of starting terminals in the series circuit.

* But in the long tube, electrons are already present, this induced voltage is quite sufficient to breakdown the long gap.

* Thus more number of electrons collide with argon and mercury vapour atoms.

* The excited atom of mercury gives uv radiation, which will not fall in visible region.

* Meanwhile these UV rays are made to strike phosphor material.

* It causes the reemission of light of different wavelengths producing illumination, called luminescence.

Advantages

* High efficiency.
* The life of the lamp is three times of the ordinary filament lamp.
* The quality of light obtained is much superior.
* Less chance of glare.
* These lamps can be mounted on low ceiling, where other light sources would be unsatisfactory.

Methods of Lighting Calculations:

i) Watts-per-Square-meter method.
ii) Lumen or light flux method.
iii) Point-to-point method.

i) Watts-per-Square-meter method.

* According to illumination required, this method makes an allowance of watt per square meter of area to be illuminated.

ii) Lumen (or) light flux method:

* Lumen method is applicable for the cases in which all the sources produce uniform illumination over the working plane or an average value is required.

Total lumens received on working plane =	No. of lamps × wattage of each lamp × efficiency of each lamp × co-efficient of utilization

iii) Point to point or inverse square law method:

* This method is used to calculate the illumination

at any particular point due to several no of sources whose candle powers are known values.

* Illumination can be calculated as,

$$N = \frac{E \times A}{\phi \times UF \times MF}.$$

N: No. of fitting required.

E : Illumination required in lux.

A : working area (m^2).

ϕ : luminous flux produced per lamp in lumen

UF: utilization factor

MF : maintenance factor :

1. A room 20 x 10m is illuminated by 60W incandescent lamps of lumen output of 1600 lumens. The average illumination required at the workplace is 300 lux. Calculate the no of lamps required to be fitted in the room. Assume utilization and depreciation factors as 0.5 and 1 respectively.

Area = 20 x 10 m.

$= 200 m^2$.

Total Illumination (E) = 300 lux.

The wattage of each lamp = 60W.

luminous o/p of lamp (ϕ) = 1,600 lumens.

UF = 0.5,

D.F = 1

Maintenance factor = $\frac{1}{D.F}$ = 1/1 = 1.

No. of lamps required = $\frac{E \times A}{\phi \times UF \times MF}$.

$= \frac{300 \times 200}{1600 \times 1 \times 0.5}$

= 7.5 lamps.

2. The front of a building 35×18m is illuminated by 15 lamps. the wattage of each lamp is 80W. The lamps are arranged so that uniform illumination on the surface is obtained. Assuming a luminous efficiency of 20 lumens/W, the co-efficient of utilization is 0.8, the waste light factor is 1.25, DF = 0.9. Determine illumination on surface.

Soln :

Area (A) = 35 × 18 = 630 m².

No. of lamps, N = 15.

Luminous efficiency, η = 20 lumens/W.

UF = 0.8 ; DF = 0.9

Waste light factor = 1.25, E = ?

$$N = \frac{A \times E \times DF \times \text{Waste light factor}}{UF \times \eta \times \text{wattage of each lamp}}$$

$$15 = \frac{630 \times E \times 1.25 \times 0.9}{0.8 \times 20 \times 80}$$

$$E = 27.07 \ (\text{lumens}/m^2 \text{ or lux})$$

Types of Lighting Schemes:

* A good lighting scheme results in an attractive and commanding presence of objects and enhances the architectural style of the interior of a building.
* Depending upon the requirements and the way of light reaching the surface, lighting schemes are classified as,

i) direct lighting.
ii) Semidirect lighting.
iii) indirect lighting.
iv) Semi-indirect lighting.
v) general lighting.

i) **Direct lighting Schemes:**

* By using deep reflectors, it is possible to make 90% of light falls just below the lamp.

* This method is more efficient but it suffers from hard shadows and glare.

ii) **Semidirect Lighting Schemes:**

* Here about 60-90% of lamps luminous flux is made to fall downward directly by using some reflectors and the rest of the light is used to illuminate walls and ceiling.

iii) **Indirect lighting Schemes:**

* Here 90% of total light is thrown upwards to the ceiling.

* In this scheme, ceiling acts as lighting source

and glare is reduced to minimum.

* It provides shadowless illumination, used for drawing offices and in workshops.

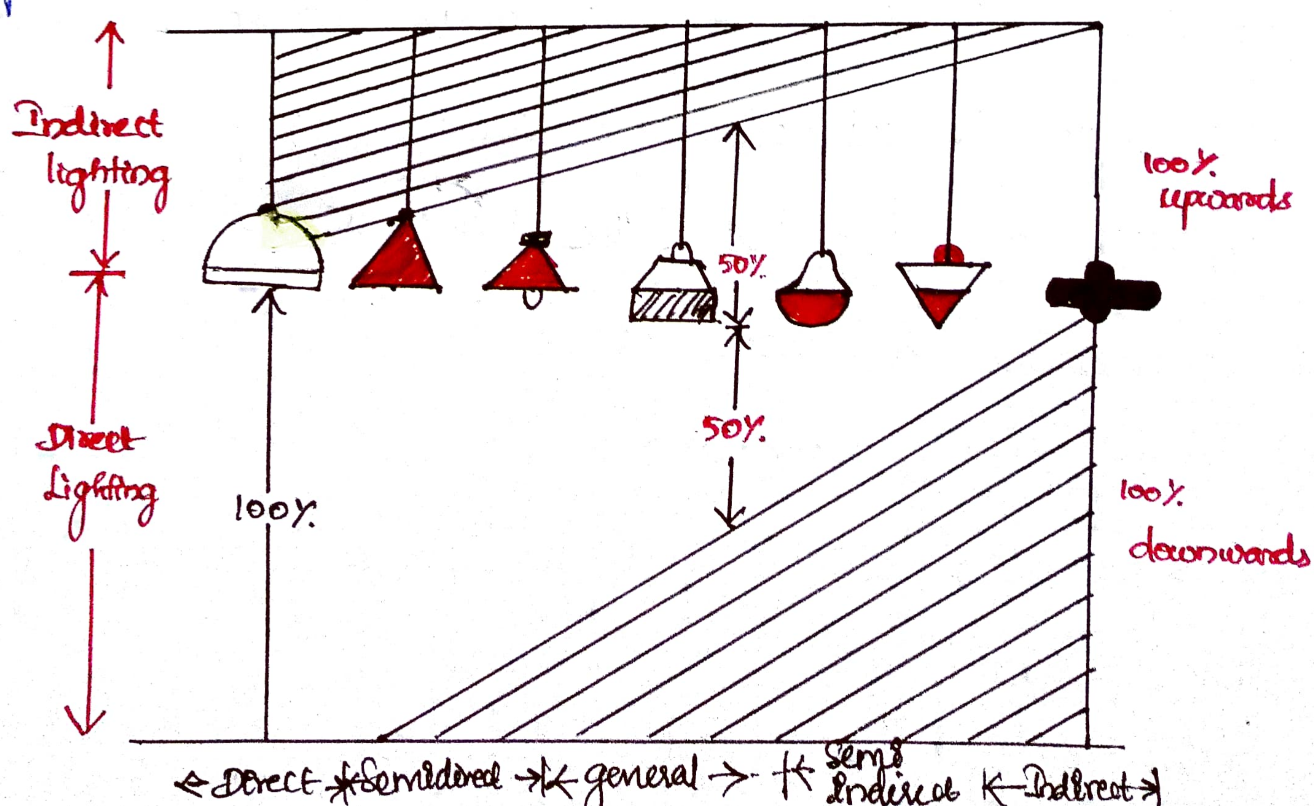
iv) Semi-indirect lighting Schemes:

* About 60–90% of light from lamp is thrown upwards to the ceiling & remaining luminous flux reaches the working surface.

* Glare will be completely eliminated with such type of lighting scheme.

v) General lighting Scheme:

* This scheme of lighting use diffusing glasses to produce the equal illumination in all directions



Design of lighting schemes:

*The lighting scheme should be such that,

i) It should be able to provide sufficient illumination.

ii) It should be able to provide the uniform distribution of light throughout the working plane.

* It should be able to produce the light of suitable color.

* It should be able to avoid glare and hard shadows as much as possible.

Factors to be considered:

* Illumination Level.

* The size of room.

* The mounting height & space of fitting.

Illumination Level.

* The intensity of illumination required on the surface is depending on the type of work being done.

* For each type of work, there is range of brightness

that causes minimum fatigue and gives maximum output in terms of quality and quantity.

* Moving objects and the objects that are seen for longer duration require more illumination than those for stationary object of casual work.

S.No	Occupancy	Illumination (lux)
1.	Covered areas	
	(i) Proofreading	95 - 185
	(ii) Drawing an exhibition	55 - 95
	iii) Museums	35 - 55
	iv) Bedrooms & waiting room.	18 - 32
	v) Hospital, railway yards & platforms.	5 - 10
2.	Hotels and restaurants	
	i) Reception, dining room, bedroom	150 - 200
	ii) Accounts & writing desks	300 - 400
3.	Power Station:	
	i) Boiler house, turbine stage, transformer.	100 - 150.
	ii) Control room	200 - 300

4.	Canteens	100 - 200.
5.	Outdoor areas.	
	i) Boxing rings	1750 - 2750
	ii) Race tracks	185 - 280.
6.	Sport ground.	
	i) Football ground	100 - 200
	ii) Tennis court.	300 - 400
	iii) Stadium	200 - 300
7.	Industrial purpose.	
	i) Precision machine room	240 - 500
	ii) Lathe & sewing machine.	140 - 185
	iii) General lighting factory	18 - 85
8.	Schools & Colleges.	
	i) Labs, library, lecture hall	200 - 300
	ii) Drawing rooms.	400 - 500
	iii) Waiting room & stair.	100 - 150

ii) Size of the Room:

* The luminous flux emitted from the source will not be completely utilised at the workplace

* A portion of flux will be lost in lamp fitting

some other will be absorbed, & rest of it is reflected.

* This absorbtion & reflection are depending upon the size & colour of walls & ceiling.

* Illumination in any room depends upon the reflected light from the walls and ceiling.

* White colour walls reflect more light.

(iii) **Mounting height & space fittings:**

* To provide adequate illumination over the working plane, the distance of a light source from the wall should be half of the distance b/w the 2 adjacent lamps and also the distance b/w the source fitting or spacing should not exceed more than 1·5 times the mounting height.

$$\frac{\text{Space}}{\text{height}} \leq 1.5$$

Street Lighting:

* The purpose of street lighting are,

i) To increase the community value of the street.

ii) To clear the traffic easily in order to promote safety & convenience.

iii) In order to make the street more attractive so that obstructions on the road clearly visible to the drivers of vehicles.

*The basic principle employed for street lighting are,

I. Diffusion Principle:

*In this method, light is directed downwards from the lamp by the suitably designed reflectors.

* The design of these reflectors are in such a way that they may reflect total light over the road surface uniformly as much as possible.

* The reflectors are made to have a cutoff between 30° and 45°, so that the filament of the lamp is not visible expect just below the source, which results in eliminating

glare.

* Illumination at any point on the road surface is calculated by applying inverse square law or point by point method.

ii) <u>Specular Reflection principle</u>:

* The specular reflection principle enables a motorist to see an object about 30m ahead. In this case, the reflectors are curved upwards, so that the light is thrown on the road at a very large angle of incidence.

* This can be explained with the help of figure.

* An object resides over the road at 'P' in between the lamps S_1, S_2 and S_3 and the observer at 'Q'.

* Thus the object will appear immediately against the bright road surface due to the lamps at a longer distance.

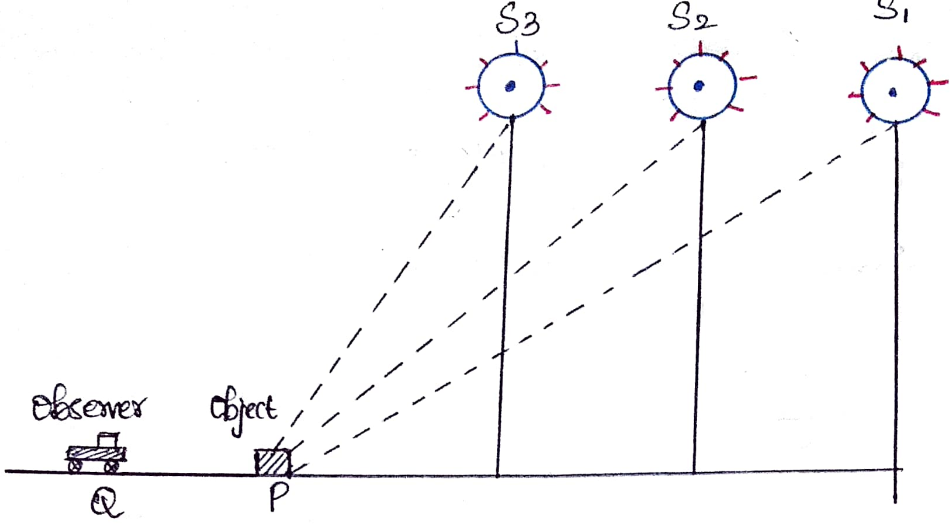


Fig. Specular Reflection for street lighting

Illumination required for different areas of street lighting:

Area	Illumination (lumen/m²)
1. Road junctions & important shopping centres	30
2. Poorly lighted sub-urban streets	4
3. Average well-lighted street	8 – 15

* Mercury Vapour and sodium Vapour discharge lamps are preferable for street lighting since the overall cost of the installation of discharge lamps are less than filament lamps. and also
* the less power consumption for a gⁿ. amount of power output.

* Normal spacing for the standard lamps is 50m with a mounting height of 8m.
* Lamp posts should be fixed at the junction of roads.

Factory Lighting:

* Industry (or) factory lighting must satisfy following pts.
  - ⇒ The quality of work is to be improved.
  - ⇒ Accidents must be reduced.
  - ⇒ The productivity of labor should be increased.
* The above requirements can be met by the factory lighting only when the lighting scheme provides:
  - ⇒ Adequate illumination on the working plane.
  - ⇒ Minimum glare.
  - ⇒ Clean and effective source fitting.
  - ⇒ Uniform distribution of light over the working plane.
* The lamps used for factory lighting are fitted with specially designed reflectors and they can be easily cleaned.

* The requirements of most of the installations of industrialized area can be met by following lamp fitting.

* Industrial lighting fittings.
* Standard reflectors.
* Diffused fittings.
* Concentrating reflectors.
* Enclosed diffused fittings.
* Angle reflectors.

Flood Lighting:

⇒ Flood lighting means flooding of large surface areas with light from powerful projectors.

⇒ A special reflector and housing is employed in floodlighting in order to concentrate the light emitted from the lamp into a relatively narrow beam which is known as floodlight projector.

⇒ This projector consists of a reflecting surface that may be a silvered glass or chromium plate or stainless steel.

* The efficiency of silvered glass and polished metal are 85-90% and 70% respectively.
* Usually metal reflectors are robust: therefore they can be preferred.
* An important application of illumination engineering is the floodlighting of large and open areas.
* It is necessary to employ floodlighting to serve one or more of the following purposes.

i) Esthetic floodlighting:

* They are used for enhancing the beauty of monuments, ancient buildings and churches by floodlighting.

ii) Industrial and commercial floodlighting:

Used for illuminating sports arenas, railway yards quarries, car parks etc.

iii) Advertising:

* Illuminating showcases and advertisement boards and for the decoration of houses etc.
* The projectors of floodlighting schemes are

Classified according to the light beam are,

i) **Narrow beam projectors:**

Light beam with such a projector spreads b/w 12° and 25°, for distance of 70m.

ii) **Medium angle Projectors:**

Projectors with beam spread b/w 25° and 40°. for distance of 30-70m.

iii) **Wide angle projectors:**

Projectors with beam spread b/w 40° and 90°. for distance of 30m or below.

Economically, the wide angle projectors with high wattage lamps and narrow beam projectors with low wattage lamps are used.

Calculation:

The total number of projectors required ;

$$N = \frac{A \times E \times \text{depreciation factor} \times \text{Waste light factor}}{\text{Utilization factor} \times \text{wattage of each lamp} \times \text{luminous efficiency of lamp}}$$

Residential Lighting:-

* Residential lighting resonates around indoor & outdoor lighting solutions for your home

* The light in home can be peaceful, comfortable, intimate, cheerful & festive.

* Options for lighting each room are as varied as the colors of paint and features of carpet selected.

* For Eg., rating of lamps for illuminating a lightly coloured drawing room of size 8m long, 3m wide 3.5m high. are,

Illumination : 100 lumens/m^2.

UF : 0.5

1. A room size of 10x4m is to be illuminated by ten 150W lamps. The MSCP of each lamp is 800. Assuming a depreciation factor of 0.8 and UF of 0.5. Find average illumination produced on the floor.

$$A = 10 \times 4$$

$$= 40 m^2.$$

Total luminous flux emitted by 10 lamps (ϕ).

candlepower ω

$$= 10 \times 150 \times 4\pi$$

lumen = CP × S.A (ω).

$$= 18,849.5 \text{ lumens.}$$

Total luminous flux reaching working plane.

$$= \frac{\phi \times UF}{D.F}.$$

$$= \frac{18,849.5 \times 0.5}{0.8}$$

$$= 11,780.97 \text{ lumens.}$$

$$E = \frac{\phi}{A}.$$

$$= \frac{11,780.97}{40}.$$

$$= 294.52 \text{ lux.}$$

2. A drawing with an area of 18×12 m is to be illuminated with an average of illumination of about 150 lux. The lamps are to be fitted at 6 m height. Findout the number & size of incandescent lamps required for an efficiency of 20 lumens/W. UF = 0.6, M.F = 0.75.

η = 120 lumens/W.

E = 150 lux.

A = 18 × 12 = 216 m^2.

The total gross lumens required, $\phi = \dfrac{E \times A}{UF \times MF}$

$= \dfrac{150 \times 216}{0.6 \times 0.75}$

= 72,000 lumens.

Total watts = $\dfrac{\text{lumens}}{\eta} = \dfrac{72000}{20}$

= 3,600W.

To find No. of lamps:

If suppose 24 lamps are used,

For 6m height (given).

Space to height ratio = 1.

$\frac{\text{Space}}{\text{height}} = 1$

Space = height.

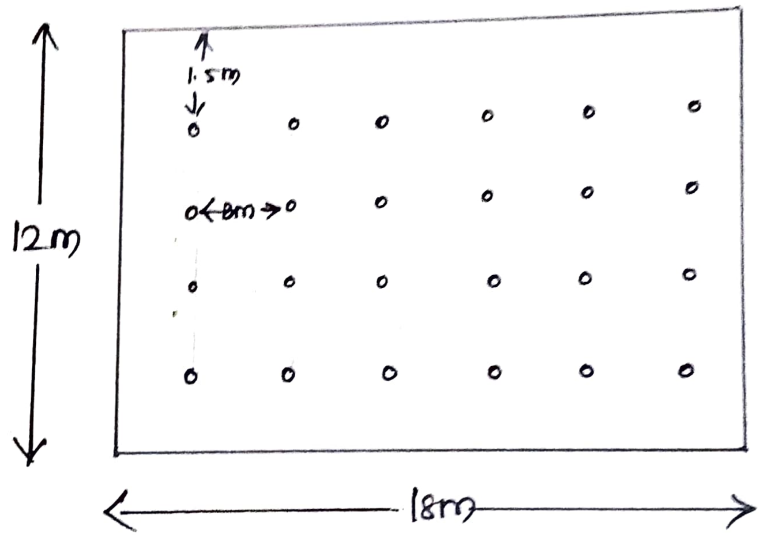
ie : 6.

6 lamps along 18m length:

$\therefore 18/6 = 3m$ (Spacing).

4 lamps along 12m width:

$12/4 = 3m.$



Wattage of each lamp = $\frac{3600W}{24}$

= 150W.

$\frac{\text{Total wattage}}{\text{No. of lamps}}$.

1. A hall of 30x20 m area with a ceiling height of 6m is to be provided with illumination of 200 lumens/m². taking UF = 0.6 ; D.F = 1.6 . Determine no. of fluorescent tubes required, their spacing, mounting height & total wattage. Take luminous efficiency

as 25 lumens/w for 300W tube

Area = 30×20

$= 600 m^2$.

$E = 200$ lumens/m^2

Gross lumens, $\phi = \frac{A \times E \times DF}{UF}$.

$= \frac{600 \times 200 \times 1.6}{0.6}$

$= 320000$ lux.

Total wattage $= \phi/\eta = \frac{3,20000}{25}$.

$= 12800$.

No. of lamps (tubes) $= \frac{\text{total wattage}}{\text{wattage of each tube}}$

$= \frac{12,800}{300}$.

$= 42.66$

$\simeq 44$.

44 lamps by taking (11) lamps along length.

$30/11 = 2.727 m$.

(4) lamps along width ; $20/4 = 5m$.

$\frac{\text{Space}}{\text{height}} = \frac{2.727}{5} = 0.545$.

LED Lamp:

* LED lamps have lifespan and electrical efficiency which are several times greater than incandescent lamps.

* More efficient than, most fluorescent lamps, with some chips able to emit more than 300 lumens per watt.

* LEDs come to full brightness without need for a warm up time.

* The initial cost of LED is usually higher, degradation of LED dye & packaging materials reduces light o/p to some extent over time.

* Most LEDs donot emit light in all directions and their directional characteristics affect the design of lamp, although omnidirectional lamps which radiate light over a 360° are common.

* LED chips require controlled direct current (dc) and LED driver is required to convert alternating current to dc used by LEDs.

* LEDs are affected by high temperature, so LEDs include, heat dissipation elements such as heat

sinks of cooling fins.

* LED drivers provide additional features like dimming and control.

* Two types of drivers available:

⇒ Built in type : LED drivers put inside lamp or luminaire.

⇒ Independent type : LED drivers put outside.

⇒ outdoor driver : street light.

⇒ Indoor driver : down light.

⇒ Indoor linear driver : panel light.

Types of LED Lighting:

i) Standard Shape A19.

ii) 3-way LED.

iii) Vintage LED bulbs.

iv) Wet location LED bulbs.

v) Decorative LED bulbs.

vi) LED tubes.

Benefits of LED lighting:

1. No mercury, so cleaner alternative to fluorescent & CFL.
2. The lowest energy consumption of any lighting product.
3. Life is 20 times than some traditional lighting products.

UNIT - II

REFRIGERATION AND AIR CONDITIONING

Refrigeration:

* The term refrigeration means cooling a space, substance or system to lower and/or maintain its temperature below the ambient one.
* Its a artificial (human-made) cooling.

Refrigerants:

* They are chemical compounds that are alternately compressed & condensed into a liquid & then permitted to expand into a vapour or gas as they are pumped through mechanical refrigeration system to cycle.
* Eg:- CFC, HCFC, HFC etc.

Domestic Refrigerator:

* A domestic refrigerator is an electrical appliance used in many households for keeping foods cool enough so that they won't spoil.
* 5 main components of domestic refrigerator;

* Thermostat – detect temperature changes.
* a compressor – increases the pressure of working gas.
* a capillary tube – very thin tubes. (capillary action)
* evaporator – liquid to vapour – converter.
* Condenser : vapour to liquid.

Thermostat:

* Thermostat controls the cooling process by monitoring the temperature and then switching the compressor on and off.
* When the sensor senses that its cold enough inside a refrigerator, it turns off the compressor.
* If it senses too much heat, it switches the compressor on and begins the cooling process again.

Compressor:

* It's the heart of a refrigerator.
* It circulates the refrigerant throughout the sys and adds pressure to the warm part of the circuit, & makes the refrigerant hot.

Capillary tube :

* The capillary tube is a thin piece of tube that serves as an expansion device.

* The liquid refrigerant is routed through the capillary tube & sprayed into the low pressure environment of the evaporator.

Evaporator :

* The evaporator is located inside a refrigerator & which makes the items in refrigerator cold.

* As the Refrigerant turns from a liquid into a gas through evaporation, it cools the area around it producing the proper environment for storing food.

Working principle:

* Refrigerator works on the principle of thermodynamics cycles and second law of thermodynamics.

* Thermodynamic cycle is a closed cycle in which a substance undergoes series of processes and is always brought back to initial state.

Condenser:

* The condenser or cooler consists of coils of pipe in which the high pressure & temperature vapour refrigerant is cooled & condensed.

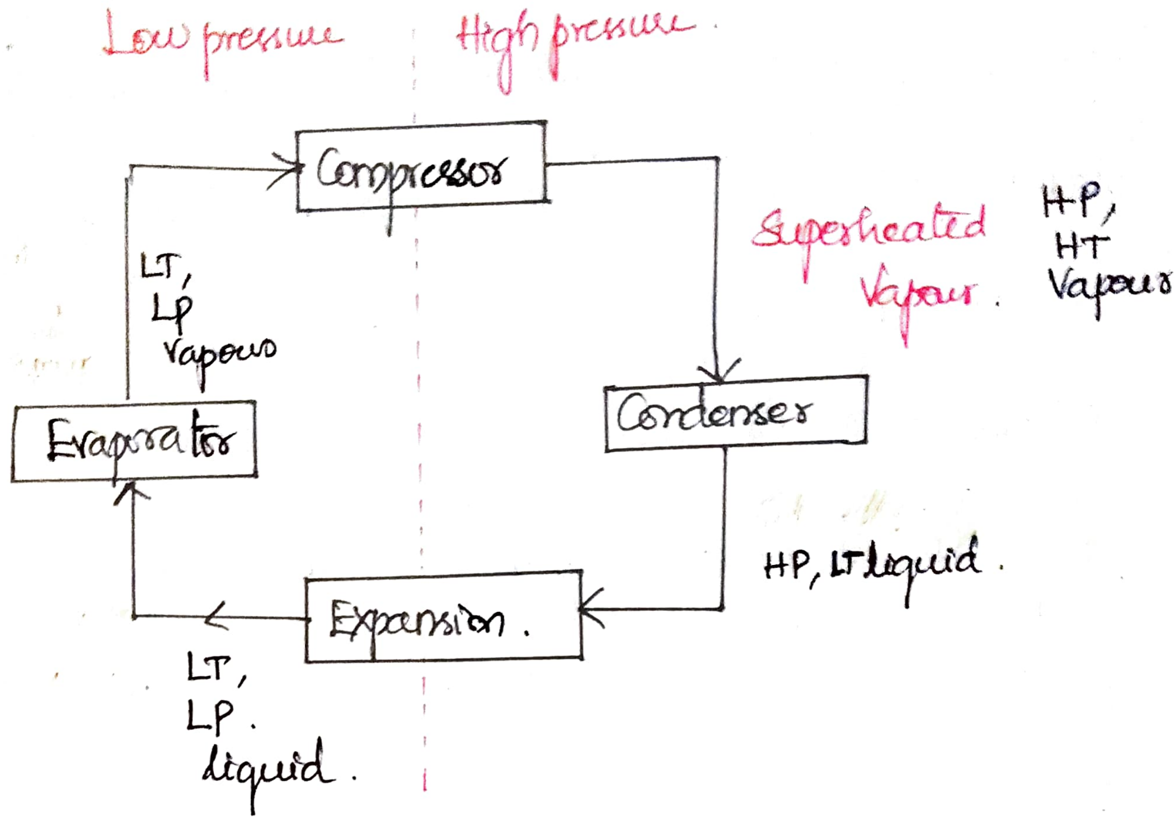
* The refrigerant while passing through the condenser rejects its latent heat to the external surrounding air.

* Thus hot refrigerant vapour received from the compressor is converted into liquid form in the condenser.

Working:

* The refrigerant is circulated through various components explained above with the help of motor installed in the compressor unit where it undergoes a number of changes in its state or condition.

* Each thermodynamic cycle consists of 4 fundamental changes in the state of refrigerant. They are expansion, vapourization, compression & condensation.



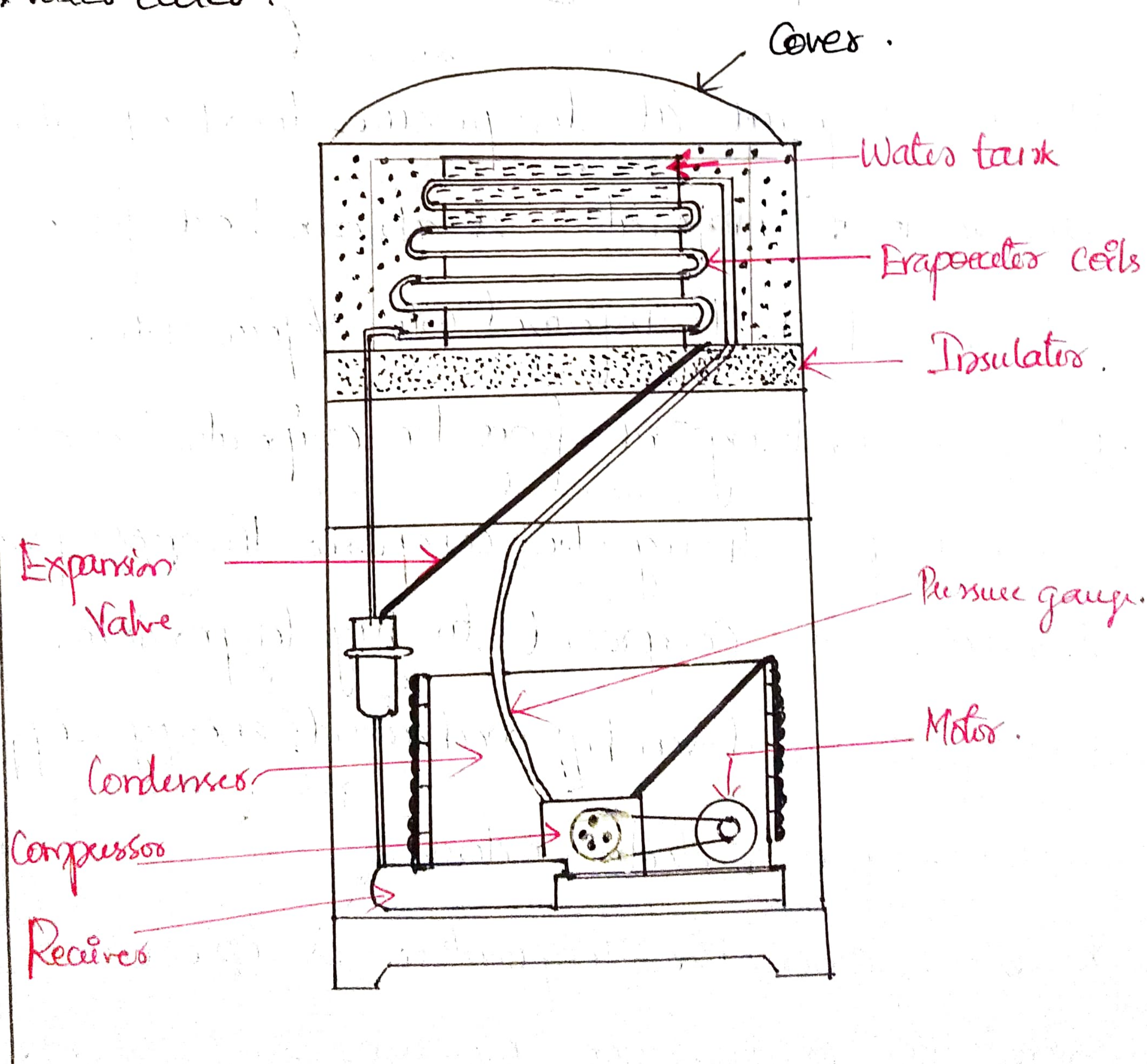
* When refrigerant at low pressure, low temperature enters in-to the evaporator, it absorbs heat from the substance & its transformed into. Vapour state.
* Vapours evolving out from the evaporator are then allowed to pass through the compressor through pipes.
* Vapours are compressed to high temperature.
* Compressor is driven by mechanical energy supplied by an engine or electric motors.
* In compressor, the temperature is increased above the Condensating medium temperature.
* In the Condenser, the high temperature, high

pressure Vapour is converted into high pressured liquid

* The process of reducing pressure of refrigerant is done by expansion devices.

* Here high pressure liquid is converted to low pressure liquid, capable of absorbing heat. This process is called expansion.

Water cooler :



Working Principle of Water Cooler:

* Its based on vapour compression refrigeration cycle.

* The refrigerant is compressed by the compressor and is delivered to the condenser which is cooled by a fan.

* The high pressure liquid after cooled by a condenser is collected in a receiver from where it goes to expansion valve.

* The expansion valve takes the required quantity of refrigerant depending upon the load on the evaporator.

* As the refrigerant passed through the expansion valve, its temperature falls down considerably upto -10°c.

* Its pressure also falls down.

* Then this liquid refrigerant passes through the evaporator coils, which surround the water tank. (stored water)

* The liquid refrigerant in the coils absorbs its latent heat from the water, leaving it cooled.

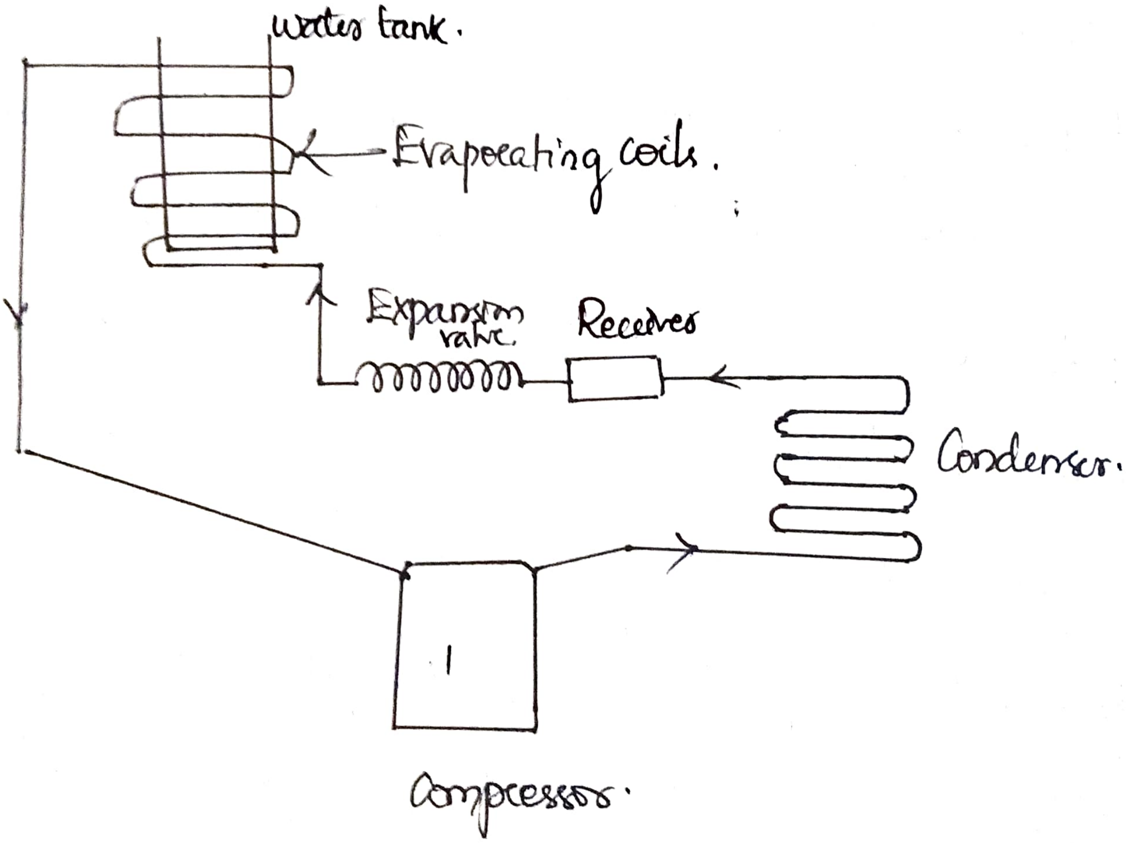
* The liquid refrigerant as it flows through the evaporator coils is converted into vapour & by the time it leaves the coils, it is almost converted into

dry vapour.

* This vapour is again compressed through the compressor.

* This way this cycle is repeated again & again.

* The cooled water may be taken out & fresh water may be added to the tank for cooling.



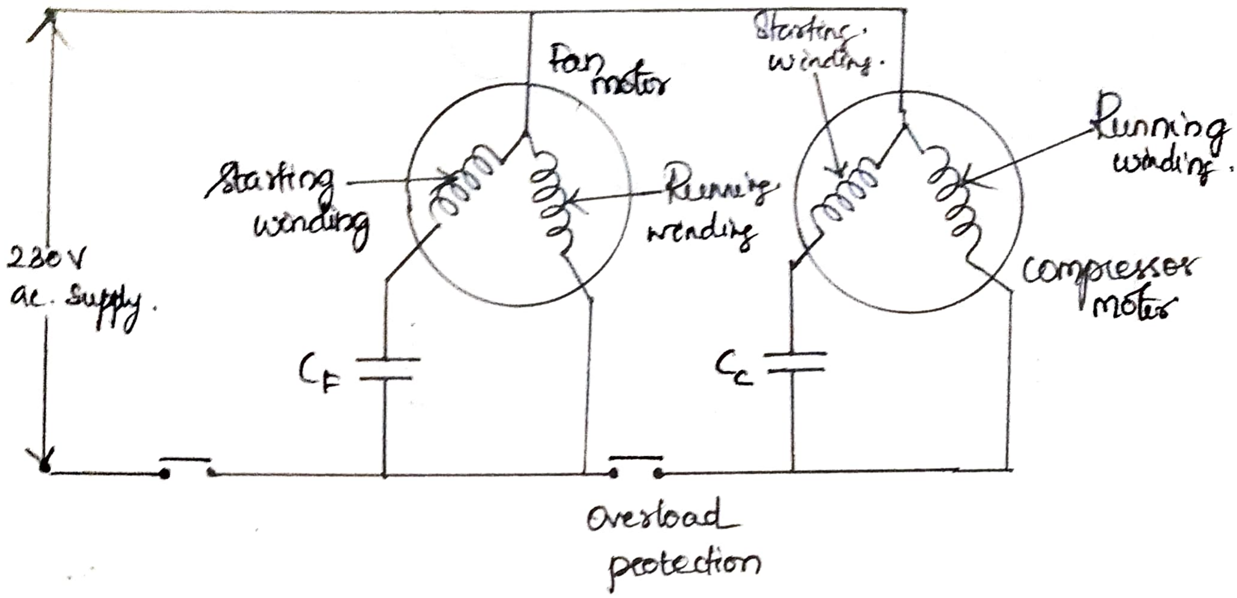
Electrical circuit in water cooler

* 2 single phase induction motors are used.

* One is fan motor other is compressor motor.

* The fan motor is a capacitor start motor

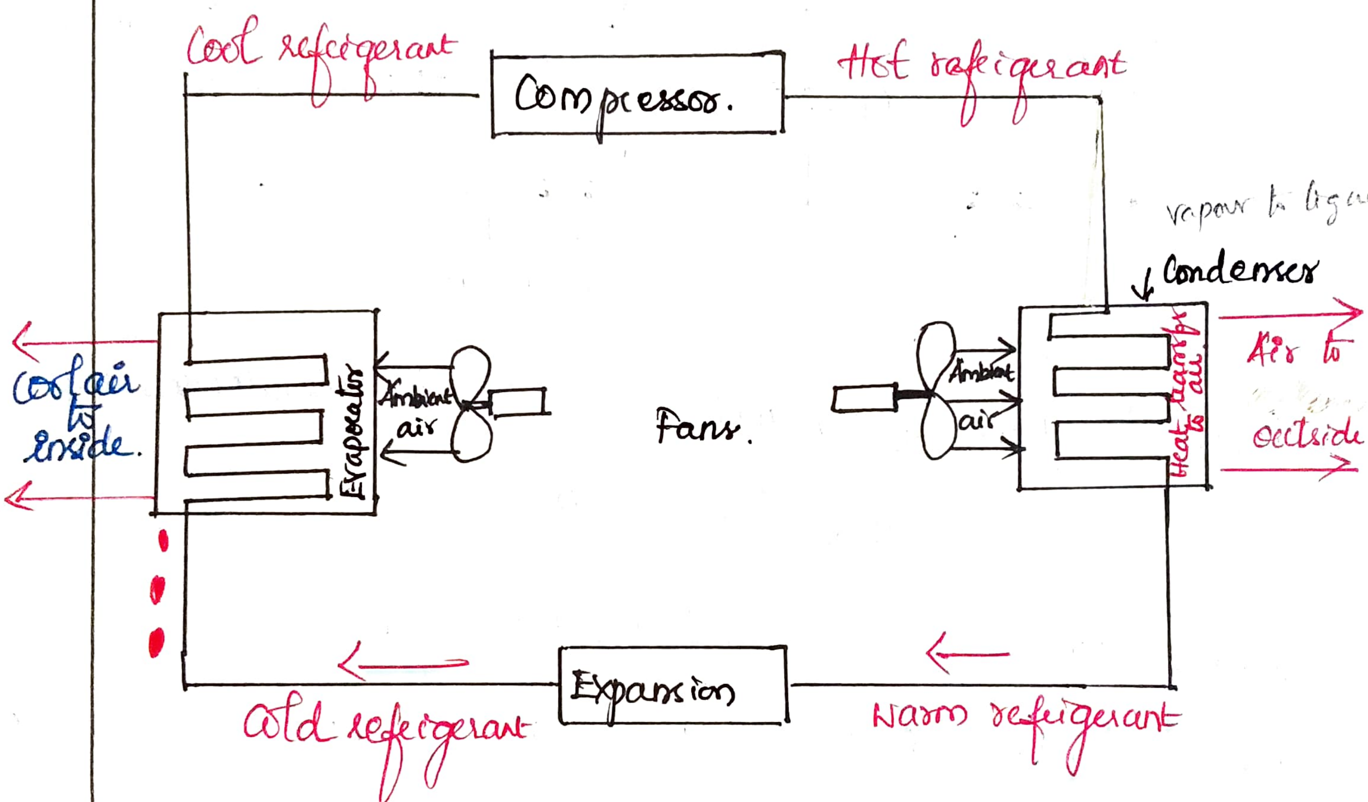
but its capacitor remains in the circuit during running also.



* The function of fan motor is to cool the condenser by forced air circulation by a fan.
* The compressor is circulated by a fan.
* The compressor motor is a capacitor start capacitor run motor.
* The capacitor C_c used in compressor motor is of large capacity as compared to fan motor.
* The capacitor (C_c) used in compressor motor is of large capacity as compared to the fan motor.
* The capacitor improves the power factor and starting torque of motor.

Air Conditioning :-

An air conditioner collects hot air from a particular room, processes with a help of refrigerant & a series of coils and then releases cool air into the same room where the hot air was originally collected.



* The evaporator coil absorbs heat & expels moisture from the incoming air.

* This hot refrigerant is then passed to the compressor located on the external unit in case of AC.

* The compressor compresses the cooling gas to heat up because compressing the gas raises its heat.

* This hot high pressure gas then moves to condenser
* Condenser condenses hot air vapour to become a liquid
* The heat is transmitted to the surrounding atmosphere through metal fins.
* As the refrigerant leaves the condenser, it loses its high temperature & becomes a more cooling liquid
* Then it flows through an expansion valve - and after it reaches evaporator.
* The entire process is repeated until the desired temperature is attained.
* Filters are usually located to clean the air by removing dust & dirt particles.

Smart Air Conditioning System:

* Smart AC allows to maintain home temperature using a smartphone.

* Their function can be controlled via an app that you can download on your phone.

* The ability of smart air conditioning system to connect to internet.

* The smart ACs look similar to the conventional AC that you have in your home, but are one step ahead in saving energy.

* Geolocation: Geolocation is a feature helps in determining the location of an object. This feature in smart AC allows to program its functioning as per your location like air conditioner shutting off when we exit home, with smartphones. Allows to set temperature triggers based on distance from home or office. This helps in saving energy.

* Weekly scheduling:

* Schedules can be set regarding fan speed, cooling mode, vane direction etc.

* Can set a particular temperature at particular ^time day or night.

* can set our AC to operate at certain time alone when return from office.

* Wifi controls allow us to pause or edit our ACs schedule from anywhere, anytime if there is change in routine.

Smart home Integration:

* Smart ACs can be integrated with smart home system such as google Assistant, siri, Alexa, allowing to control AC through Voice commands.

Smart AC modes:

* Additional modes are available in addition to heat, dry, fan, cool, eco etc.

* Eg. Comfy mode :- which lets you set up your preferences for your room temperature, atomatically adjust the settings. with changing climate.

Usage details:

* By keeping a track of ACs usage history, we can save energy & thus save energy bills.

Motor Life Cycle:

* 3 types of motors have been considered.
  1) Synchronous reluctance motor.
  2) Permanent magnet assisted Synchronous reluctance motor.
  3) Induction motor.

* The assessment of life cycle has been made in terms of its 4 stages.
  i) Manufacturing.
  ii) Distribution.
  iii) Use.
  iv) End of life.

* It is not yet standard engineering practice to make a life cycle cost analysis & base investment decisions on the least cost.

* It involves a careful estimate of operating conditions, energy & maintenance costs, taking into account the dynamics & magnitude of potential annual annual energy cost increases.

* It is much more Common to make a simple payback period analysis comparing the total cost of investment to commercial operating profits.

* More efficient motors contain more active material than standard efficiency motors & thus incur additional costs.
* Actual sale prices are not publicly available.
* They are heavily dependent on individual discount & rebate schemes based on customer volume.

→ discounts seem not to vary with efficiency classes.

→ discounts of 30% to >70% compared to published list prices are common.

→ Prices tend to vary with potential purchase volume & copper price.

→ Specific motor prices tend to be almost flat b/w 5kW & 15kW.

→ Relative motor prices for higher efficiency classes are higher below 20kW.

→ Additional prices for VFD are much higher than one or ~~two~~ additional efficiency classes.

* The transition b/w old classification scheme (Eff1, Eff2 and Eff3) and the new IE scheme (IE3, IE2, IE1) has not been fully digested.

* As long as market demand stimulated by MEPS doesnot require IE3, no stable Volume or stock is available & as a result no price competition exists.

* It is envisaged that the price premium b/w IE3 & IE2 & IE1 will fall and that the additional cost of VFD with standard & integrated solutions will diminish.

* Based on current average European electricity price for industry (EUR 0.075/KWh), the key criterion for cost effectiveness of premium IE3 motors to replace IE1 or IE2 is annual hours of operation. Motors with over 2000 hours per year are cost effective with current industry electricity prices.

UNIT - III

Heating and Welding

Electric heating:

Heat produced by passing the current through the material to be heated is called electric heating.

Advantages of Electric heating.

i) Economical.
ii) Dust & ash completely eliminated.
iii) No pollution.
iv) Temperature can be controlled.
v) Substances can be heated uniformly.
vi) overall efficiency is high (75-100 %)
vii) Heat development in non-conducting material such as wood & porcelain is possible.
viii) Electric heating is safe.

Modes of Heat transfer:

1. Conduction.
2. Convection.
3. Radiation.

Conduction:

* Heat transfer from one part to other part without the movement of molecule of substance.

Convection:

* In this mode heat transfer takes place from one part to another part due to motion of molecule.

Eg. Immersion water heater.

Radiation:

* Heat transfer from source to the substance to be heated without heating the medium in b/w.

Eg. solar heater.

Essential element of good heating Element (or) properties:

i) High Specific Resistance: So that small length of wire may be required to produce necessary heat.

ii) Should have high melting point; so that it can withstand for high temperature.

iii) Free from oxidation: The element material should not be oxidised when it is subjected to high temperature.

iv) Material should have high mechanical strength and should withstand for mechanical vibration.

v) The element should not corrode.

vi) Cost should not be high.

Material used for heating element:

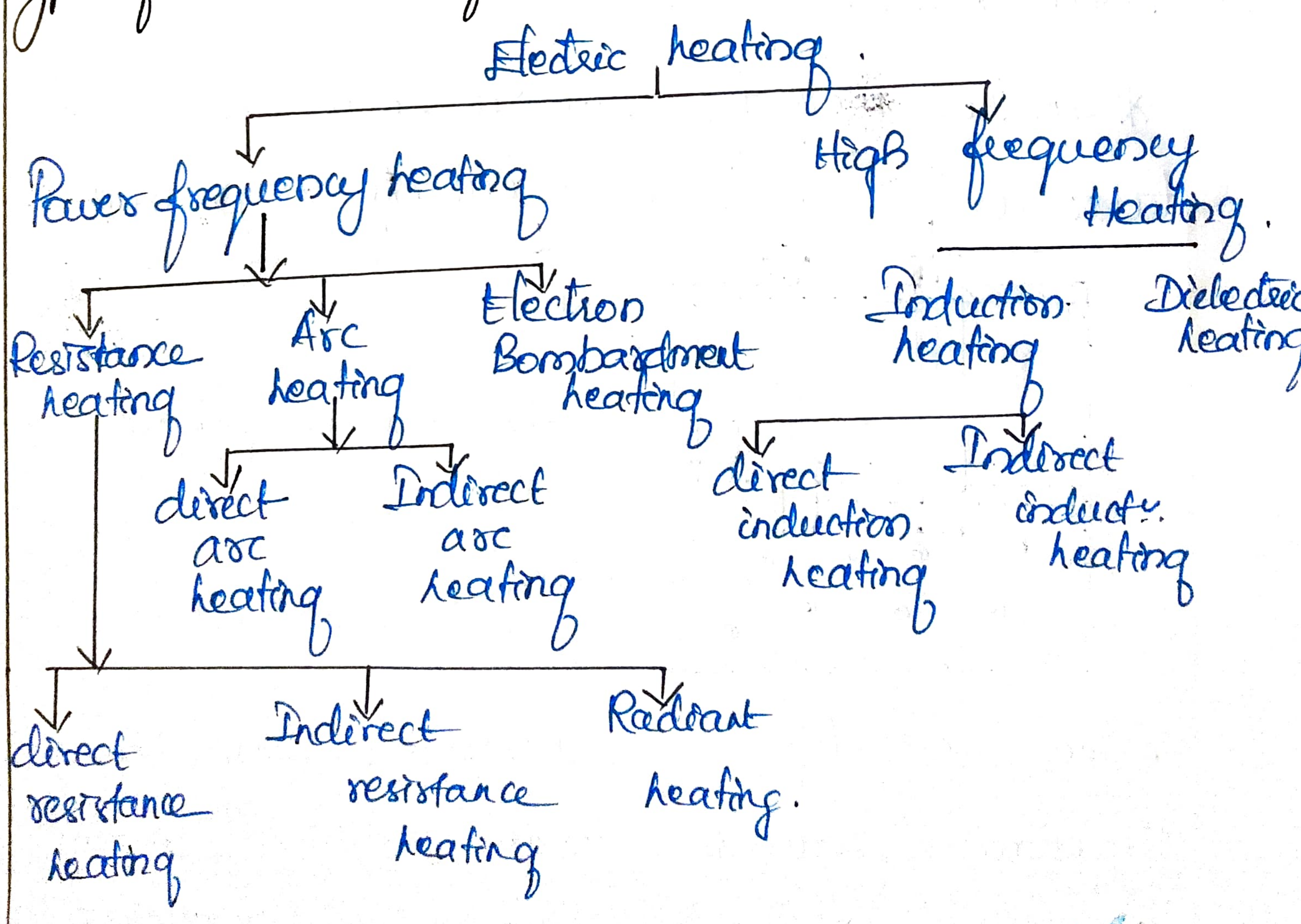
i) Nickel-chromium.

ii) Nickel-chromium-iron.

iii) Nickel-chromium-aluminium.

iv) Nickel-copper.

Types of Electric heating:



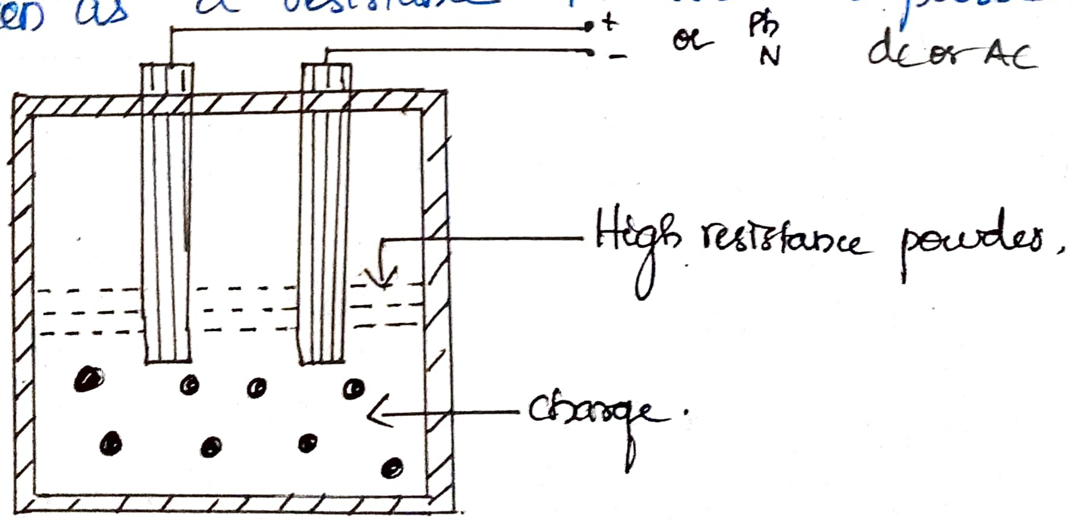
Resistance Heating:

* When electric current is made to pass through a resistive body, a powerloss takes place in it, which result in the form of heat energy called Resistance heating.

* Applications are
  → drying.
  → baking of potteries.
  → domesting cooking.

i) Direct Resistance heating:

* In this method, material to be heated is taken as a resistance & current is passed thro it.



* The electrodes are immersed in a charge. The charge may be in the form of powder, pieces or liquid & electrodes are connected to supply.

* The electrodes are connected to AC or DC.

* In case of dc or 1-ϕ ac, two electrodes are required. But 3-electrodes are needed in case of 3-ϕ supply.

* When metal pieces are to be heated, the powder of lightly resistive is sprinkled over the surface of charge.

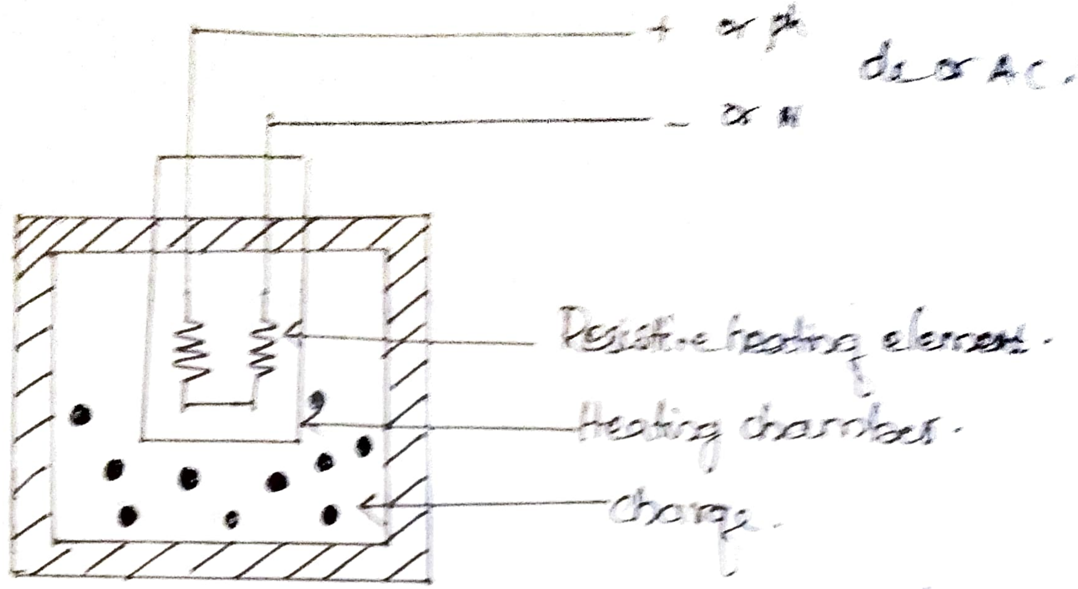
* The current flow through the charge and heat is produced in charge itself.

* This method is highly efficient, since heat is produced in the charge itself.

Indirect Resistance Heating:

* In this method, high I is passed through heating element.

* In case of industrial heating, the heating resistance is placed in a cylinder which is surrounded by a charge placed in a jacket called heating chamber.



* The arrangement provide uniform temperature and automatic temperature control.

* It is mainly used in immersion water heater, room heater & resistance oven.

(ii) <u>Radiant heating</u>:-

* In this method of heating, heat transfer takes place from source to the body to be heated through radiation. for low & medium temperature applications.

* In radiant heating, the heating element consists of tungsten filament lamps together with reflector & to direct all the heat on the charge.

* Tungsten filament lamps are operating at 2,300°c

Instead of 3000°C to give greater portion of infrared radiation & a longer life.

* The radiant heating is mainly used for drying enamel or painted surfaces.

* The high concentration of radiant energy enables the heat to penetrate the coating of paint or enamel to a depth sufficient to dry it out without wasting energy in the body of the workpiece.

* The main advantage of radiant energy is that the heat absorbtion remains approximately constant whatever the charge temperature, whereas with the ordinary oven the heat absorbtion falls off very considerably as the temperature of the charge rises.

* The lamp ratings used are usually b/w 250 & 1000 W and are operating at Voltage of 115V in order to ensure a robust filament.

Induction Heating:

* The heating of conducting material, such as ferro-magnet and non-ferromagnet is known as induction heating.

* The induction heating process make use of the current induced by electromagnetic action in the material to be heated.

* The factors affecting the induction heating is,

  i) Primary coil current.

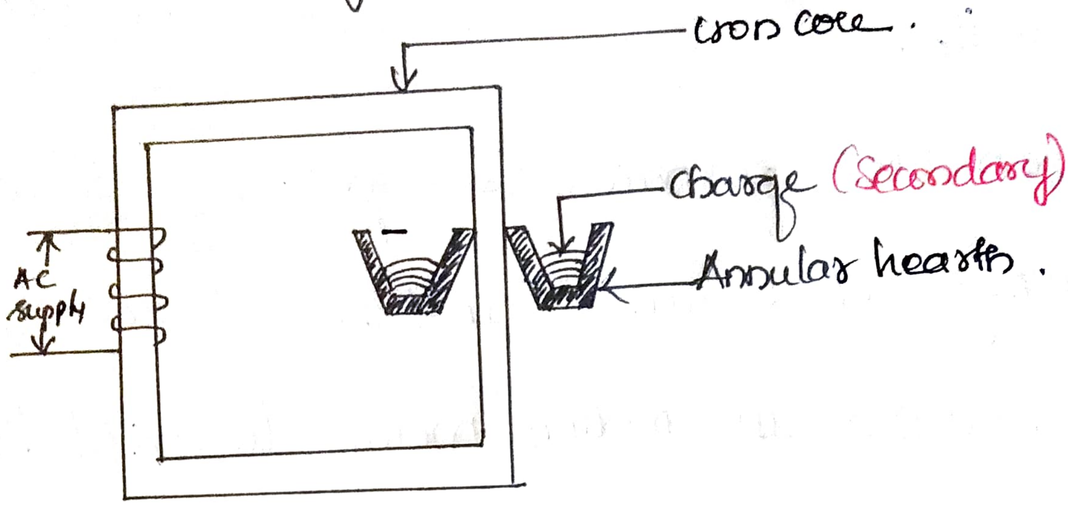
  ii) The no. of turns of the coil.

  iii) Supply frequency.

Types of Induction furnace.

- Induction
  - core type
    - direct core type
    - indirect core type
    - Vertical core type.
  - coreless type

Direct Core type Inductance furnace :



* It consists of an iron core, primary winding connected to an ac supply.
* For secondary, the charge is kept in the crucible, which form a single turn short circuited secondary circuit.
* The furnace consists of circular hearth, which contains the charge to be melted in the form of an annular ring.
* The magnetic coupling between primary & secondary is weak, it results in high leakage reactance & low power factor.
* To overcome the leakage reactance, the

furnace should be operated at low frequency of 10 Hz.

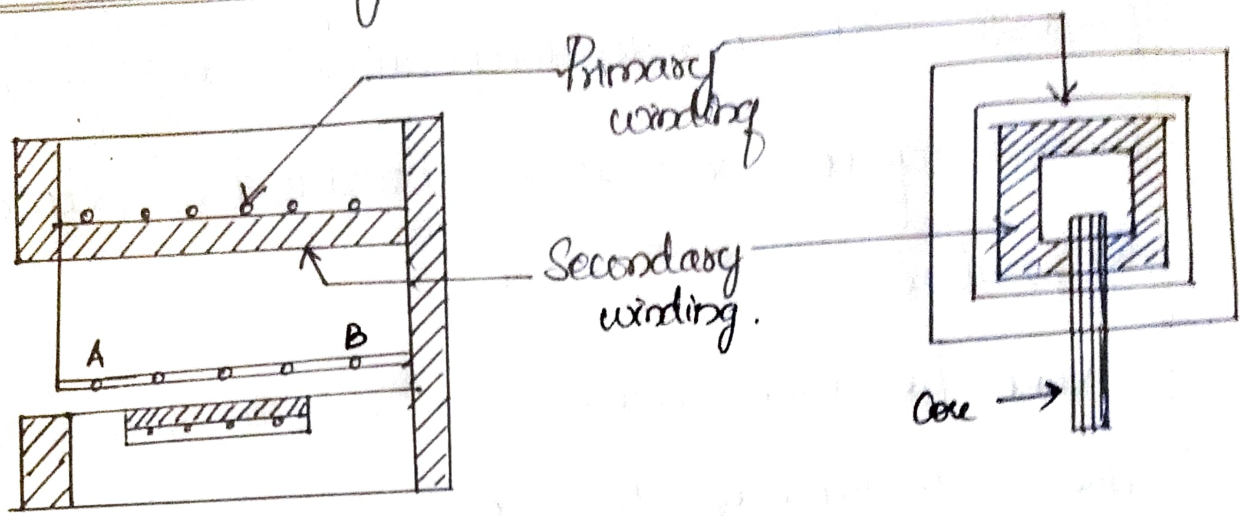
* When the furnace is operating at normal frequency which cause unstable & severe stirring action in molten metal to avoid this difficulty, it is also necessary to operate the furnace at low frequency.

* Inorder to obtain low frequency supply, seperate motor - generator set or frequency changer is to be provided, which involves extra cost.

* When there is no metal in the hearth, the secondary becomes open circuited thereby cutting of secondary current.

* Hence to start the furnace, molten metal has to be taken in the haarth to keep the secondary as short circuit.

Indirect Core type Induction Furnace:



* In this type of furnace, an individually heated element is made to transfer its heat to the charge by radiation.
* It consists of iron core linking with primary winding & secondary winding.
* Primary winding is connected to ac supply.
* Secondary consists of a metal container forming the wall.
* It consists of magnetic circuit AB made up of special alloy & kept inside the chamber of furnace.

* The magnetic circuit loses its magnetic properties at certain temperature and regains them again when it is cooled to the same temperature.

* When the oven reaches to critical temperature the reluctance of magnetic circuit increases many times & inductive effect decreases there cutting off the supply heat.

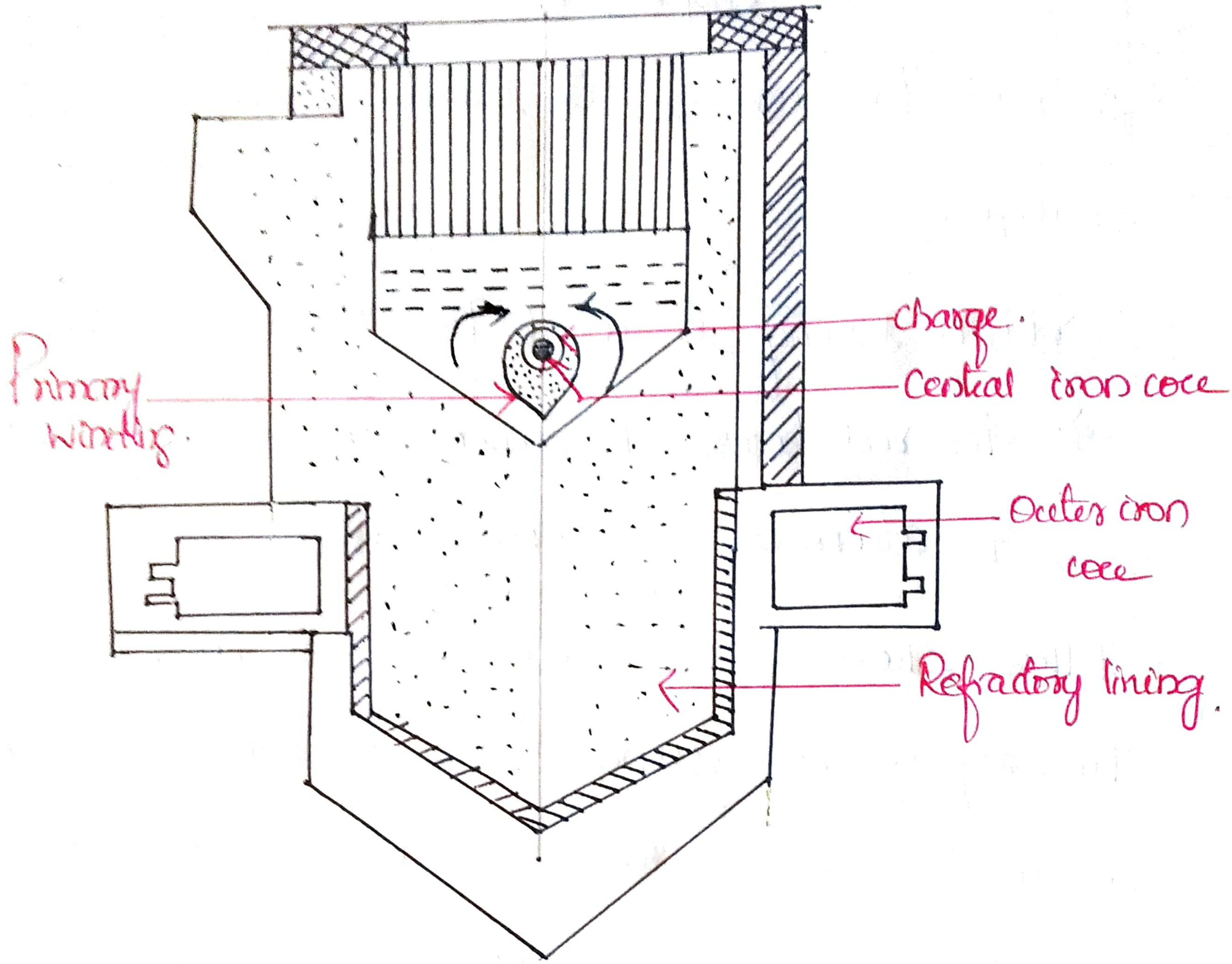
* The magnetic circuit 'AB' is detachable type that can be replaced by the other magnetic circuit having critical temperature ranging b/w 400°c & 1000°c.

* The furnace operate at a p.f around 0.8.

* Temperature control is possible.

Vertical core type Induction Furnace:

* This is an improved form of furnace, to overcome the disadvantage of direct core inductance furnace.



* It is also known as Ajax - wyatt inductance furnace.

* This type of furnace consists of vertical core instead of horizontal core.

* V_channel is narrow, so even a small quantity of charge is sufficient to keep the secondary circuit closed.

* In certain furnaces instead of V-shaped channels U- shaped channel or rectangular

channels are employed.

* Inside of the furnace is lined depending upon the charge.

⇒ clay lining is used for yellow brass.

→ For red brass & bronze an alloy of magnesia & alumina is employed.

* The shell of a furnace is of heavy steel. The top of the furnace is covered with an insulated cover which can be removed for charging.

* Hydraulic arrangement are usually made for tilting the furnace to take out the molten metal.

<u>Advantages:</u>

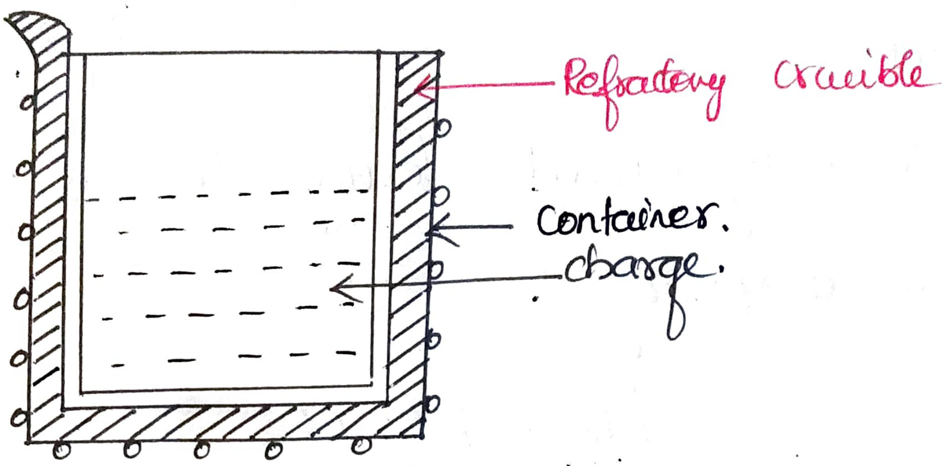
i) Accurate temperate control.

ii) High power factor with normal supply frequency.

iii) High efficient heat, low operating cost.

<u>Coreless type Induction Furnace:</u>

* It is a simple furnace with no core.



* In this furnace, heat developed in the charge due to eddy current flowing through it.
* The furnace consists of a refractory or ceramic crucible cylindrical in shape enclosed within a coil that forms primary of transformer.
* The furnace also contain a conducting or non-conducting container that act as a secondary.
* When primary coil are excited by an alternating source, the flux setup by these coils induce the eddy current in the charge.
* The direction of the resultant eddy current is in the direction opposite to the current in primary coil.

* There current heat the charge to the melting point.

* The eddy current developed in any magnetic circuit is g. by,

$$W_e \propto B_m^2 f^2.$$

B_m : maximum flux density.

f : frequency in Hz.

W_e : eddy current loss.

Dielectric Heating:

* When a non-metallic material ie. insulators such as wood, plastic, china glass are subjected to high voltage alternating source the atom get stress due to friction caused by the repeated deformation & rotation of atomic structure, heat is produced. This is called dielectric loss.

* This loss is due to reversal of magnetism.

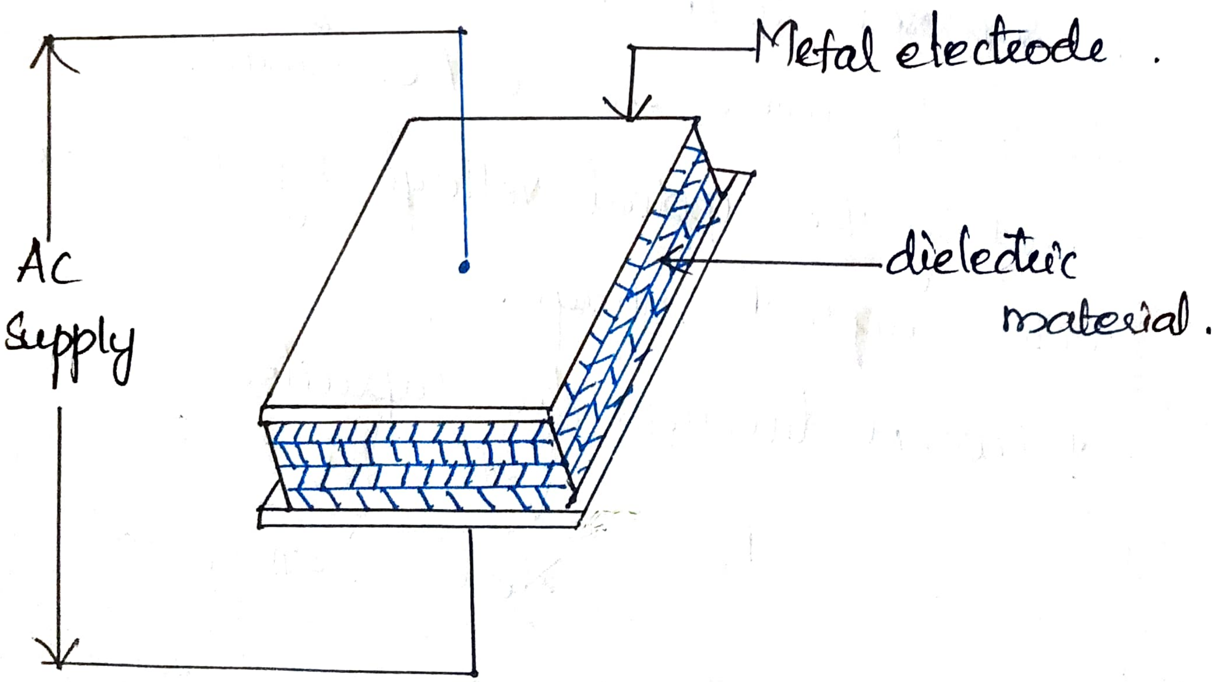
* These losses developed in a material

that has to be heated.

* The material to be heated is placed as a slab between metallic plates or electrodes connected to high frequency ac supply.

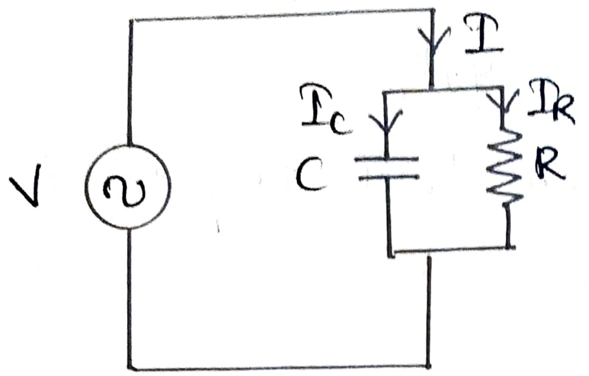
* For producing sufficient heat frequency 10 & 30 MHz is used.

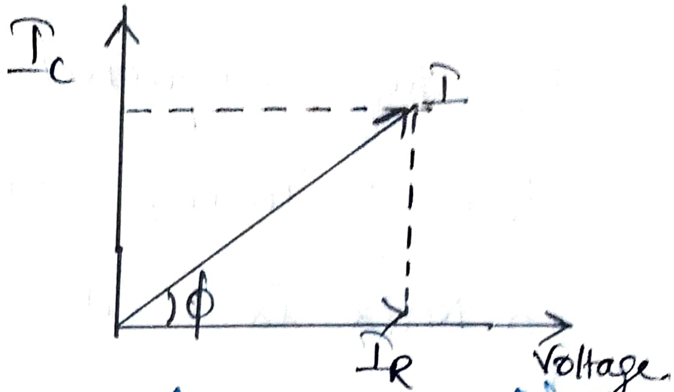
* Voltage 20kV is used but for personnel safety point of view Voltage between 600V & 3kV are in common use.



* When an ac supply Voltage is applied across its two plates due to current, heat is produced in the dielectric material.

* All dielectric material can be represented by a parallel combination of a leakage resistor 'R' and capacitor 'C'.





* If an AC voltage is applied across a piece of insulator, an electric current flows, total current I supposed to be made up of two components I_c & I_R where I_c is the capacitive current leading the applied voltage by 90° & I_R in phase with applied voltage.

* Current through the capacitor,

$$I_c = \frac{V}{X_c} = \frac{V}{1/2\pi f c}$$

$$I_c = V 2\pi f c \text{ (amp)}.$$

c (farads).

V → Volts.

* The current drawn from supply,

$$I = I_c = 2\pi f C V \quad \text{(amp)}.$$

Power produced, $P = V I \cos\phi$.

$$= V \times 2\pi f C V \times \cos\phi \quad \text{(watt)}.$$

$$P = 2\pi f C V^2 \cos\phi \quad \text{(watt)}.$$

* Therefore, the dielectric heating depends upon the frequency & Voltage.

* By varying one of these 2 quantities the rate of dielectric heating can be varied.

* The capacity of the condenser can be calculated from,

$$C = \frac{\varepsilon_0 \varepsilon_r A}{t} \quad \text{(farads)}$$

ε_r → relative permittivity of dielectric.

ε_0 → absolute permittivity of vacuum & equal to 8.854×10^{-12} F/m.

t → thickness of dielectric (m)

A → Surface area of plates (m^2).

Advantages:

i) The heating of non-conducting material is very rapid.

ii) The uniform heating of material is possible.

iii) Heat is produced in the whole mass of the material.

Application:

i) The drying of paper, wood etc.

ii) The gluing of wood.

iii) The heating of bones & tissues.

iv) The processing of rubber, synthetic materials, chemical etc.

v) It is used in plastic industry.

Arc heating:

* If the high voltage is applied across an air gap, the air in the gap get ionized under the influence of electrostatic force and becomes conducting medium, current flows in the form of a continuous spark known as arc.

* A very high voltage is required to establish an arc but very small voltage is sufficient to

maintain it, across the air gap.

* The high voltage required for striking an arc can be obtained by using a step-up transformer fed from a variable AC supply.

* Another method of striking the arc by using low voltage is by short circuiting the 2 electrodes.

* Electrode made up of carbon or graphite are used in the arc furnace when the temperature obtained in the range of 3000 - 3500°c.

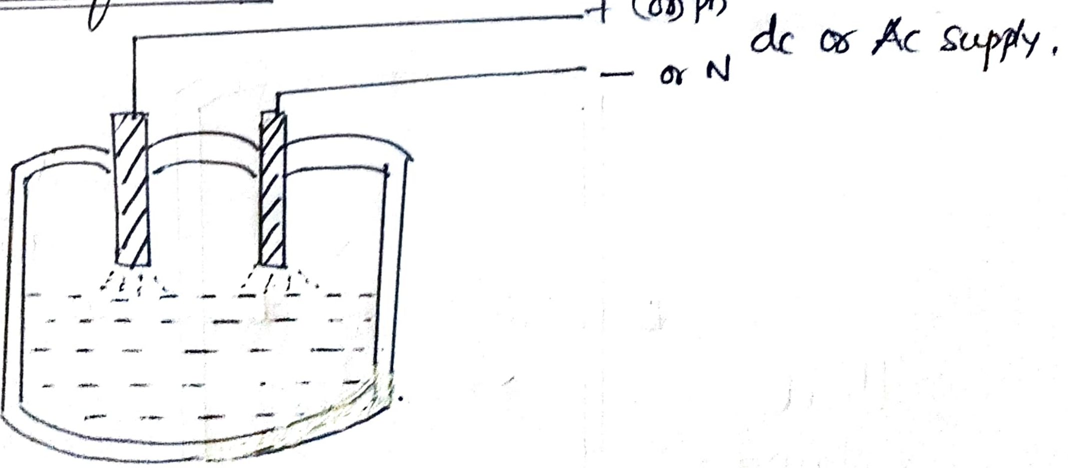
Types of Arc Furnace :

There are 2 types of arc furnace, they are

i) direct arc furnace.

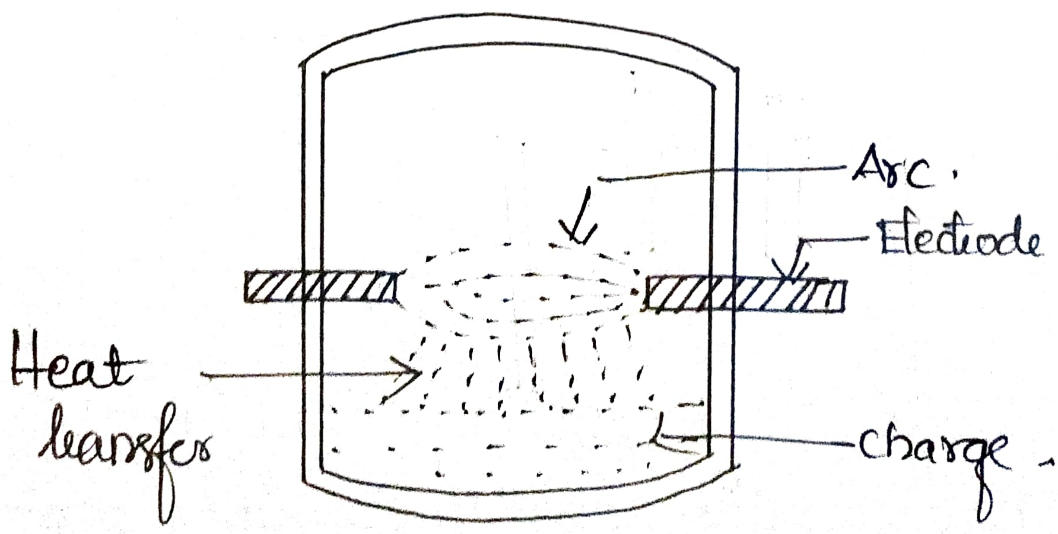
ii) Indirect arc furnace.

Direct arc furnace :



* when supply is given to the electrodes two arc are established and current passes through charge.
* As the arc is in direct contact with the charge and heat is also produced by current flowing through the charge itself it is known as direct arc furnace.
* If the available supply is dc or 1-ϕ AC supply 2 electrodes are sufficient, if the supply is 3-ϕ AC, 3 electrodes are needed.
* It is very simple and easy to control, the power factor of arc furnace is 0.8 lagging.

Indirect arc furnace :



* In indirect arc furnace the arc is formed between 2 electrode above the charge & heat is transmitted by the charge by radiation.
* In this case the temperature of the charge is lower than that of direct arc furnace.
* In this furnace current doesnot flow through the charge there is no stirring action and the furnace is required to be rocked mechanically.
* This furnace is made of cylindrical shape, with electrodes projecting through the chamber from each end & along the horizontal axis.
* By rocking action there is thorough mixing of the charge. This furnace is also sometimes called as rocking arc furnace.
* The charge in this furnace is heated not only by radiation from the arc b/w electrode tips but also by conduction from the heated refractor during rocking action.

* Efficiency of the furnace is high.

Application:

* Melting of non-ferrous metal like copper, bronze gun metal, nickel etc.
* Power factor is 0.87 & efficiency 70%.

Electric Welding:

Welding is the process of joining two pieces of metal or non-metal together by heating them to their melting point.

Advantages of Welding:

* Welding is the most economical method to permanently join 2 metal parts.
* It joins all the commercial metals.
* Both similar & dissimilar metals can be joined by welding.
* Portable welding equipment are available.

Disadvantage.

* Welding gives out harmful radiation & fumes.

* If welding is not done carefully, it may result in the distortion of workpiece.
* Skilled welding is necessary to produce good welding.

Electric Welding

- Resistance Welding
  - Spot welding.
  - Seam welding
  - Projection welding
  - Butt welding.
- Arc welding
  - Metal Arc welding
  - carbon arc welding
  - Atom hydrogen arc welding
  - Helium (or) argon welding

Resistance Welding:

* Resistance Welding is defined as process in which a sufficiently strong electric current is sent through the two metal piece in contact to be welded which melts the metal by the resistance they offer to the flow of electric current.

* The heat produced by the resistance to the

flow of current is given by,

$$H = I^2Rt.$$

I – current through the electrodes.

R – Resistance of the interface.

t – time for which current flow.

Advantage of Resistance welding:

* Welding process is rapid & simple.
* Maintenance cost is less.
* Less skill is required.
* Both similar & dissimilar metal are welded.

Disadvantage of Resistance Welding:

* Initial cost is high.
* High maintenance cost.
* The workpiece with heavier thickness cannot be welded, since it requires high input current.

Application:

* It is used for manufacturing tubes, thinner gauge metals.

UNIT - IV .

TRACTION

Merits of Electric traction - Requirements of electric traction system - Supply System - Mechanics of train movement - traction Motors & control - Braking Recent trends in Electric traction.

Merits of Electric traction :

* Electric traction system is more clean and easy to handle.
* No need of storage of coal & water that in turn reduces the maintenance cost as well as the saving of high grade coal.
* The maintenance & running costs are comparitively low
* The speed control of the electric motor is easy.
* Regenerative Braking is possible so that the energy can be fedback to the supply system during the Braking period.

* In electric traction, electric braking can be used that reduces the wear on the brake shoes, wheels etc.
* Electric energy is sufficient for fan, lights inside locomotives.

Requirements of Traction System:

* The speed control should be easy.
* Vehicles should be able to run on any route, without interruption.
* It must be free from smoke, ash, dirt etc.
* Regenerative braking should be possible & braking should be in such a way to cause minimum wear on the break shoe.
* Locomotive should be self-contained & it must be capable of withstanding over loads.
* Interference to communication lines should be eliminated while the locomotive running along track.
* High rapid accelerelation must be there.

Supply System:

Classified as,

(i) DC system.

(ii) Single phase AC system.

(iii) Three phase AC system.

(iv) Composite System.

DC system:

* The electric motors employed for getting necessary (உந்துதல், drive) propelling torque should be selected in such a way that they should be able to operate on DC supply.

* Eg. Tramways (rails), Trolley (rubber tyre) Buses.

* Usually DC series motors are preferred for Tramways & trolley Buses.

* The operating voltages of Vehicles for DC track electrification system are 600, 750, 1500 and 3000V.

* DC at 600-750V is universally employed for tramways in urban areas.

* For many suburban and main line railways 1500 – 3000V is used.
* DC supply for traction motor can be obtained from substations equipped with rotary converters to convert AC power to DC.

Single phase AC System:

* AC Series motors are commonly used for getting necessary propelling power.
* Normally 15 – 25KV, at reduced frequency of $16\frac{2}{3}$ Hz or 25 Hz is used, by frequency converter.
* Reason for low frequency is, AC series motors are more efficient at low frequency.
* The high Voltages are step down to 300 – 400V by means of step-down transformer.
* Low frequency operation reduces line reactance.
* Single phase AC System is mainly preferred for suburban services where rapid acceleration &

retardation is not required.?

Three phase AC System :

* 3-ϕ Induction motors are employed.

* The operating voltage is 3000V – 3,600 V AC at either normal frequency or 16 2/3 -Hz frequency

* 3-ϕ Induction motors have many advantages like simple and robust construction, high operating efficiency provision of regenerative braking, better performance at both normal & reduced frequencies.

* But there are disadvantages like low starting torque, high starting current & absence of speed control

* The main disadvantage of 3-ϕ AC is high cost of overhead distribution structure.

* This distribution system consists of 2 overhead wires and track rail for third phase.

* Three phase AC system is mainly adopted for the services where the output power required is high & regeneration of electric energy is possible.

Composite System:

Why?

* 1-ϕ AC system is preferable in the view of distribution cost & distribution voltage can be stepped up to high voltage with the use of transformers (reduces losses)
* Whereas in DC system, DC series motors have most desirable features & for 3-ϕ system, 3 ϕ IM has advantage of automatic regenerative Braking.

So it is necessary to combine the advantage of DC/AC and 3-ϕ/1-ϕ Systems. Hence Composite Systems.

2 types:

(i) Single phase to DC System.
(ii) Single phase to 3-ϕ S/m (or) Kando S/m.

i) Single phase to DC System:

* The advantage of 1-ϕ & DC systems are combined.

⇒ 1-ϕ S/m : High voltage for distribution for reducing losses. ← (achieved).

DC - S/m : DC series motor is employed for producing necessary propelling torque (achieved)

* Hence 1-ϕ + DC S/m s are combined.

* 1-ϕ AC distribution network results minimum cost with high transmission efficiency.

* DC series motor is ideally suited for traction purpose.

* Normal operating Voltage : 25KV.

frequency : 50Hz.

* This System is employed in India.

ii) Single phase to 3-ϕ System (or) Kando System:

* In this system 1-ϕ AC system is preferred for distribution network, Since single-phase overhead distribution system is cheap.

* 3-ϕ IM are employed as traction motor because of their simple, robust construction & automatic regenerative braking.

* Voltage : 15 - 25 kV.

* frequency : 50 Hz.

* $1-\phi$ supply is converted to 3ϕ supply through phase converters.
* Frequency converters are also employed to get high starting torque & to achieve better speed control with variable supply frequency.

Mechanism of Train Movement:

i) Tractive Effort: (F_t).

⇒ It is the effective force acting on the wheel of locomotive, necessary to propel the train is known as "tractive effort".

⇒ The tractive effort is a vector quantity always acting tangential to the wheel of a locomotive.

⇒ Measured in Newton.

⇒ The net effective force or the total tractive effort (F_t) is equal to sum of tractive effort.

(i) Required for linear & angular acceleration (F_a).

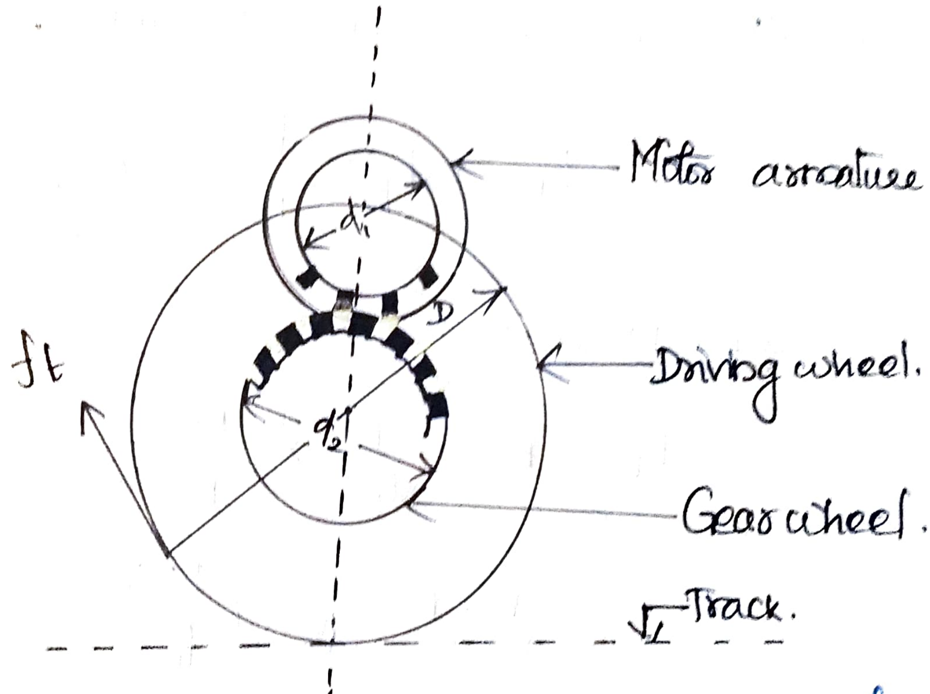
(ii) To overcome the effect of gravity (F_g)

(iii) To overcome frictional resistance (F_r)

Mechanics of train Movement. (ii) Driving Mechanism:

* The electric locomotive consists of pinion & gear wheel meshed with the traction motor & the wheel.

* Here the gear wheel transfers the tractive effort at the edge of the pinion to the driving wheel.



* Let 'T' is the torque exerted by the motor in N-m.

F_p : tractive effort at the edge of the pinion (N).

F_t : tractive effort at the wheel.

D : Diameter of driving wheel.

d_1, d_2 : diameter of pinion & gear wheel.

η : efficiency of power transmission for motor to the driving axle.

(or) efficiency of gear.

* torque developed by the motor, $T = F_p \times \frac{d_1}{2}$ (N-m)

$$F_p = \frac{2T}{d_1} \text{ (N)} \quad \text{——— (1)}$$

* The tractive effort at the edge of the pinion transferred to the wheel of locomotive is,

$$F_t = \eta \times F_p \times \frac{d_2}{D} \text{ (N)} \quad \text{——— (2)}$$

Subs (1) in (2)

$$F_t = \eta \times \frac{2T}{d_1} \times \frac{d_2}{D}$$

$$= \eta \cdot T \cdot \frac{2}{D} \cdot \left(\frac{d_2}{d_1}\right)$$

$$F_t = \eta T \frac{2}{D} \cdot \gamma$$

Gear ratio, $\gamma = \frac{d_2}{d_1}$

$$F_t = \frac{2 \eta T \gamma}{D} \quad \text{——— (3)}$$

(4) Tractive effort required for propulsion of train.

The tractive effort required for train propulsion is,

$$F_t = F_a + F_g + F_r$$

F_a : force required for linear & angular acceleration.

F_g : force required to overcome the gravity.

F_r : Force required to overcome the resistance to the motion.

Force required for Linear & Angular acceleration (F_a)

WKT,

Force = mass × acceleration.

$$F = ma.$$

let, mass of train = 1000W kg.

acceleration = α kmphps

$$= \alpha \times \frac{1000}{3600} \ (m/s^2)$$

$$= 0.2788\alpha \ (m/s^2)$$

W : weight of train (tons).

The tractive effort required for linear acceleration:

$$F_a = 1000\,W\,kg \times 0.2778\,\alpha\ (m/s^2).$$

$$= 277.8\,W\,\alpha\ kg\text{-}m/s^2\ \text{(or) } N \quad \text{——— (4)}$$

* Above eqn holds good if the accelerating body has no rotating parts.

* But train has motor armature, wheels, axels, & gear system.

* The weight of the body being accelerated including the rotating parts is known as "effective weight (or) accelerating weight." (W_e).

* The accelerating weight is much higher (8–15 %) than the dead weight (W) of the train.

* Hence eq: (4) becomes,

$$F_a = 277.8\,W_e\,\alpha\ (N).$$

Tractive effort required to overcome the train resistance (F_r):

* When the train is running at uniform speed

on a level track, it has to overcome the opposing force due to the surface friction, i.e. the friction at various parts of the rolling stock, the friction at the track and also due to the wind resistance.

* The magnitude of the frictional resistance depends upon the shape, size & condition of the track & velocity of the train etc.

* γ : Specific train resistance in N/ton of dead weight.

* W : dead weight in ton.

The tractive effort required to overcome train resistance $F_\gamma = W\gamma (N)$

iii) Tractive effort required to overcome the effect of gravity (F_g)

* When the train is moving on up gradient, the gravity component of dead weight opposes the motion of the train in upward direction.

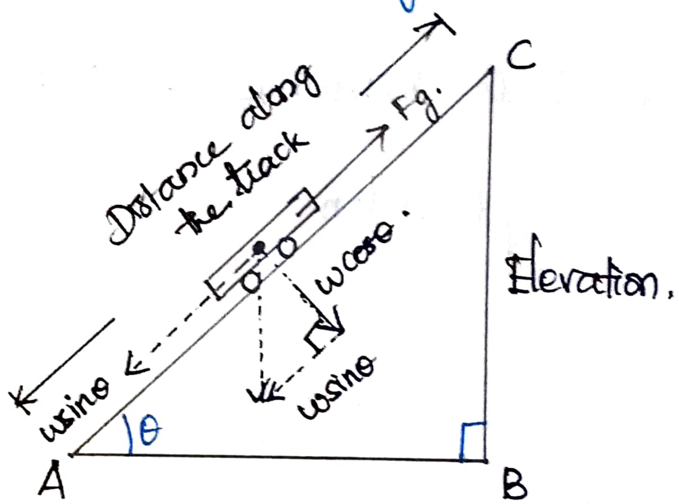
* Inorder to prevent this opposition, the tractive effort

should be acting in upward direction.

* The tractive effort required to overcome the effect of gravity,

$$F_g = \pm mg\sin\theta \quad (N).$$

$$= \pm 1000\, Wg \sin\theta \quad \text{---}(7) \quad [\because m = 1{,}000W\ kg]$$



From fig,

$$\text{Gradient} = \sin\theta.$$

$\sin\theta = \frac{opp}{hyp}$

$$= \frac{BC}{AC}$$

$$= \frac{\text{Elevation}}{\text{distance along the track}}.$$

$$\%\ \text{Gradient} = \sin\theta \times 100. \quad \text{---}(8)$$

From eq^{n}s (7) & (8)

$$F_g = \pm 1000 W g \frac{G}{100}.$$

$$= \pm 10 \times 9.81 \, WG. \qquad [g = 9.81 \, m/s^2]$$

$$= \pm 98.1 \, WG \ (N) \quad \text{———} (9).$$

$\pm$ Sign for train moving on up & down gradient.

From, (5), (6), (9)

$$F_t = 27.78 W_e \alpha + W r \pm 98.1 \, WG \quad (N).$$

Power output from the driving axle:

F_t : tractive effort (N).

V : speed of train (kmph). $\left(\frac{1000}{3600}\right)$

The power output (P) = rate of work done.

$$= \text{Tractive effort} \times \frac{\text{distance}}{\text{time}}$$

$$= \text{Tractive effort} \times \text{speed}.$$

$$= \frac{F_t \times V \times 1000}{3600} \quad (W)$$

$$= \frac{F_t \times V}{3600} \text{ (kW)}$$

If 'v' is in m/s, then $P = F_t \times v \text{ (W)}$.

$$\eta = \frac{o/p}{i/p}$$

$$\eta = \frac{F_t V}{P}$$

$$P = \frac{F_t v \text{ (W)}}{\eta} \quad \left[\text{For } m/s\right]$$

$$P = \frac{F_t V}{3600\,\eta} \text{ (kW)} \quad \left(\text{For Kmph } \frac{1000}{3600}\right)$$

Specific Energy consumption.

Specific Energy consumption $=$ $\dfrac{\text{Total energy consumption in W-h}}{\text{the weight of the train in tons} \times \text{the distance covered by train in km.}}$

Factors affecting Specific Energy Consumption

i) Distance b/w Stations.

ii) Acceleration & retardation.

iii) Maximum Speed.

iv) Gradient & train resistance.

Distance b/w Stations:

* Specific energy consumption is inversely proportional to the distance b/w stations.

* Greater the distance b/w the stops is the lesser will be the specific energy consumption.

Acceleration & Retardation:

* For a gn. Schedule speed, the specific energy consumption will accordingly be less for more acceleration & retardation.

Maximum Speed:

* For a gn. distance b/w the stops, SEC increases with increase in speed of train.

Gradient & Train resistance:

* Both gradient & train resistance are proportional to SEC.

* Normally co-efficient of adhesion will be affected by running of train, parentage gradient, condition of track etc. for wet & greasy track conditions.

※: Definitions:

Dead Weight: It is the total weight of train to be propelled by the locomotive. It is denoted by 'W'.

Accelerating weight: It is the effective weight of train that has angular acceleration due to rotational inertia including dead weight of train. (W_e).

Adhesive Weight: The total weight to be carried out on the drive in wheels of a locomotive.

Co-efficient of adhesion: The ratio of the tractive effort required to propel the wheel of a locomotive to its adhesive weight.

$$F_t \propto W.$$

$$= \mu W.$$

$$\mu = \frac{F_t}{W}$$

F_t : tractive effort.

W : adhesive weight.

Traction Motors:

* DC motors are suitable for traction because of high starting torque & capable of handling overloads.

* But speed control of DC motors is complicated through semiconductor switches.

* Regenerative Braking is also complicated in DC Series motor.

* Separately excited motors can be preferred over series motors because speed control speed control is possible through Semi controlled converters.

* Dynamic & Regenerative braking in separately excited DC motor is simple & efficient.

DC Series Motor :

* Widely used for traction purpose.

* Following features of series motor make it suitable for traction.

→ DC Series motor high starting torque and having the capability of handling overloads that is essential for traction drives.

→ Simple & robust construction.

→ Speed control is easy by series parallel control.

→ Sparkless commutation is possible

→ Series motor flux is proportional to armature current & torque. But armature current is independent of voltage fluctuations. Hence motor is unaffected by variations in supply voltage.

$$N \propto \frac{1}{\phi} \propto \frac{1}{I_a}$$

$$T \propto \phi I_a.$$

* For series motor, $\phi \propto I_a$.

$$T \propto I_a^2$$

$$\therefore \quad N \propto \frac{1}{I_a} \propto \frac{1}{\sqrt{T}}$$

* But the power output of motor is proportional to the product of torque & speed $[P = 2\pi NT/60]$.

$$\text{Motor output} \propto TN \propto \sqrt{T}$$

* That is motor input drawn from the source is proportional to the square root of the torque. Hence series motor is having self-retaining property.

DC Shunt Motor :

* DC shunt motor is a constant speed motor but for traction purpose, the speed of motor should vary with service conditions.

* Incase of DC shunt motor, the power output is independent of speed and is proportional to torque. For a gv. load torque, the shunt motor has to draw more power from the supply than series motor. $[P \propto \sqrt{T}]$

* For shunt motor, the torque developed is

proportional to armature current ($T \propto I_a$). So for a given load torque motor has to draw more current from the supply.

* The flux developed by shunt motor is proportional to shunt field current and hence supply voltage. [$\because \phi_{sh} \propto I_{sh} \propto \frac{V}{R_{sh}}$]. But the torque developed is proportional to ϕ_{sh} and I_a. Hence the torque developed by the shunt motor is affected by small variations in supply voltage.

* If 2 shunt motors are running in parallel, their speed - torque & speed - current characteristics must be flat and same. otherwise the currents drawn by the motor from the supply mains will be different and cause to unequal sharing of load.

AC Series Motor:

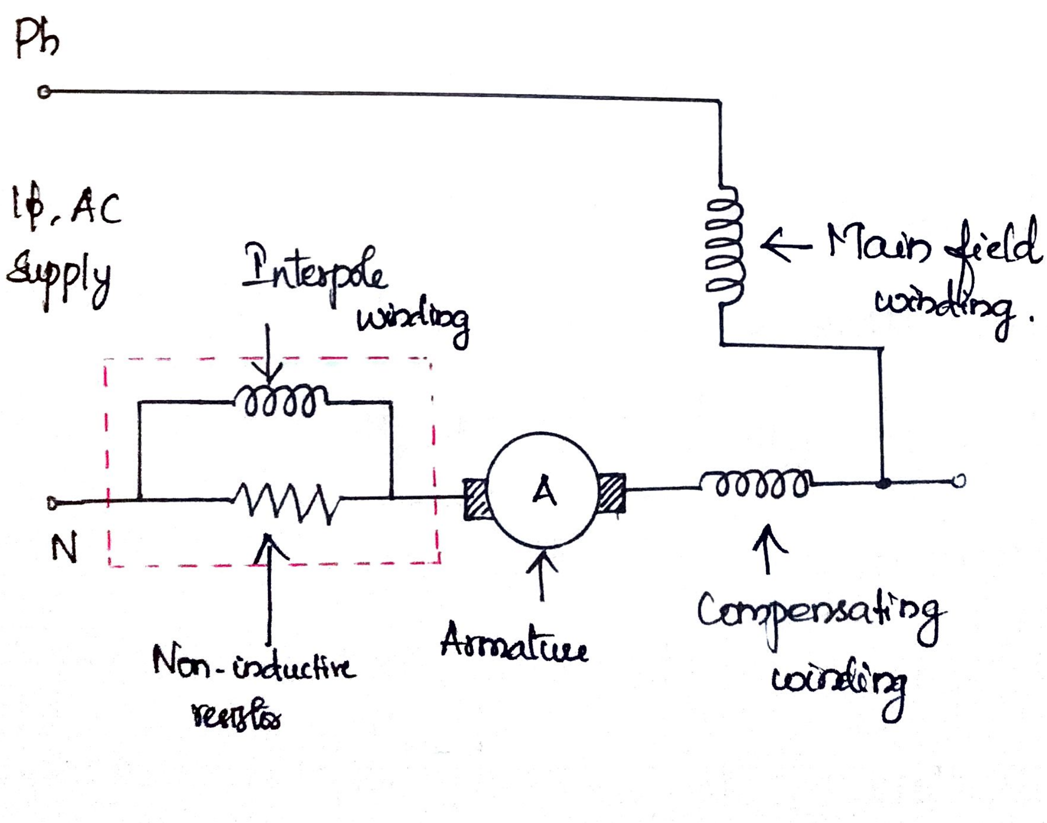
* AC series motor is best suited for the

traction purpose due to high starting torque.

*When DC series motor is fed from AC supply, it works but not satisfactorily due to following reasons.

i) If DC series motor is fed from AC supply, both the field & armature currents reverse for every half cycle. Hence unidirectional torque is developed at double frequency.

ii) Alternating flux developed by field winding causes excessive eddy current loss, which will cause the heating of motor. Hence, the operating efficiency of the motor will decrease.



iii) Field winding inductance will result abnormal Voltage drop & low power factor that leads to the poor performance of the motor.

(v) Induced emf and currents flowing through the armature coils undergoing commutation will cause sparking at the brushes & commutator segments.

Modifications in DC Series motor on AC supply:

i) In order to reduce the inductive reactance of the series field, the field winding of AC series motor must be designed for few turns.

ii) The decrease in the number of turns of the field winding reduces the load torque, i.e. if field turns decrease, its mmf decrease and then flux, which will increase the speed, hence the torque will decrease. But in order to maintain constant load torque, it is necessary to increase the armature turns proportionally.

iii) If the armature turns increase, the inductive reactance of the armature would increase, which can be neutralised by providing the compensating winding.

(iv) Magnetic circuit of an AC series motor should be laminated to reduce eddy current losses.

v) Series motor should be operating at low Voltage because high voltage low current supply would require large no. of turns to produce given flux.

vi) Motor should be operating at low frequency, because inductive reactance is proportional to the frequency. So at low frequency, the inductive reactance of the field winding decreases.

* The operation of AC series motor are similar to DC series motor.

* Weight of an AC series motor is one and a half to two times that of a DC series motor.

* Operating Voltage is limited to 300V.

* They can be built up to the Size of Several hundred KW for traction work.

Three phase Induction Motor:

Advantages:

1. Simple & Robust construction.
2. Trouble free operation.
3. The absence of commutator.
4. Less maintenance.
5. Simple & automatic regeneration.
6. High efficiency.

Drawbacks:

1. Low starting torque.
2. High starting current & complicated speed control system.
3. It is difficult to employ three-phase induction motor for a multiple-unit system used for propelling a heavy train.

* 3-ϕ Induction motor draws less current when the motor is started at low frequencies.

* When a 3-ϕ induction motor is used, the cost of overhead distribution system increases and it consists of two overhead conductors & track rail for 3rd phase to feed power to locomotive, which is a complicated overhead structure and if any person comes in contact with the third rail, it may cause danger to him or her.

Kando System:

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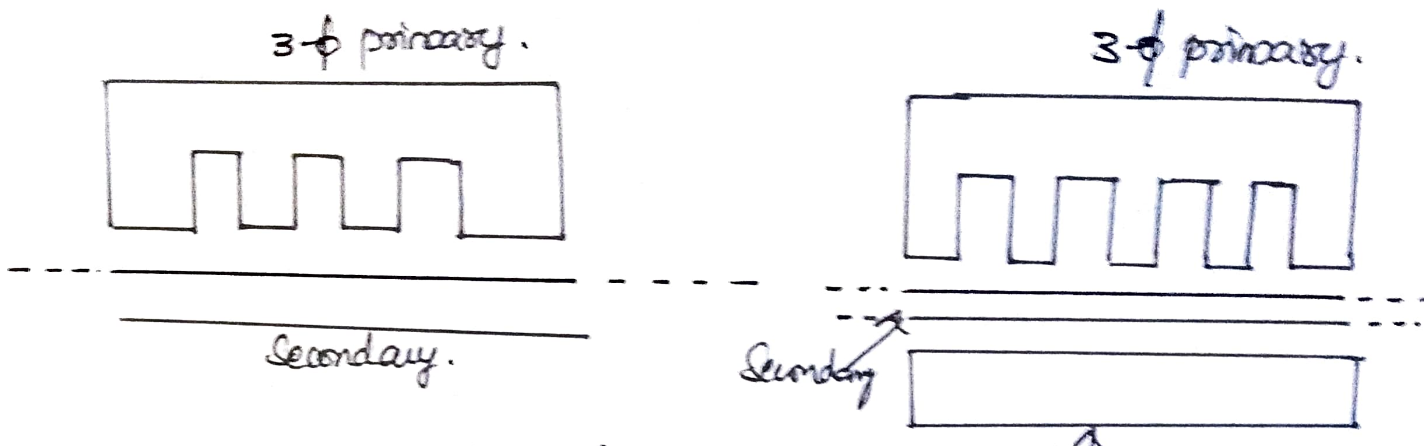
* The drawback can be overcome by Kando system.
* Here 1-ϕ supply from overhead distribution structure is converted to 3-ϕ supply by using phase converters & its fed to 3-ϕ IM.
* The speed controller of induction motor becomes smooth and easy with the use of thyristorised inverter circuits to get variable frequency supply that can be used to control the speed of 3-ϕ IM.

Linear Induction Motor:

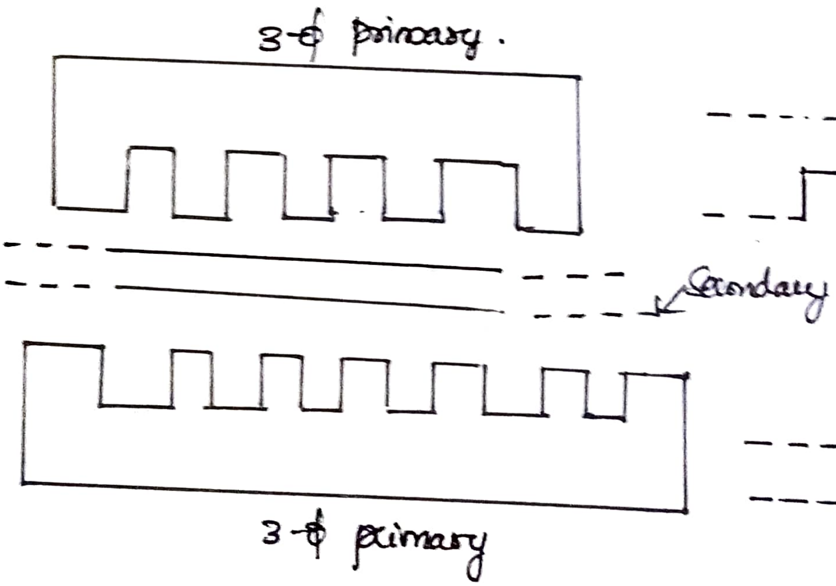
* It's a special type of induction motor.

that gives linear motion instead of rotational motion.

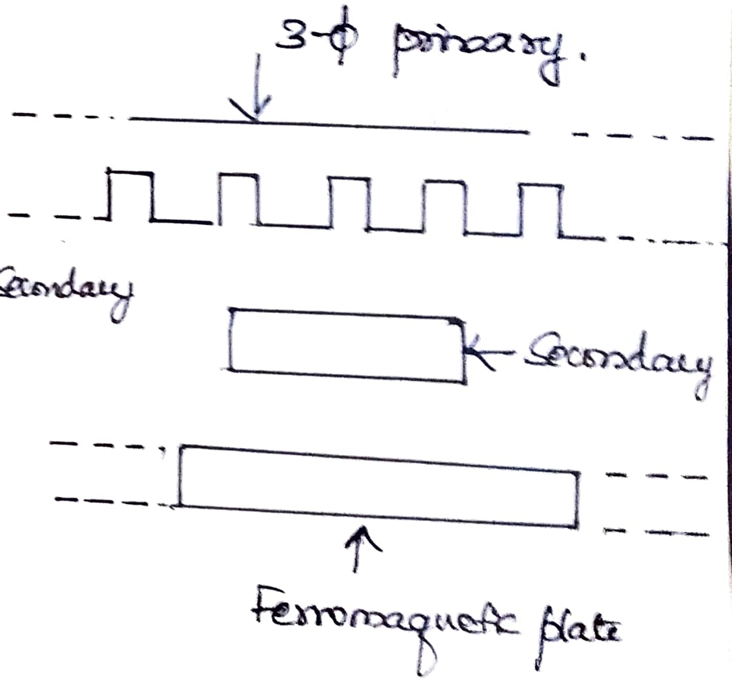
* Both movement of field & conductors are linear.



(a) Short single primary.



(b) Short double primary.



(c) Short Secondary.

* A linear induction motor consists of 3-ϕ distributed field winding placed in slots, and secondary is nothing but a conducting plate made of either copper or aluminium.

* The field system may be either single primary or double primary system.
* In single primary system, a ferromagnetic plate is placed on the other side of copper plate.
* It is necessary to provide low reluctance path for magnetic flux.
* When primary is excited by 3-ϕ AC supply, according to mutual induction, the induced currents are flowing secondary & ferromagnetic plate.
* Now ferromagnetic plate energised & attracted toward the primary causes to unequal air gap between primary & secondary (a).
* This drawback can be overcome by double primary system (b).
* In this system, 2 primaries are placed on both sides of secondary, which will be shorter in length compared to other depending upon the use of motor.

* Generally short secondary form is preferred for limited operating distance. (c).

* The linear synchronous speed is g. by.

$$V_s = 2\tau f \quad (m/s)$$

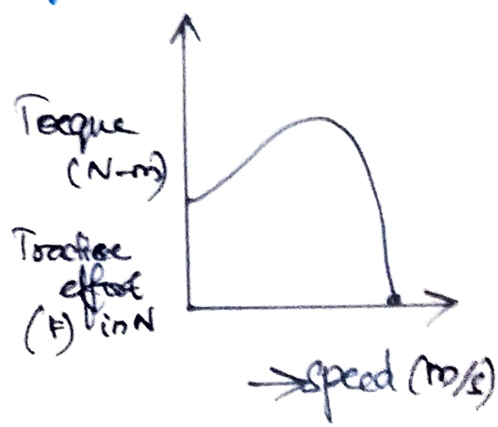
τ : pole pitch (m).

f : supply frequency (hz)

* The slip of linear IM is g. by,

$$S = \frac{V_s - V}{V_s}.$$

V: actual speed.



Torque-speed characteristi

Advantages:

i) Simple in construction.

ii) Low initial cost.

iii) Maintenance cost is low.

iv) Max. speed is not limited due to centrifugal forces.

v) Better power to weight ratio.

Disadvantages:

i) High cost of providing collector system.

ii) Poor efficiency & low power factor, due to high currents drawn by the motor because of large air gap.

Applications:

* High speed rail traction.

* Trolley cars & metallic belt conveyors.

* Electromagnetic pumps.

Synchronous Motor:

* Synchronous motor is a constant speed motor running from no-load to full load.

* The construction of synchronous motor is similar to the AC generator.

* Armature winding is excited by giving 3-ϕ AC supply.

* Field winding is excited by giving DC supply.

* The synchronous motor can be operated at leading

and lagging power factors by varying field excitation.

* The synchronous motor can be widely used various applications because of constant speed from no-load to full load.

* High efficiency.

* Low- initial cost.

* power factor improvement of 3 ϕ AC industrial circuits.

Braking:

* It is required to stop an electric motor, then the electric supply must be disconnected from its terminals to bring the motor to rest.

* Eventhough supply is cut off, the motor continue to rotate for long time due to inertia.

* The process of bringing the motor to rest within the predetermined time is known as braking.

Features of good Braking System:

* Braking should be fast and reliable.

* The equipment to stop the motor should be in such a way that the kinetic energy of the rotating parts of the motor should be dissipated as soon as the brakes are applied.

Braking

- Electric Braking
- Mechanical Braking.

Electric Braking:

* The kinetic energy of the rotating parts of the motor is converted into electrical energy which in turn dissipated as heat energy in a resistance or in sometimes, electrical energy is returned to the supply.