MODULE – II

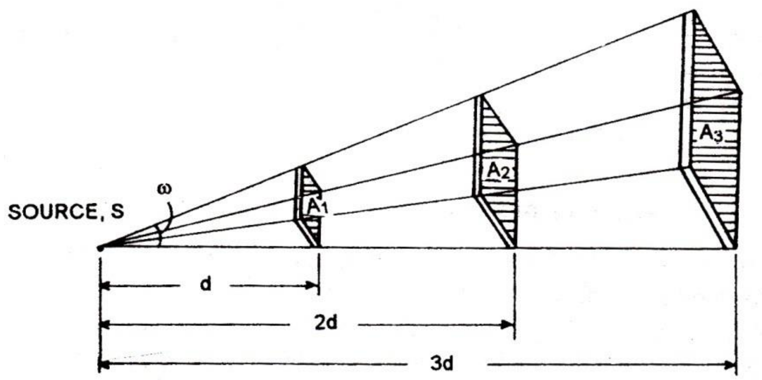
LIGHING DESIGN SCHEMES FOR NON-INDUSTRIAL INSTALLATIONS

1.1.3 LAWS OF ILLUMINATION

1. Inverse Square Law
2. Lambert's Cosine Law

1. Inverse Square Law

It states that the illumination of a surface is inversely proportional to the square of te distance between the square and the light source.



Let S= point source

A_1, A_2, A_3 = 3 parallel surface areas in m^2

d, 2d, 3d = distance of A_1, A_2, A_3 in m

ω = solid angle

I = luminous intensity

For area A1 solid angle $\omega = \frac{A_1}{d^2}$ ……………………………………..(1)

Flux φ_1 on area A_1 = luminous intensity × solid angle

= Iω……………………………………..(2)

Substitute the equation (1) in (2)

$$\varphi_1 = I\frac{A_1}{d^2}$$

$$= \frac{IA_1}{d^2} \text{ ……………………………………..(3)}$$

Illumination E on area $A_1 = \frac{flux}{area} = \frac{\varphi_1}{A_1}$ ……………………………………..(4)

Substitute the equation (3) in (4)

$$= \frac{IA_1}{d^2} \times \frac{1}{A_1}$$

$$= \frac{IA_1}{d^2 A_1}$$

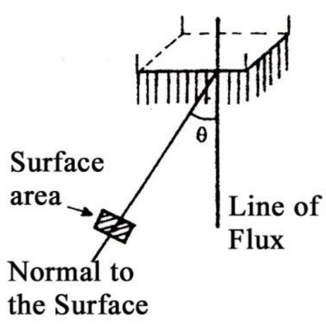
$$E_1 = \frac{I}{d^2} \text{ lux} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(5)$$

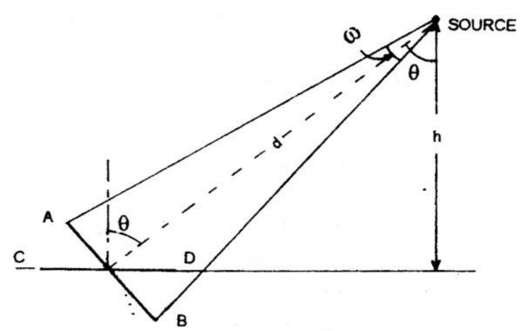
Similarly illumination on A_2, $E_2 = \frac{I}{(2d)^2}$ lux

Illumination on A_3, $E_3 = \frac{I}{(3d)^2}$ lux

From this we can see that the illumination of surface is inversely proportional to the square of the distance between source and the object. Thus inverse square law is proved.

2. Lambert's Cosine Law





It states that the 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.

Let,

AB = surface area normal to the source and inclined at θ to the

vertical axis = CDCosθ

CD = normal to the vertical axis and inclined at θ to the source.

$$= \frac{AB}{\cos\theta}$$

d= distance between the source and surface

h= height of the source from the surface

I = luminous Intensity

ω = Solid angle

Illumination on the surface AB = $\frac{flux}{area}$

$$= \frac{I}{d^2}$$

Illumination on the surface, $E_{CD} = \frac{flux}{area(CD)}$

$$= \frac{flux}{\left(\frac{AB}{\cos\theta}\right)} = \frac{flux}{area, AB} \times \cos\theta$$

We have, $\frac{flux}{area, AB} = \frac{I}{d^2}$

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

From the figure above,

Where $\cos\theta = \frac{h}{d}$ or $d = \frac{h}{\cos\theta}$

Substitute the value of d in the above equation

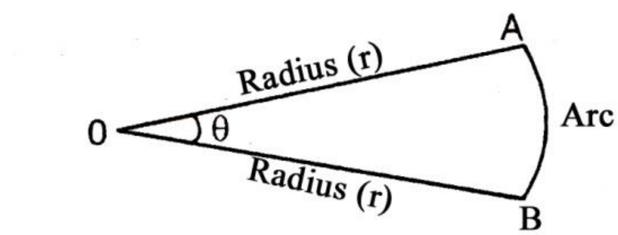
$$E_{CD} = \frac{I}{\left(\frac{h}{\cos\theta}\right)^2} \times \cos\theta$$

$$= \frac{I}{h^2} \times \cos^2\theta \times \cos\theta$$

$$E_{CD} = \frac{I}{h^2} \times \cos^3 \theta$$

1.1.4 Some Terms Used in Illumination

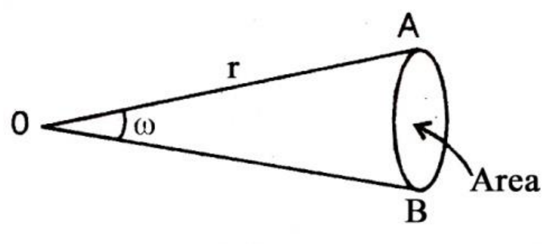
Plane Angle



A plane angle is subtended at a point in a plane by two straight convergent lines. It is represented by θ. The unit of plane angle is **radian**.

Plane angle θ = $\frac{arc}{radius}$. The largest angle subtended at a point is 2π radian.

Solid Angle



A Solid angle is subtended at a point in space by an area and is the angle enclosed in the volume formed by an infinite number of lines on the surface of the volume and meeting at the point. It is measured in **steradian**. It is represented by ω. The largest solid angle subtended at the center of the sphere is 4π steradian.

Solid angle, ω = $\frac{area}{r}$

Flux or Luminous Flux

It is the rate of energy radiated in the form of light wave by a luminous body. It is represented by φ of F. its unit is **lumen**

Luminous flux, F = $\frac{radient\ energy}{time}$ lumen

Candle Power

It is the number of lumens emitted by that source in a unit solid angle in a given direction.

Candle power, $C_P = \frac{lumens}{\omega}$

It is represented by lumen/steradian or candla.

Lumen

One lumen may be 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

= cp × ω

It is the unit of luminous flux

Luminous Intensity

It is the luminous flux per unit, in a given direction. It is measured in candla or lumen/steradian.

$$\text{Luminous intensity, I} = \frac{luminous\ flux}{\text{solid angle}} = \frac{F}{\omega}$$

Brightness or Luminance (B or L)

It is the luminous intensity of the lamp per unit projected area of eithr light source or reflecting surface.

$$\text{B or L} = \frac{I}{A} cd/m^2 \quad \text{where,}$$

I = luminous intensity (candela)

A = Projected or normal area (m^2)

Illumination

It is the luminous flux received by the surface per unit area. It is represented by E. the unit of illumination is lux

$$\text{Illumination, E} = \frac{flux}{\text{area}} \text{ lux}$$

Lumen-Hour

It is the quantity of light delivered in one hour by source having a flux of one lumen. It is similar to watt-hour.

One watt = 670 lumen

Mean Horizontal Candle Power (MHCP)

It is the mean of the candle power in horizontal plane in all directions and in all places from the source of light.

Mean Spherical Candle Power (MSCP)

It is the man of candle powers in all directions and in all planes from the source of light.

$$\text{MSCP} = \frac{total\ flux}{4\pi}$$

Mean Horizontal Spherical Candle Power (MHSCP)

It is defined as the mean of the candle power in all directions below the horizontal plane.

$$\text{MHCP} = \frac{flux\ emitted\ in\ hemisphere}{2\pi}$$

Lamp efficiency

It is the ratio of luminous flux to the electrical input. It is expressed in lumen/watt

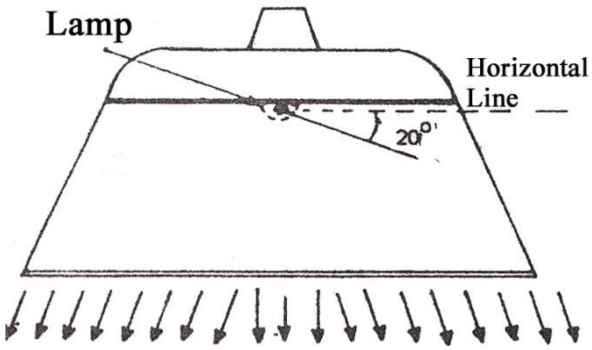
1.1.5 TYPES OF LAMP FITTINGS OR LIGHTING SCHEMES

The following are the different types of lamp fitting used in different situations.

1. Direct fitting (90 – 100% down wards)
2. Semi direct fitting (≈ 75% downwards)
3. Semi indirect fitting (25% downwards)
4. Indirect fitting (10% downwards)

1. **Direct Fittings**

   In this method of scheme about 90 – 100 % of the light from the source is directed towards the working plane or object or surface to be illuminated. The remaining about 10% of the total flux goes to the other direction or upper hemisphere. Light may be directed on the working plane by the use of suitable reflector or bracket lamps or by additional pendant fittings.

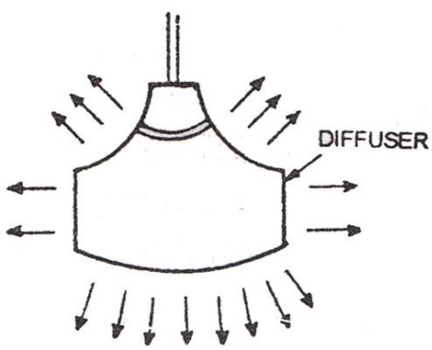


Direct light is cut off an angle 20^0 below the horizontal line. The height of the lamp from the working plane should be ⅔rd of the lamp spacing. When the lamps are to be mounted at considerable height from the working plane, the angle of cut off may be 30^0.

Application

1. Industrial lighting
2. Decorative lighting
3. Local lighting

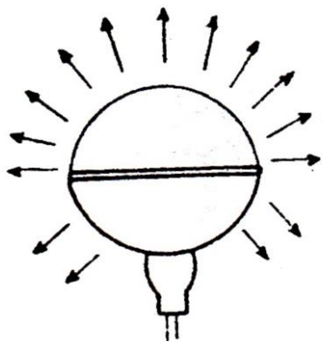
2. Semi Directed Fitting



In this method, about 60 – 90% of the light from the source is directed towards the working plane. The remaining 10 - 40% goes to the other direction or upper hemisphere. For this purpose translucent reflectors are used, as shown in figure. These fittings produce soft shadows and are well suited for commercial application.

3. Semi Indirect Fitting

In this type of fittings about 10 – 40 % of the light flux from the source is directed on the working surface or lower hemisphere. The remaining 90– 60% of the light flux goes to upper hemisphere. The flux on the working surface is mostly due to the reflectivity of the ceiling and walls. Frequent cleaning is necessary due to its shape and collects dust and insects. The



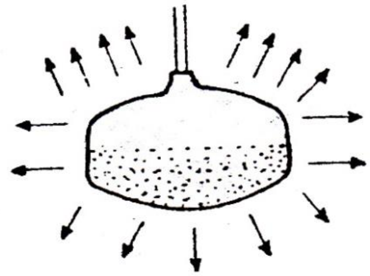
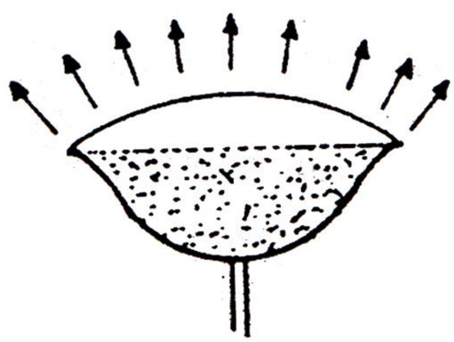


figure illustrates eh semi indirect fitting. These fittings produce faint shallows and are used for decorative lighting purpose in parks, parking lots...etc.

4. Indirect Fitting



In this method 0 – 10% of the light flux from the source is reach on the working plane or lower hemisphere. The remaining 90 – 100% light goes to upper hemisphere. Actually 0-10% of the light on the working plane is also due to the reflectivity of the ceilings. Figure C above illustrate the indirect fitting. High intensity lamps will be used for this purpose. These fittings do not produce any glare or shadows. This type of fittings is used for clubs and restaurants

ADVANTAGES OF LAMP FITTINGS

Direct Fittings

1. Mounting of lamps is easy
2. Light emanated from the lamp is fully utilized on working plane.
3. The objects are visible clearly.
4. Domestic and industrialist prefer direct lighting.
5. It is cheap
6. Extra fittings are not required.

Semi Direct Fittings

1. Well suited for commercial products

2. Customers can be attracted

3. Soft shadows can be produced

General Fittings

1. Different colors can be produced by using color reflectors

2. Lamps attract viewers

Semi Indirect Fittings

1. Lamp fittings of different shapes can be used.

2. Lamps attracts the viewers

Indirect Fittings

1. It does not produce any glare or shadow

2. Clubs and restaurant prefer this lighting

1.1.6 Numerical Problems

1.1.7 Definitions

1. Utilization Factor or Co-Efficient of Utilization

It is defined as the ratio of total lumens received on the working plane to the total lumens emitted by the light source.

$$\text{Utilization factor} = \frac{lumens\ received\ on\ the\ working\ plane}{lumens\ emitted\ by\ the\ lamp}$$

Factors Affecting the Utilization Factor

1. Type of light fittings, ie, direct or indirect

2. Colour and surface of the walls and ceilings.

3. Mounting height of the lamps.

4. Area to be illuminated

The lumen on the working plane is less than the total lumens emitted by the lamp.

2. Depreciation or Maintenance Factor

It may be defined as the ratio of illumination under normal working condition to the illumination when everything is clean or new

$$\text{Depreciation factor} = \frac{Illumination\ under\ normal\ working\ condition}{Illumination\ when\ everythig\ is\ clean}$$

Its value is around 0.8. This is due to the accumulation of dirt and dust on the lamp. **When Depreciation factor is greater than 1**, then the formula will be as follows

$$\text{Depreciation factor} = \frac{Illumination\ when\ everythig\ is\ clean}{Illumination\ under\ normal\ working\ condition}$$

Relation between Depreciation Factor and Candle Power Depreciation Factor

Depreciation Factor = 1- Candle Power Factor

3. Space Height Ratio

It is the ratio of the horizontal distance between the lamps to the mounting height of the lamp above the working plane.

$$\text{Space height ratio} = \frac{Horizontal\ Space\ between\ lamp}{Mounting\ height\ above\ the\ woking\ plane}$$

4. Reflection Factor or Reflection Ratio or Co-Efficient of Reflection

It is the ratio of luminous flux leaving the surface to the luminous flux incident on the surface

$$\text{Reflection Factor} = \frac{Reflected\ light}{Incident\ light\ on\ the\ surface}$$

Its value will be always less than1

5. Reduction Factor or Spherical Reduction Factor

It is the ratio of the mean spherical candle power of a source to its mean horizontal candle power.

$$\text{Reduction factor} = \frac{MSCP}{MHCP}$$

6. Luminous Efficiency or Specific Output

It is the ratio of luminous flux to the electric power intake of a source

$$\text{Luminous efficiency} = \frac{luminous\ flux\ emitted}{electric\ power\ intake\ of\ a\ source}$$

Its unit is lumen/watt (lm/W)

Sodium vapour lamp efficiency $\approx$100 lm/W

Mercury $\approx$40-80 lm/W

Fluorescent lamp $\approx$ 75 lm/W

Incandescent lamp $\approx$12-20 lm/W

7. Absorption Factor

When the atmosphere is full of fog or snow or smoke fumes, it absorbs some of the light energy hence absorption factor may be defined as the ratio of net lumens available on the working plane after absorption to the total lumens emitted by the lamp.

$$\text{Absorption Factor} = \frac{Net\ lumens\ on\ working\ suface\ after\ absorption}{Total\ lumens\ emitted\ by\ the\ lamp}$$

Its value will be 1 for clean atmosphere and $\approx$ 0.5 for bad atmosphere.

8. Specific Energy Consumption

It is the ratio of power input to the light source to its luminous intensity. It is measured in watt per candela or watt per MSCP.

$$\text{Specific Consumption} \quad \frac{Power\ input\ to\ lamp}{Luminous\ intensity\ of\ the\ lamp}$$

1.1.8 Illumination Levels

The following chart shows the recommended illumination level for various places

Sl. no	Place	Sub Places	Recommended level	
			Max	Min
1	Office	Drawing office	1500	750
2		Office premises(normal work, typing, correspondence, book keeping…etc.	800	400
3	School	General class room	500	200
4		Art Class room	800	400
5		Drawing Hall	1000	500
6	House	Reading Room	800	250
7		Kitchen	500	250
8		Bed rooms, Bath rooms	200	100
9		Living rooms	1000	500
10		Stair case, corridors	100	50
11	Shop	Show rooms	1000	500
12		Other places	400	200
13	Industry	Fine or Best works	1500	1000
14		Assembly/Medium work	1000	800
15		Rough work	300	150
16	Sport	Indoor games	800	500
17		Outdoor games	500	100
18	Hall	Church, Temple….etc.	150	75
19	Hospital	Operation theatre	1000	350
20		Wards	400	300

Factors Affecting Illumination

1. size of the room
2. Height of the light above work area
3. Reflective capacity of wall and surfaces
4. Condition of light surface (dust free)
5. Atmosphere in the room (smoke, fume,dust..etc.)
6. Type of light
7. Colour of the ceiling of walls

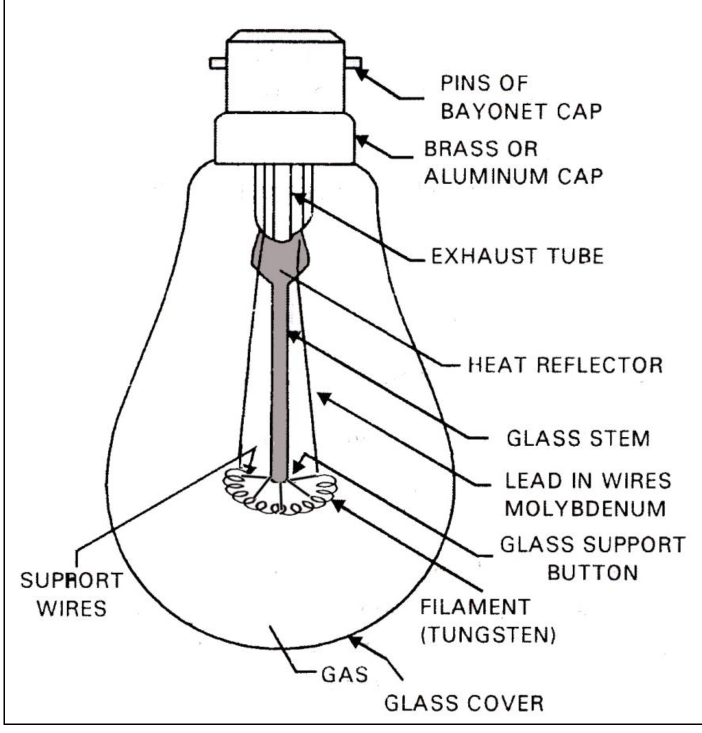
1.1.10 Lighting Arrangement Numerical Problems

1.1.11 Types of Lamps

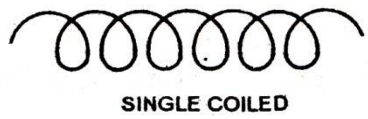
An electric lamp converts electrical energy into light energy. It is an artificial method of producing light. Electric lamps, broad sense may be classified into three groups

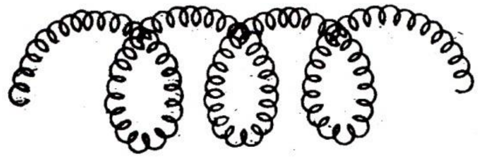
1. Incandescent lamp
2. Arc lamps
    a. Carbon arc lamps
    b. Flame arc lamps
    c. Magnetic arc lamps
3. Electric discharge lamps
    a. Sodium vapour lamps
    b. Mercury vapour lamps
    c. Neon lamps
    d. Fluorescent lamps

1. Incandescent Lamp or Filament Lamp



An incandescent lamp essentially consists of a fine wire (filament) of high resistance material placed in an evacuated glass bulb as shown in figure. the electric current while passing through the filament rises its temperature so high that the filament emits for heat and light waves in addition to heat waves is known as incandescent and hence the name incandescent lamp. To prevent the filament from oxidation, all the air must be pumped out of the bulb.





Coiled coil

The materials which are used for filaments of incandescent lamp must fulfill the following requirements.

1. High melting point
2. At high temperature the material having high melting point should not evaporate and becomes black.
3. The material must be ductile
4. It must have high specific resistance
5. Low temperature co-efficient
6. Low vapour pressure
7. Good mechanical strength to withstand vibrations
8. Commercially available
9. Cost must be reasonable

The materials which can be used for preparing incandescent lamp filaments are carbon, osmium, tantalum, tungsten. Tungsten has a melting point of 3500^0 c, high resistivity, and low vapour pressure, low temperature co- efficient, mechanically strong and ductile. In modern incandescent bulb the chemically inert gas like nitrogen and argon are filled due to the following advantages.

1. It is stable and does not react with the lamp components at the high temperature
2. Heat conductivity will be low
3. It decreases the evaporation of the filament
4. The life of the bulb increases
5. The filament working temperature can be increased
6. Prevents the flashing

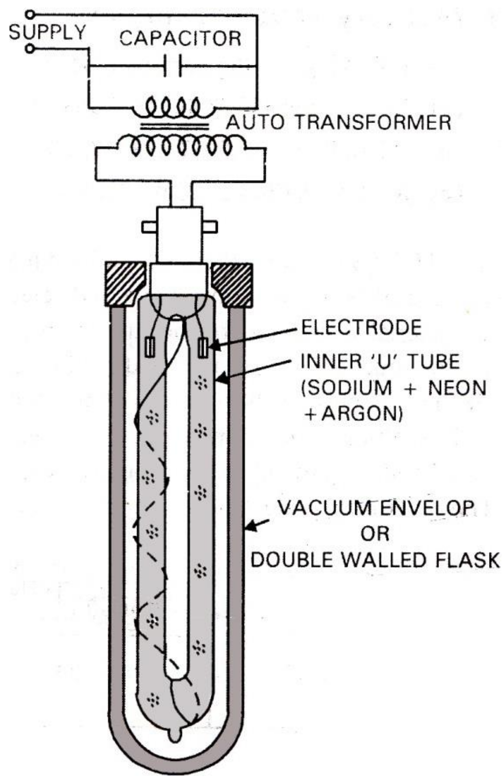
The filaments of all the incandescent lamps are either single coiled or coiled coil are as shown in the figure. The coiled coil filament leads to reduce the effective exposure to gases, concentrating the heat and allows high operating temperature. This gives greater radiant efficiency.

$$\text{Radiant efficiency} = \frac{Energy\ radiated\ in\ the\ form\ of\ light}{Total\ energy\ radiated\ in\ the\ form\ of\ light\ and\ heat}$$

The life of incandescent lamps is considered as 1000hrs, and is mainly governed by the rate at which vaporization of the filament takes place

GAS FILLED LAMPS

2. Sodium Vapour Lamp



This lamp consists of an inner U tube which can withstand high temperature of the electrical discharge. Is has two sets of electrodes connected to a pin type base. In the inner U tube there is a combination of sodium, neon and argon gases. The neon gas serves to start the discharge and develop enough heat to vapourise the sodium. Below 60^0 C sodium is in solid state. The lamp operates at about 300^0 C.

The tungsten coated electrodes are connected across auto transformer having relatively high leakage reactance. The secondary voltage is about 450 to 470 V. this voltage initiate a discharge through neon gas.

Working

When the supply is switched ON the high voltage of the auto transformer initiates the electric discharge through the neon gas and gives red-orange colour glow. The metallic sodium which is on the walls of the inner tube gradually vapourises and discharge takes place through the sodium vapour. The lamp will take 15 – 20 minutes to attain its full brightness. The luminous efficiency of the lamp is about 40 – 50 lumen/watt. The life span is approximately 3000hrs.

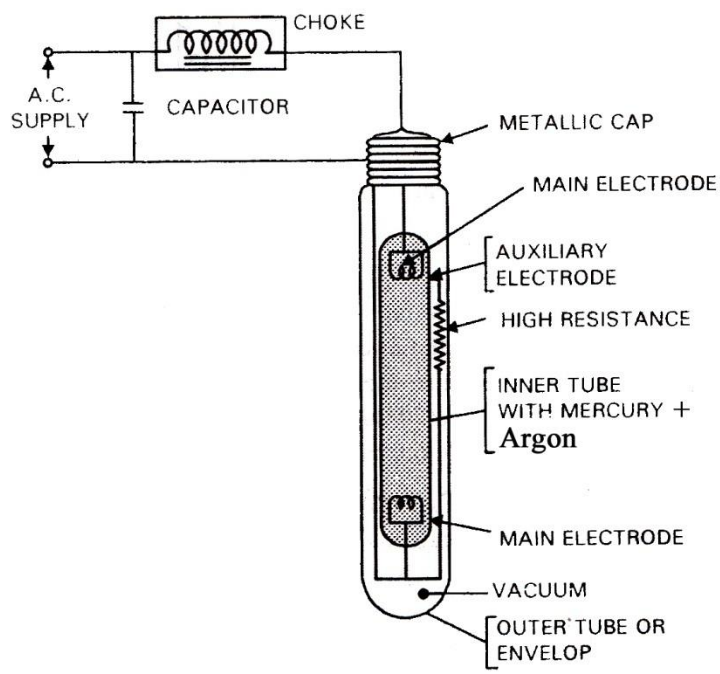
Advantages

1. Most of the radiation is on visible region
2. First excitation level is achieved with low voltage and requires less energy compared to other vapours

Disadvantages

1. It gives monochromatic orange –yellow light.
2. It operates at very poor power factor about 0.3 lag, it needs a capacitor.
3. It needs a large size U tube of special glass

Mercury Vapour Lamp (High Pressure)



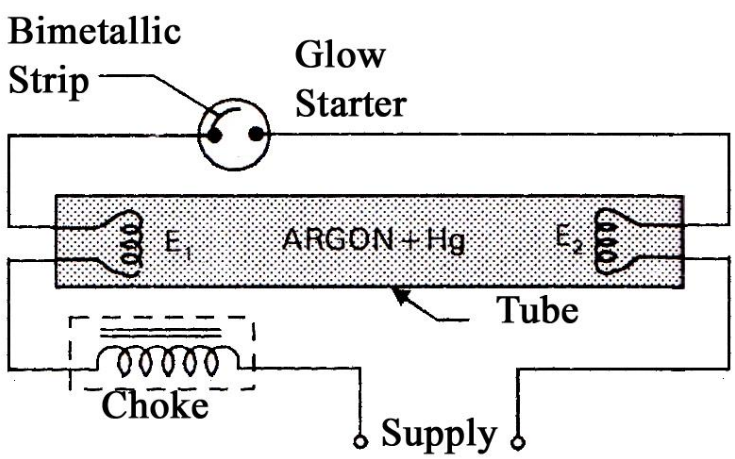
This is similar in construction of sodium vapour lamp. It consist of a discharge envelop enclosed in an outer bulb of ordinary glass. The inner envelope is made up of hard glass or quartz. The space between the bulb is partially or completely evacuated to prevent hear loss by convection. The outer bulb absorbs harmful ultraviolet rays. The inner bulb contains argon and mercury. There are two main electrodes and auxiliary electrode. It is connected through a high resistance. The main electrodes are made up of tungsten wire. The cathode is heated by heavy mercury ions.

The chock is provided to limit the current to a safe value. This chock lowers the power factor. So a capacitor is connected across the circuit to improve the power factor. These lamps are normally operated vertically.

Working

When the supply is switched ON, the voltage is applied between the auxiliary electrode and neighboring main electrode. The **argon** gas between these two electrodes is first **ionized** because of small distance between them. The small arc flow results in building up of pressure due to warming or heating of mercury. Finally the discharge takes place between two main electrodes. Due to the low resistance of the ionized path between the two main electrodes, the discharge shifts from the auxiliary electrode circuit to main electrodes. The temperature of operation inside the bulb is about 600^0 C; it gives greenish blue colour light. The efficiency is about 30 – 40 lumen/watt. The pressure of vapour in this lamp is 2 - 3 atmosphere. These types of lamps are generally used for industrial lighting, railway yards, ports, working areas, shopping centres…etc. Normal working voltage is 250 – 270V.

Low Pressure Mercury Vapour Lamp (Fluorescent Lamp)



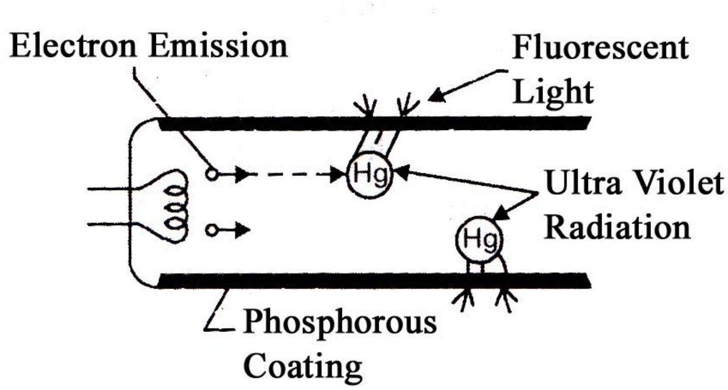
A fluorescent lamp tube is filled with a gas containing low pressure mercury vapor and Argon, Xenon, Neon, or Krypton. The pressure inside the lamp is around 0.3% of atmospheric pressure. The working principle of the fluorescent lamp is, when the supply is given, the low pressure mercury gas start conducting. This will radiate UV rays.
This UV rays are converted into visible light with the help of phosphor coating on the glass tube. The initial gaseous discharge can be started in the fluorescent lamp by two methods.

1. Applying high voltage with the help of starter and electromagnetic ballast
2. Applying high frequency with the help of electronic ballast

In the case of electromagnetic ballast, the high voltage (around 1100V) is induced with the help of starter. The chock also limits the current flow through the lamp, when the lamp is burning.

Working

The starter consists of a gas filled tube consisting of two small electrodes, out of the two electrodes one is bimetallic strip. When supply is given, a small current flow through the bimetallic strip, and it will heated up and open and cut the current flow through the starter.



This action will cause to develop a high voltage enough to start the low pressure mercury to conduct between the electrodes of the fluorescent lamp. If the first attempt is failed to start the conduction, it will make next attempt, till the lamp starts.

A bypass capacitor also provide inside the started to minimize the radio frequency interference generated during opening of the bimetallic strip. In the electronic ballast, an electronic circuit converts the main frequency into a frequency of 28 – 35 MHz, with the help of a high frequency inverter.

When the supply is given, there is a current flow through the bimetallic switch of the starter through the two filaments of the fluorescent lamp. The current flow through the filament will initially heat up and produces electrons due to thermionic emission (**Thermionic emission** is the heat-induced flow of charge carriers from a surface or over a potential-energy barrier). During this period, the bimetallic strip is heated up and opens the circuit at a rapid speed. This will induce a high voltage (up to 1100V) to start the conduction inside the lamp.

Fluorescent lamp is the ideal source for white light and suitable for good observation application. Its efficiency is 60lumens/watt.

Compact Fluorescent Lamp

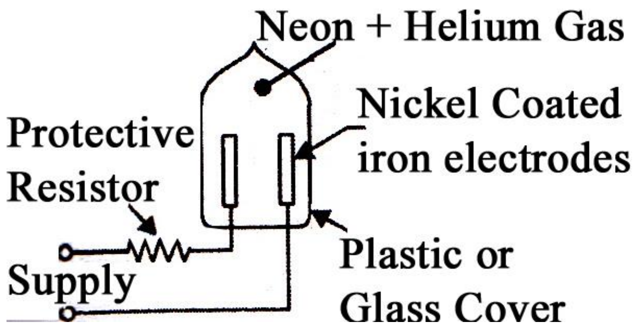
A **Compact Fluorescent Lamp** (**CFL**), also called **Compact Fluorescent Light**, **energy-saving light**, and **compact fluorescent tube**, is a fluorescent lamp designed to replace an incandescent lamp; some types fit into light fixtures formerly used for incandescent lamps. The lamps use a tube which is curved or folded to fit into the space of an incandescent bulb, and a compact electronic ballast in the base of the lamp.

Compared to general-service incandescent lamps giving the same amount of visible light, CFLs use one-fifth to one-third the electric power, and last eight to fifteen times longer. A CFL has a higher purchase price than an incandescent lamp, but can save over five times its purchase price in electricity costs over the lamp's lifetime. Like all fluorescent lamps, CFLs contain mercury, which complicates their disposal.

CFLs radiate a spectral power distribution that is different from that of incandescent lamps. Improved phosphor formulations have improved the perceived colour of the light emitted by CFLs, such that some sources rate the best "soft white" CFLs as subjectively similar in colour to standard incandescent lamps

Neon Lamps

A small electric current, which may be AC or DC, is allowed through the tube, causing it to glow orange-red. The formulation of the gas is typically the classic Penning mixture, 99.5% neon and 0.5% argon, which has lower striking voltage than pure neon. At the striking voltage, the lamp enters a breakdown mode and exhibits a glow discharge. Once lit, the voltage required to sustain the discharge is significantly (~30%) lower than the striking voltage. This is due to the organization of positive ions near the cathode. When driven from a DC source, only the negatively charged electrode (cathode) will glow.



When driven from an AC source, both electrodes will glow (each during alternate half cycles). These attributes make neon bulbs (with series resistors) a convenient low-cost voltage testers; they determine whether a given voltage source is AC or DC, and if DC, the polarity of the points being tested.

Once the neon lamp has reached breakdown, it can support a large current flow. Because of this characteristic, electrical circuitry external to the neon lamp must limit the current through the circuit or else the current will rapidly increase until the lamp is destroyed. Larger neon sign sized lamps often use a specially constructed high voltage transformer with high leakage inductance or other electrical ballast to limit the available current.

The potential needed to strike the discharge is higher than what is needed to sustain the discharge. When there is not enough current, the glow forms around only part of the electrode surface. Convective currents make the glowing areas flow upwards, not unlike the discharge in a Jacob's ladder. A photoionization effect can also be observed here, as the electrode area covered by the glow discharge can be increased by shining light at the lamp.In comparison with incandescent light bulbs, neon lamps have much higher luminous efficacy.

Halogen Lamp

A **halogen lamp**, also known as a **tungsten halogen lamp** or **quartz iodine lamp**, is an incandescent lamp that has a small amount of a halogen such as iodine or bromine added. The combination of the halogen gas and the tungsten filament produces a **halogen cycle** chemical reaction which redeposits evaporated tungsten back on the filament, increasing its life and maintaining the clarity of the envelope. Because of this, a halogen lamp can be operated at a higher temperature than a standard gas-filled lamp of similar power and operating life, producing light of a higher luminous efficacy and color temperature. The small size of halogen lamps permits their use in compact optical systems for projectors and illumination.

In ordinary incandescent lamps, evaporated tungsten mostly deposits on the bulb. The halogen sets up a reversible chemical reaction cycle with the tungsten evaporated from the filament. The halogen cycle keeps the bulb clean and the light output remains almost constant throughout life. At moderate temperatures the halogen reacts with the evaporating tungsten, the halide formed being moved around in the inert gas filling. At some time it will reach higher temperature regions, where it dissociates, releasing tungsten and freeing the halogen to repeat the process. The overall bulb envelope temperature must be higher than in conventional incandescent lamps for the reaction to work.

The bulb must be made of fused silica (quartz) or a high-melting-point glass (such as aluminosilicate glass). Since quartz is very strong, the gas pressure can be higher, which reduces the rate of evaporation of the filament, permitting it to run a higher temperature (and so luminous efficacy) for the same average life.

The tungsten released in hotter regions does not generally redeposit where it came from, so the hotter parts of the filament eventually thin out and fail. Regeneration of the filament is also possible with fluorine, but its chemical activity is so great that other parts of the lamp are attacked.

The lamp is equipped with an open tube that permits the halogen gas to be withdrawn and re-introduced as desired. When switched on, the filament is operating in a vacuum. After a few seconds the bulb is observed to blacken; this is caused by tungsten atoms that evaporate from the filament and condense on the bulb wall. Once completely blackened, the halogen gas is re-introduced back into the bulb. It quickly begins to react with the tungsten that has been deposited on the relatively cold bulb wall, and transports it back to the hot filament. The result is that the wall is returned to its original clarity. In this experiment the concentration of halogen gas used is higher than normal so as to achieve the rapid clean-up. In a standard lamp, the speed of the halogen regenerative cycle is much slower, but it operates continuously to prevent the bulb from blackening and thus maintaining a constant light output during lamp life.

High temperature filaments emit some energy in the UV region. Small amounts of other elements can be mixed into the quartz, so that the *doped* quartz (or selective optical coating) blocks harmful UV radiation. Hard glass blocks UV and has been used extensively for the bulbs of car headlights. Alternatively, the halogen lamp can be mounted inside an outer bulb, similar to an ordinary incandescent lamp, which also reduces the risks from the high bulb temperature. Undoped quartz halogen lamps are used in some scientific, medical and dental instruments as a UV-B source.

For a fixed power and life, the luminous efficacy of all incandescent lamps is greatest at a particular design voltage. Halogen lamps made for 12 to 24 volt operation have good light outputs, and the very compact filaments are particularly beneficial for optical control (see picture). The range of MR-16 (50 mm diameter) reflector lamps of 20 W to 50 W were originally conceived for the projection of 8 mm film, but are now widely used for display lighting and in the home. More recently, wider beam versions are available designed for direct use on supply voltages of 120 or 230 V.

ARC LAMPS

This types of lamps produce light by an electric arc between two electrodes. The modern lamp consists of two metal electrodes in an inert gas chamber made up of glass. Generally, arc lamp means carbon arc lamp. In carbon arc lamp, the rods are carbon placed in the air. During the initial stage, the rods are touched together, thus allowing a relatively low voltage to strike the arc. The rods are then slowly drawn apart, an arc is produced between the gap and heat develops in the rods. The tips of the carbon rods are heated and the carbon vaporizes. This carbon vapour in the arc is very luminous, which produces bright light.