Illumination

As a body is gradually heated above room temperature, it begins to radiate energy in the surrounding medium in the form of electromagnetic waves of various wavelengths. The nature of this radiant energy depends on the temperature of the hot body.

The usual method of producing artificial light consists in raising a solid body or vapour to incandescence by applying heat to it. It is found that as body is gradually heated above room temperature, it begins to radiate energy in the surrounding medium in the form of electromagnetic waves of various wavelengths. The nature of this radiant energy depends on the temperature of the hot body. Thus, when the temperature is low, the radiated energy is in the form of heat waves only, but when a certain temperature is reached, light waves are also radiated out in addition to heat waves and the body becomes luminous. Further increase in the temperature produces an increase in the amount of both kinds of radiations but the colour of light or visual radiations change from bright red to orange, to yellow and finally, if the temperature is high enough, to white. As the temperature is increased, the wavelength of visible radiation goes on becoming shorter. It should be noted that heat waves are identical to light waves except that they are of longer wavelength and hence produce no impression on retina. Obviously, from the point of view of light emission, heat energy represents wasted energy.

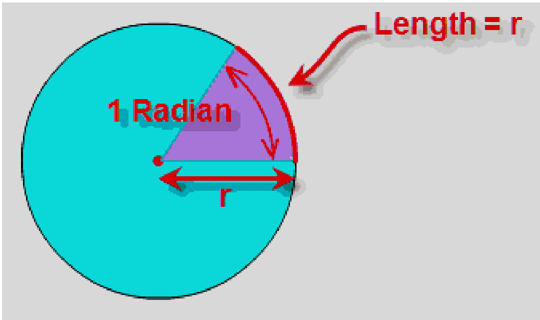
Radiant efficiency of the luminous source is defined as the ratio of "energy radiated in the form of light" to "total energy radiated out of the hot body" and it depends on the temperature of the source. As the temperature is increased beyond that at which the light waves were first given off, the Radiant efficiency increases, because the light energy will increase in greater proportion than the total radiated energy. When emitted light becomes white, i.e. it includes all the visible wavelengths, from extreme red to extreme violate, then a further increase in temperature produces radiations which are of wavelengths smaller than that of violate radiations. Such radiations are invisible and are known as ultra violate-radiations. It is found that maximum radiant efficiency would occur at about 6200^0 C and even then the value of this maximum efficiency would be 20%. Since this temperature is far above the highest that has yet been obtained in practice, it is obvious that the actual efficiency of all artificial sources of light i. e. those depending on temperature incandescence, is low.

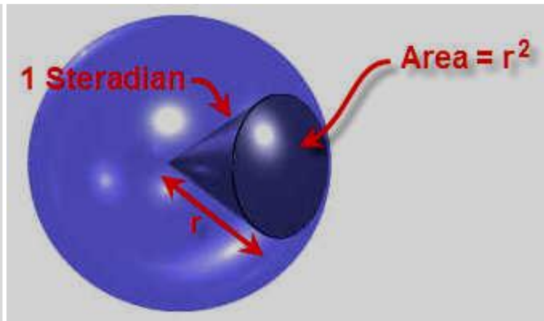
Light is thus a part of radiant energy that propagates as a wave motion through ether, approx velocity being $3x10^8$ m/sec. The wavelengths which can produce sensation of sight have a range from $4x10^{-5}$ cm to $7.5x10^{-5}$cm. For expressing wavelength of light, another unit called Angstrom Unit (1 A.U. = 10^{-8} cm= 10^{-10} m) is used. Thus the visible radiation lies between 4000 AU to 7500 AU. Typically a wavelength of 6000 AU produce yellow colour and 4000 AU produces violate colour.

For a wave motion we have $\boldsymbol{frequency\ f = \frac{velocity\ v}{wavelength\ \lambda}}$

Definitions

a) **Plane angle**- A plane angle is subtended at a point and is enclosed by two straight lines lying in the same plane. In radians, plane angle is the ratio$\frac{arc}{radius}$.





b) **Solid angle**- A solid angle (ω) 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 lying on the surface of the volume and meeting at the point. In steradian, solid angle is the ratio$\frac{area}{radius^2}$. It can also be defined as the angle subtended at the centre of the sphere by a part of its surface having an area equal to (radius)^2.

The solid angle subtended by a point at the center by whole of the spherical surface in all directions in space =$\frac{\boldsymbol{area}}{\boldsymbol{radius^2}} = \frac{\boldsymbol{Area\ of\ sphere}}{\boldsymbol{r^2}} = \frac{\boldsymbol{4\pi r^2}}{\boldsymbol{r^2}} = \boldsymbol{4\pi\ steradians}$.

Relationship between plane angle (θ) and solid angle (ω) is given by ω=2π (1-cos$\frac{\theta}{2}$)

c) **Luminous flux** is the light energy radiated out per second from the body in the form of luminous light waves. It is thus the rate of energy radiation in the form of light. It is energy per second (and hence comparable to Power). Its unit is *lumen*. Approximate relation between lumen and electric unit of power i.e. watt is given as:

1 lumen=0.0016 watt (approx) or 1 watt=625 lumen (approx)

d) **Lumen** is defined as the <u>luminous flux</u> emitted <u>in a unit solid angle</u> by <u>a source of one candle power</u>. i. e. Lumen=candle power x solid angle= cp x ω.

e) **Luminous intensity (I) or Candle-power** of a point source in a given direction is the luminous flux (number of lumens) radiated out per unit solid angle. In other words, it is solid angular flux density of a source in a specified direction. **Its unit is Candela (cd) or lumens per steradian.** A source of one candela emits one lumen per steradian. Hence total flux emitted by it all-round is 4πx1=4π lumen.

An ordinary 60-watt lamp as used for domestic lighting, when viewed from the floor, havs a luminous intensity of about 70- candle power, while a search light viewed from above the beam may have a luminous intensity of as much as a million candle power.

f) **Mean spherical candle-power (MSCP)**: Generally, the luminous intensity or candle power of a source is different in different directions. The average candle-power of a source is the average value of its candle power in all the directions. Obviously, it is given by flux (in lumen) emitted in all directions in all planes divided by 4π. This average candle-power is also known as mean spherical candle-power (MSCP).

$$MSCP = \frac{total\ flux\ in\ lumens}{4\pi}$$

Mean Hemispherical candle-power (MHSCP): It is given by the total flux emitted in a hemisphere (usually the lower one) divided by the solid angle subtended at the point source by the hemisphere.

$$MHSCP = \frac{flux\ emitted\ in\ a\ hemisphere}{2\pi}$$

g) **Illumination (E) or Illuminance:** When the luminous flux falls on a surface, it is said to be illuminated. **Illumination** is the luminous flux received by a surface per unit area. Its unit is Lux or metre-candle or lumens per m^2.

Imagine a sphere of radius of one meter around a point source of one candela. This flux falls normally on the curved surface of the sphere which is $4\pi\ m^2$.Obviously, illumination at every point on the inner surface of this sphere is $\frac{4\pi\ lumen}{4\pi\ m^2} = 1\ lm/m^2$

Also, Illumination=$\frac{lumen}{Area}$=$\frac{cp\ \times\ \omega}{area}$. But ω= $\frac{area}{d^2}$ where d is the distance between the area and the point where solid angle is formed.

$$\therefore Illumination = \frac{cp}{area} \times \frac{area}{d^2} = \frac{cp}{d^2}$$

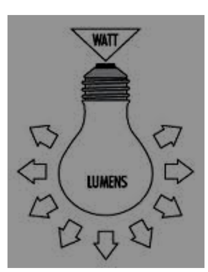
Residential		Commercial	
Kitchen	200	Classroom	300-400
Bathroom	300	Jewellery Work	700-800
Bedroom	300	Entrance Foyers	150-200
Dining	150	Office	200-300
Stairs	100	Hospital Treatment Room	400-500
Study	300	Stairs	80-100
Drawing Hall	300	Laboratories	300-400
Living	300		

Note: For industrial lighting, ask for the specific requirements from the consultants/ users.

h) **Brightness** of a surface is defined as the luminous intensity per unit projected area of the surface in the given direction. Unit of brightness is Lambert.

i) **Color Rendering Index (CRI)** is a measure of the effect of light on the perceived color of objects. A low CRI indicates that some colors may appear unnatural when illuminated by the lamp.

j) **Specific output or efficiency** of a lamp is the ratio of luminous flux to the power intake. Its unit is lumens per watt (lm/w).



Type of light source	Typical Luminous Efficiency (lm/W)
Incandescent bulb	8-18
Fluorescent Lamp	46-60
Mercury Vapour Lamp	44-57
CFL	40-70
Sodium Vapour Lamp (Low Pressure or LPSV)	101-175
Sodium Vapour Lamp (High Pressure or HPSV)	67-121
Metal Hallide	60-80
LED	30-50
Best LED	105

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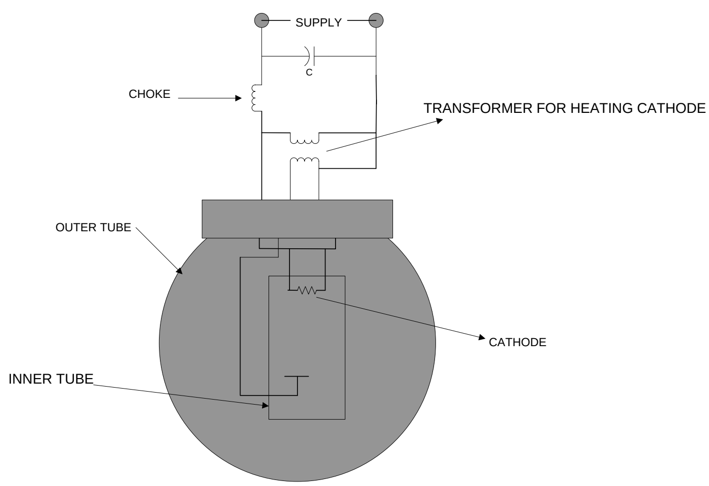
Lamps and Their Working Principle

I) Sodium Vapour Lamps:

Sodium vapour has the highest theoretical luminous efficiency and gives monochromatic orange-yellow light. The monochromatic light makes objects look grey, on account of which these lamps are used for street and highway lighting.

The lamp consists of a discharge tube having special composition of glass to withstand the high temperature of the electric discharge. The discharge tube is surrounded by an outer tube as shown in fig. For heating the cathode a transformer is included. Sodium below 60^0C is in solid state. For starting the lamp the electric discharge is allowed to take place in neon gas. The temperature inside the discharge tube rises and vaporizes sodium. Operating temperature is around 300^0C. It takes about 10 minutes for the sodium vapour to displace the red colour of the neon by its own yellow colour. The lamp takes around half an hour to reach full output. A choke is provided for stabilizing the electric discharge and a capacitor for power factor improvement. Although the theoretical efficiency is 475 lumens/watt, the practical light output is around 40-50 lumen/watt.

HPSV lamps are used for lighting of public thoroughfares, storage yards, open-air work sites, process plants, interiors with high ceiling heights, etc.



SODIUM VAPOUR LAMP

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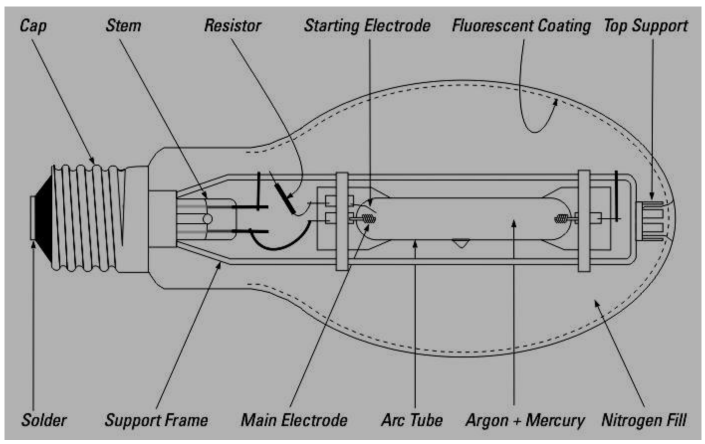
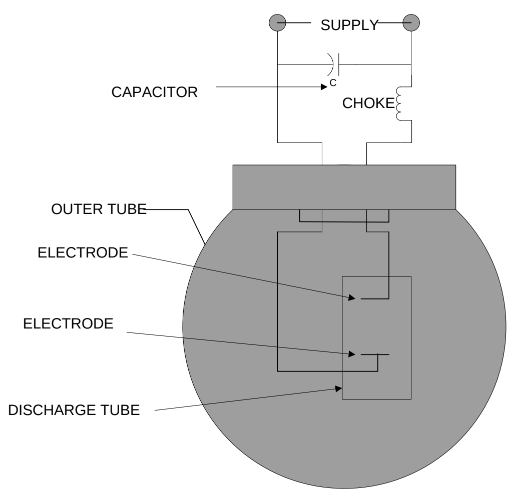
II) Mercury Vapour Lamps:

It is similar to construction of the sodium vapour lamp. The electrodes are tungsten coils containing an electron emitting material, which may be small piece of thorium or an oxide mixture. Argon is introduced to help start the lamp. The electric discharge first takes place through argon and this vaporizes the mercury drops inside the discharge tube. The electron emitting material supplies electrons to maintain the arc.

The space between two bulbs is filled with an inert gas. The pressure inside the discharge tube may range from one to ten atmospheres in lamps used for lighting purposes, as at these pressures the radiation is in visible spectrum. Although the theoretical efficiency is 298 lumens/watt, the practical light output is around 20-30 lumen/watt. (The ordinary tungsten filament or incandescent bulb has practical efficiency of 10-20 lumens/watt as against theoretical efficiency of 143 lumens/watt)

HPMV Lamps are used for lighting of secondary roads, car parking areas, parks and gardens, factory sheds, etc.





MERCURY VAPOUR LAMP

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III) Fluorescent Lamps:

In the mercury vapour lamp considerable amount of radiation is in ultra-violate range. By coating the inside of the tube by phosphor, this ultra violate radiation is converted in visible light. Phosphors have definite characteristic colours, but when mixed together, they produce a large variety of colours. These phosphors are stable compounds and give a high output throughout the life of the lamps. The colours of fluorescence produced by various phosphors are given below:

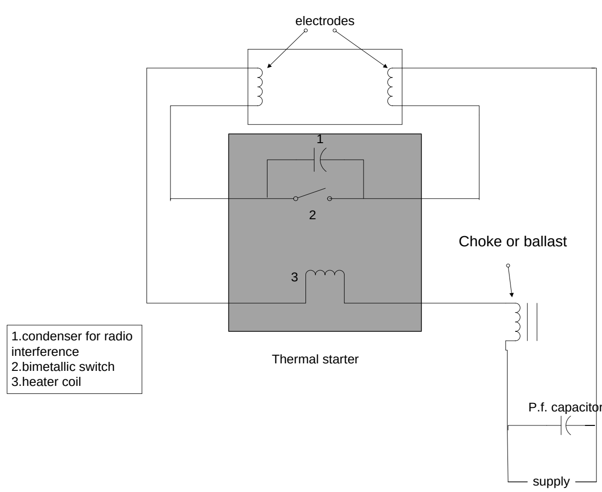
Phosphor	Colour
Zinc Silicate	Green
Calcium tungstate	Blue
Cadmium Borate	Pink
Calcium Halo Phosphate	White of various shades
Magnesium tungstate.	Bluish white

Tungsten cathode Preheated Type Fluorescent lamp: In these types, the electrons are produced by thermionic emission. Lower starting and operating voltages are adequate. A transient voltage of 300-600 V, applied by the starter, initiates the arc stream. The cathodes, which are coated with emitting materials, lose a little bit of this material every time the lamp is started. The constant impact of electrons on the cathode also dislodges some of the emitting material. Finally so little of the materials remain that it is not possible to emit any electrons and the lamp becomes dead. Therefore this type of lamp is unsuitable for frequent starting.

The efficiency is dependent on the mercury vapour pressure (and hence temperature) inside the tube. For efficient light production, these types of lamps are not used below a temperature of 10^0C surrounding.

Fluorescent lamps produce flicker or stroboscopic effect, since on 50 Hz supply; they are extinguished 100 times a second. Single lamps cannot be operated without flicker. Flicker correction can be applied to pairs of lamps. Radio interference is another effect produced by fluorescent lamps and has to be removed by suitable filter circuits.

Starters of automatic starting switches care of two types i) thermal type, and ii) glow discharge type.
The thermal starter has a heater coil which heats a bimetallic strip. The heater coil remains energized to keep the bimetallic switch open throughout the operation of lamp. It, therefore, consumes a small amount of power.

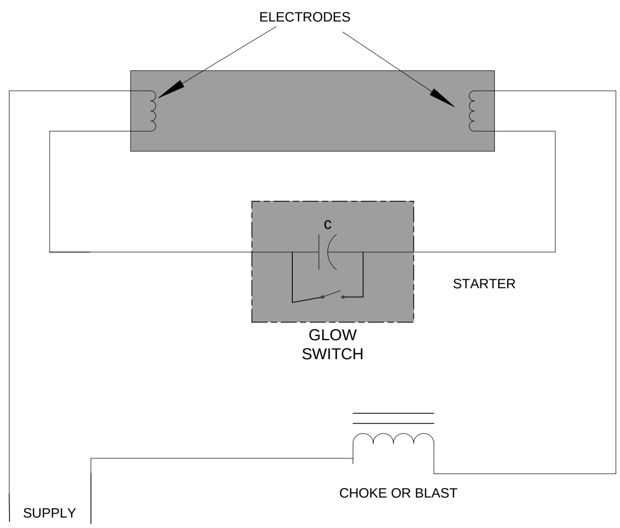


FLUORESCENT LAMP USING THERMAL STATE

When the supply is switched on, the contacts of the bimetallic switch are **closed** and the current passes through the electrodes and heat them. But after an interval of few seconds, the heater coil heats up the bimetal strip and the bimetallic switch contacts open. This starts a high voltage transient across the electrode due to the presence of choke or ballast in the circuit. An arc is struck between the electrodes, due to the high voltage transient. The high frequency radio interference is bypassed through the filter circuit provided by the radio interference suppression condenser.

The glow starter is enclosed in a glass bulb filled with neon or argon gas. One of the electrodes is a bimetallic strip.

When the normal voltage is applied to the lamp, a glow discharge takes place across the glow switch and a small amount of current flows through the electrodes. The bimetallic strip expands due to the heating effect of current in the glow discharge. The expansion of bimetallic strip causes the electrodes touch each other (???) and the electrodes get pre-heated due to the flow of appreciable amount of current. Meanwhile the bimetal cools, the glow switch opens and the resultant high voltage transient starts the arc discharge through the tube. If the lamp does not strike, the foregoing cycle is repeated. The switch cannot glow after the lamp has started operating, as the available electrical potential is not high enough to establish the glow discharge. Thus the starter consumes no power during the normal lamp operation.



FLOURESCENT LAMP USING GLOW STARTER

C-RADIO INTERFERENCE SUPPRESSION CONDENSER

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References:

i. A course in Electrical Power by Soni, Gupta, Bhatnagar
ii. A Text book of Electrical Technology by B. L. Theraja, A. K. Theraja
iii. Utilisation of Electrical Energy by E. Openshaw Taylor

Note: Refer above books for numerical based on illumination design.

Design of Lighting Schemes and Layouts

A well designed lighting scheme is one which

- Provides adequate illumination
- Avoids glare and hard shadows
- Provides sufficiently uniform distribution of light all over the working plane.

Following two factors are important for lighting design:

i) Utilization factor or Coefficient of Utilization: it is the ratio of the lumens actually received by a particular surface to the total lumens emitted by a luminous source. It is an indication of the effect of the lighting equipment and the interior combined in producing horizontal illuminance. For example UF of 0.3 means that the lumen reaching horizontal plane is 30% of the lumens of the lamp operated bare under standard conditions.

The value of this factor varies widely and depends on the following factors:

- Type of lighting system, whether direct, indirect etc
- The type and mounting height of fittings
- The colour and surface of walls and ceiling
- To some extent the shape and dimensions of the room.

ii) **Depreciation factor/ Maintenance factor**: It is the ratio of illuminance halfway through a cleaning cycle, to what the illuminance would be if the installation was clean. This factor allows for the fact that the effective candle power of all lamps or luminous sources deteriorates due to blackening and/ or accumulation of dust or dirt on the globes and reflectors etc. Similarly walls and ceilings also do not reflect as much light as when they are clean.

Taking into consideration the utilization and depreciation or maintenance factors, the expression for gross lumens required is:

Total lumens $\emptyset = \frac{Desired\ illumination\ E\ in\ lumens\ per\ sqm\ \ X\ Area\ of\ working\ plane\ to\ be\ illuminated\ A\ sqm}{Depreciation\ factor\ X\ utilization\ factor}$

Example:

The illumination in a drawing office 30 m x 10 m is to have a value of 250 lux and is to be provided by a number of 300-Watts filament lamps. If the coefficient of utilization is 0.4 and depreciation factor is 0.9, determine the number of lamps required. The luminous efficiency of each lamp is 14 lm/W.

Solution: Given E= 250 lm/sqm, A=30x10= 300 sq m, D.F. = 0.9, U.F. = 0.4.

Total lumens $\emptyset = \frac{Desired\ illumination\ E\ in\ lumens\ per\ sqm\ \ X\ Area\ of\ working\ plane\ to\ be\ illuminated\ A\ sqm}{Depreciation\ factor\ X\ utilization\ factor}$

$$\therefore \boldsymbol{total\ lumens\ required} = \frac{\mathbf{250x300}}{\mathbf{0.9\ x\ 0.4}} = \mathbf{208333\ lm}.$$

Flux emitted per lamp = 300x14= 4200 lm. ∴ Number of lamps required = 208333/4200 = 50.

Questions:

A. Explain construction and working of sodium vapour lamp. (6M)

B. Explain various factors related to illumination. (6M)

C. Write a short note on Polar Curves. (6M)

D. Define following terms: Lumen, Candle power, MHCP, MSCP, Luminous flux, depreciation factor, Maintenance factor, Coefficient of utilization. (1 M each)

E. Derive relationship between plane angle & solid angle. (4M)

F. With the help of a neat sketch, explain the working principle of mercury vapour lamp and compare the same with the other light sources. (6M)

G. Explain working principle of fluorescent lamps. (5M)

H. Which type of lighting fittings is used for a section having hazardous chemicals in a factory? (3M)

I. Give a list of different types of lamps available in market and discuss their luminous efficacy (lm/W) (5M)

Numerical

1. A playground of 10 meters x 45 meters size is to be illuminated by 10 lamps of 1000 W each. The luminous efficiency of each lamp is 20 lumens/ watt. Allowing a depreciation factor of 0.75 and utilization of 0.45, determine the illumination on ground. (7M)
2. Design a suitable lighting scheme for a factory 120 m x 40 m with a height of 7 met. Illumination required is 60 lux. State the number, location and mounting height of 40 W fluorescent tubes giving 45 lumens/ Watt. Assume depreciation factor of 1.2, utilization factor of 0.5) (7M)
3. A hall measuring 15 m x 30 m is illuminated by 20 lamps of 500 Watts each. The luminous efficiency of each lamp is 15 lumens/ watt. Allowing a depreciation factor of 0.7 and coefficient of utilization of 0.5, determine the illumination on floor. (7M)
4. A hall measuring 40 m x 16 m is illuminated by certain number of tube light fixtures of 80 W each. The illumination efficiency of each fixture is 80 lumens/ W. Allow depreciation factor of 0.65 and coefficient of utilization of 0.75. Determine the total number of fixtures required to achieve an average illumination of 175 lux on the floor. (7M)
5. A hall of 50 m x 30 m is illuminated by indirect lighting. An average illumination of 150 lumens/ sqm is to be provided on a horizontal plane parallel to the floor and 0.75 m above it. The walls and ceilings are brightly painted. Design a suitable scheme of illumination using filament lamps. Coefficient of utilization is 0.35 and depreciation factor is 0.9.

   If instead of indirect lighting, 80 W fluorescent lamps are used, what would be the saving in power consumption? (7M)
6. The flux emitted by a lamp in all the directions is 800 lumens. Calculate MSCP. (4M)
7. A lamp having a uniform CP of 200 in all directions is provided with a reflector which directs 60 % of total light uniformly on a circular area of 10 m diameter. The lamp is hung 6 m above the area. Calculate the illumination (i) at the center (ii) at the edge of the surface; with and without reflector.

   Determine also the average illumination over the area without reflector. (7M)
8. A room 12x 8 m is to have indirect lighting giving illumination of 80 lux on the working plane 70 cm above floor. Coefficient of utilization is assumed to be 0.5 and depreciation factor is 0.8. Find out the number of lamps and their ratings. Lamp efficiency may be taken as 15 lumens per watt. (6M)

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