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CHAPTER 49

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ILLUMINATION

When some materials are heated above certain temperatures, they start radiating energy in the form of light. This phenomenon is called luminance. Electric lamps are made based on this phenomenon.

49.1. Radiations From a 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 the 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, 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 temperature produces an increase in the amount of both kinds of radiations but the colour of light or visible radiation changes from bright red to orange, to yellow and then finally, if the temperature is high enough, to white. As temperature is increased, the wavelength of the 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 the retina. Obviously, from the point of view of light emission, heat energy represents so much wasted energy.

The ratio $\dfrac{\text{energy radiated out in the form of light}}{\text{total energy radiated out by the hot body}}$ is called the ***radiant*** efficiency of the luminous source and, obviously, depends on the temperature of the source. As the temperature is increased beyond that at which light waves were first given off, the radiant efficiency increases, because 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 violet, then a further increase in temperature produces radiations which are of wavelength smaller than that of violet radiations. Such radiations are invisible and are known as ultra-violet radiations. It is found that maximum radiant efficiency would occur at about 6200°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.

As discussed above, light is radiant energy which is assumed to be propagated in the form of transverse waves through an invisible medium known as ether. These light waves travel with a velocity of 2.99776×10^8 m/s or 3×10^8 m/s approximately but their wavelengths are different. The wavelength of red light is nearly 0.000078 cm and that of violet light 0.000039 cm. Since these wavelengths are very small, instead of using 1 cm as the unit for their measurement, a submultiple 10^{-8} cm is used. This submultiple is known as Angstrom Unit (A.U.)

$$1 \text{ A.U.} = 10^{-8} \text{ cm} = 10^{-10} \text{ m}$$

Hence, the wave-length of red light becomes $\lambda_r = 7800 \times 10^{-10}$ m or 7800 A.U. and $\lambda_v = 3900 \times 10^{-10}$ m or 3900 A.U. The sensation of colour is due to the difference in the wavelengths and hence frequencies of the light radiations.

49.2. Solid Angle

Consider an area A which is part of a sphere of radius r (Fig. 49.1). Let us find the solid angle ω subtended by this area at the centre C of the sphere. For this purpose, let point C be joined to every point on the edges of the area A. Then, the angle enclosed by the cone at point C gives the solid angle. Its value is

$$\omega = \frac{A}{r^2} \text{ steradian}$$

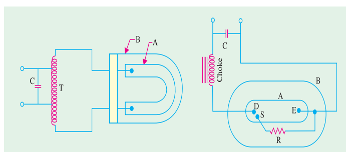

Fig. 49.1

The unit of solid angle is ***steradian*** (sr). If, in the above equation, $A = r^2$, then $\omega = 1$ steradian. Hence, steradian is defined as the angle subtended at the centre of a sphere by a part of its surface having an area equal to $(\text{radius})^2$.

Obviously, the solid angle subtended at the centre by whole of the spherical surface = $4\pi\, r^2/r^2 = 4\pi$ steradian (sr).

Fireworks radiate light energy of different frequencies, which appear in different colours

49.3. Definitions

Before proceeding further, definitions of a few principal terms employed in connection with illumination, are given below :

1. Candela. It is the unit of luminous intensity of a source. It is defined as 1/60th of the luminous intensity per cm^2 of a black body radiator at the temperature of solidification of platinum (2045°K).

A source of one candela (*cd*) emits one lumen per steradian. Hence, total flux emitted by it allround is $4\pi \times 1 = 4\pi$ lumen.

2. Luminous Flux (F or Φ). It is the light energy radiated out per second from the body in the form of luminous light waves.

Since, it is a rate of flow of energy, it is a sort of *power* unit. Unit of luminous flux is *lumen* (lm). It is defined as the ***flux contained per unit solid angle of a source of one candela or standard candle*** (Fig. 49.2).

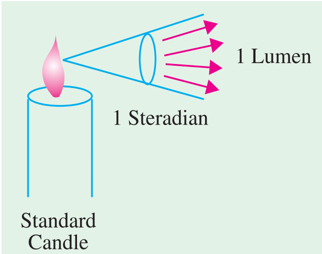

Fig. 49.2

Approximate relation between lumen and electric unit of power *i.e.* watt is given as

$$1 \text{ lumen} = 0.0016 \text{ watt (approx.)}$$

3. Lumen-hour. It is the quantity of light delivered in one hour by a flux of one lumen.*

4. Luminous Intensity (I) or Candle-power of a point source in any particular direction is given by the ***luminous flux radiated out per unit solid angle in that direction***. In other words, it is solid angular flux density of a source in a specified direction.

If $d\Phi$ is the luminous flux radiated out by a source within a solid angle of $d\omega$ steradian in any particular direction, then $I = d\Phi/d\omega$.

If flux is measured in lumens and solid angle in steradian, then its unit is lumen/steradian (lm/sr) or candela (*cd*).

If a source has an average luminous intensity of I lm/sr (or I candela), then total flux radiated by it all around is $\Phi = \omega I = 4\pi I$ lumen.

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 directions. Obviously, it is given by total flux (in lm) emitted in all directions in all planes divided by 4π. This average candle-power is also known as ***mean spherical candle-power*** (M.S.C.P.).

$$\therefore \qquad \text{M.S.C.P.} = \frac{\text{total flux in lumens}}{4\,\pi}$$

If the average is taken over a hemisphere (instead of sphere), then this average candle power is known as ***mean hemispherical candle-power*** (M.H.S.C.P.).

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.

$$\therefore \qquad \text{M.H.S.C.P.} = \frac{\text{flux emitted in a hemisphere}}{2\,\pi}$$

* It is similar to watt-hour (Wh)

5. Reduction Factor of a source is given by the ratio, f = M.S.C.P./M.H.C.P. where M.H.C.P. is the mean horizontal candle power.

It is also referred to as spherical reduction factor.

6. Illuminance or Illumination (E). When the luminous flux falls on a surface, it is said to be illuminated. The illumination of a surface is measured by the normal luminous flux per unit area received by it.

If $d\Phi$ is the luminous flux incident normally on an area dA, then $E = d\Phi/dA$ or $E = \Phi/A$.

Unit. Since flux Φ is measured in lumens and area in m^2, unit of E is lm/m^2 or lux. The alternative name is metre-candle (m-cd). Let us see why ? Imagine a sphere of radius of one metre around a point source of one candela. Flux radiated out by this source is 4π lumen. 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 $4\pi\ lm/4\pi\ \text{m}^2 = 1\ lm/\text{m}^2$. However, the term lm/m^2 is to be perferred to metre-candle.

7. Luminance (L) of an Extended Source. Suppose ΔA is an element of area of an ***extended*** source and Δt its luminous intensity when viewed in a direction making an angle ϕ with the perpendicular to the surface of the source (Fig. 49.3), then luminance of the source element is given by

$$L = \frac{\Delta I}{\Delta A \cos\phi} = \frac{\Delta I}{\Delta A'}\ cd/\text{m}^2 \quad ...(i)$$

where $\Delta A' = \Delta A \cos\phi$

= area of the source element projected onto a plane perpendicular to the specified direction.

As will be seen from Art. 49.5.

$$E = \frac{I \cos\theta}{d^2} \quad \text{or} \quad \Delta E = \frac{\Delta I}{d^2}\cos\theta$$

Substituting the value of ΔI from Eq. (i) above, we get

$$\Delta E = \frac{L.\Delta A'}{d^2}\cos\theta = L\cos\theta.\,d\omega$$

where $d\omega = \Delta A'/d^2$ steradian

$$E = \int L\cos\theta\,.\,d\omega = L\int\cos\theta\,.\,d\omega$$

—if L is constant.

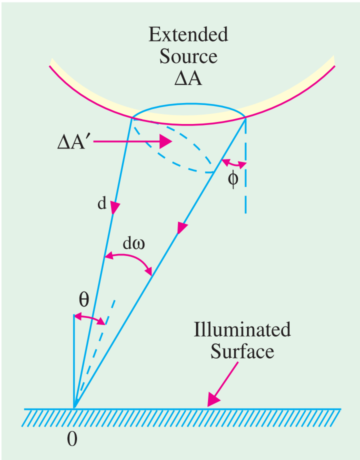

Fig. 49.3

8. Luminous Exitance (M) of a Surface. The luminous exitance (M) at a point on a surface is defined as luminous flux emitted per unit area in all directions. If an element of an illuminated area ΔA emits a total flux of $\Delta\Phi$ in all directions (over a solid angle of 2π steradian) then

$$M = \Delta\Phi/\Delta A \qquad lm/\text{m}^2$$

It can be proved that $M = \pi L$ in the case of a uniform diffuse ***source***.

9. Transmittance (T) of an Illuminated Diffuse Reflecting Surface. It is defined as the ratio of the total luminous flux transmitted by it to the total flux incident on it.

The relation between luminous exitance (M) of a surface transmitting light and illuminance (E) on the other side of it is

$$M = TE \quad \text{or} \quad T = M/E$$

Since light falling on a surface is either transmitted, reflected or absorbed the following relation holds good

$$T + \rho + \alpha = 1$$ where α is the absorptance of the surface.

10. Reflection Ratio or Coefficient of Reflection or Reflectance (ρ). It is given by the luminous flux reflected from a small area of the surface to the total flux incident upon it

$\rho = M/E$ *i.e.* ratio of luminous exitance and illuminance.

It is always less than unity. Its value is zero for ideal 'black body' and unity for a perfect reflector.

11. Specific Output or Efficiency of a lamp is the ratio of luminous flux to the power intake. Its unit is lumen/watt (lm/W). Following relations should be taken note of :

(*a*) $\dfrac{\text{lumen}}{\text{watt}} = \dfrac{4\pi \times \text{M.S.C.P.}}{\text{watt}}$

or $\dfrac{\text{lm}}{\text{W}} = \dfrac{4\,\pi}{\text{watt/M.S.C.P.}}$

(*b*) since f = M.S.C.P./M.H.C.P. $\therefore$ $\text{lm/W} = \dfrac{4\,\pi\, f}{\text{watt/M.S.C.P.}}$

(*c*) Obviously, $\text{watts/M.S.C.P.} = \dfrac{4\,\pi}{\text{lm/W}} = \dfrac{\text{watt/M.H.C.P.}}{f}$

(*d*) Also $\text{watts/M.H.C.P.} = \dfrac{4\,\pi\, f}{\text{lm/W}} = f \times \text{watts/M.S.C.P.}$

12. Specific Consumption. It is defined as the ratio of the power input to the average candle-power. It is expressed in terms of watts per average candle or watts/M.S.C.P.

The summary of the above quantities along with their units and symbol is given in Table 49.1.

Table 49.1

Name of Qty	*Unit*	*Symbols*
Luminous Flux	Lumen	F or Φ
Luminous Intensity (candle-power)	Candela	I
Illumination or Illuminance	lm/m^2 or lux	E
Luminance or Brightness	cd/m^2	L or B
Luminous Exitance	lm/m^2	M

49.4. Calculation of Luminance (L) of a Diffuse Reflecting Surface

The luminance (or brightness) of a surface largely depends on the character of the surface, if it is itself not the emitter. In the case of a polished surface, the luminance depends on the angle of viewing. But if the surface is matt and diffusion is good, then the luminance or brightness is practically independent of the angle of viewing. However, the reflectance of the surface reduces the brightness proportionately. In Fig. 49.4 is shown a perfectly diffusing surface of small area A. Suppose that at point M on a hemisphere with centre O and radius R, the illuminance is L cd/m^2. Obviously, ***luminous intensity*** at point M is $= L \times A \cos\theta$ candela (or lumen/steradian). Now, the hemisphere can be divided into a number of zones as shown. Consider one such zone MN between θ and (θ + dθ). The width of this zone is $R.d\theta$ and length $2\pi R \sin\theta$ so that its area (shown shaded) is $= 2\pi R^2 \sin\theta.\, d\theta$. Hence, it subtends a solid angle $= 2\pi R^2 \sin\theta.d\theta/R^2 = 2\pi \sin\theta.\, d\theta$ steradian at point O. The luminous flux passing through this zone is

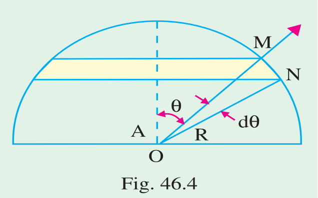

Fig. 49.4

$$d\Phi = L\ A\cos\theta \times 2\pi\sin\theta.d\,\theta = \pi L\ A \times 2\sin\theta\cos\theta\, d\,\theta = \pi\, L\, A\sin 2\,\theta\, d\theta \text{ lumen}$$

Total flux passing through the whole hemisphere is

$$\Phi = \int_0^{\pi/2} \pi L A \sin 2\,\theta\,.\,d\theta = \pi\, L\, A \text{ lumen}$$

If the ***illumination*** of the surface (produced by a light source) is E lm/m^2 and ρ is its reflection coefficient, then $\Phi = \rho\, A\, E$ lumen.

Equating the two values of flux, we have $\pi L A = \rho A\, E$

or $\qquad L = \rho E/\pi \text{ cd/m}^2 = \rho E \text{ lm/m}^2$

For example, consider a perfectly diffusing surface having $\rho = 0.8$ and held at a distance of 2 metres from a source of luminous intensity 100 candela at right angles to the direction of flux. Then

$$E = 100/22 = 25 \text{ lm/m}^2$$

$$L = \rho E/\pi = 25 \times 0.8/\pi = 6.36 \text{ cd/m}^2 = 636 \times \pi = 20 \text{ lm/m}^2$$

49.5. Laws of Illumination or Illuminance

The illumination **(*E*)** of a surface depends upon the following factors. The source is assumed to be a point source or is otherwise sufficiently away from the surface to be regarded as such.

(i) ***E*** is directly proportional to the luminous intensity **(*I*)** of the source or $E \propto I$

(ii) ***Inverse Square Law***. The illumination of a surface is inversely proportional to the square of the distance of the surface from the source.

In other words, $E \propto 1/r^2$

Proof

In Fig. 49.5 are shown portions of the surfaces of three spheres whose radii are in the ratio 1 : 2 : 3. All these portions, obviously, subtend the same solid angle at the source and hence receive the same amount of total flux. However, since their areas are in the ratio of 1 : 4 : 9, their illuminations are in the ratio $1 : \frac{1}{4} : \frac{1}{9}$.

(iii) ***Lambert's Cosine Law***. According to this law, E is directly proportional to the cosine of the ***angle made by the normal to the illuminated surface with the direction of the incident flux***.

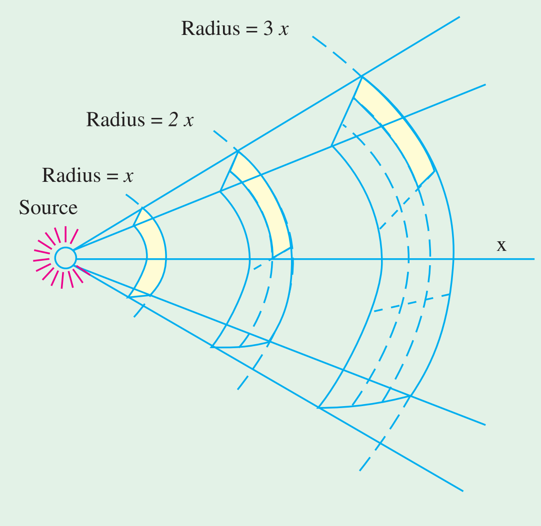

Fig. 49.5

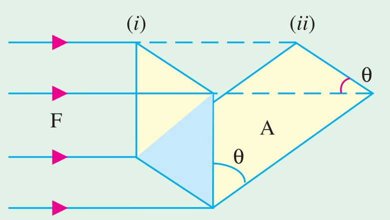

Fig. 49.6

Proof

As shown in Fig. 49.6, let Φ be the flux incident on the surface of area A when in position 1. When this surface is turned back through an angle θ, then the flux incident on it is $\Phi \cos \theta$. Hence, illumination of the surface when in position 1 is $E_1 = \Phi/A$. But when in position 2.

$$E_2 = \frac{\Phi \cos\theta}{A} \qquad \therefore \qquad E_2 = E_1 \cos\theta$$

Combining all these factors together, we get $E = I \cos\theta/r^2$. The unit is lm/m^2.

The above expression makes the determination of illumination possible at a given point provided the position and the luminous intensity or candle power (in the given direction) of the source (or sources) by which it is illuminated, are known as illustrated by the following examples.

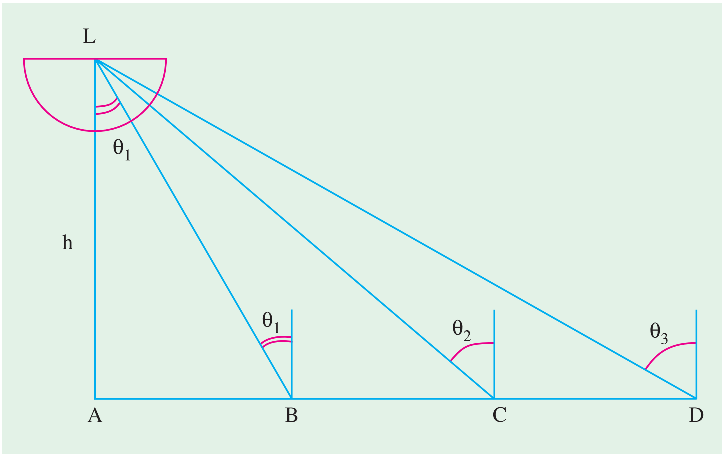

Fig. 49.7

Consider a lamp of uniform luminous intensity suspended at a height h above the working plane as shown in Fig. 49.7. Let us consider the value of illumination at point A immediately below the lamp and at other points B,C,D etc., lying in the working plane at different distances from A.

$$E_A = \frac{I}{h^2} \quad \text{—since } \theta = 0 \text{ and } \cos\theta = 1$$

$$E_B = \frac{I}{LB^2} \times \cos\theta_1. \qquad \text{Since,} \quad \cos\theta_1 = h/LB$$

$$\therefore \quad E_B = \frac{I}{LB^2} \times \frac{h}{LB} = I \times \frac{h}{LB^2} = \frac{1}{h^2} \cdot \frac{h^3}{LB^3} = \frac{1}{h^2}\left(\frac{h}{LB}\right)^3$$

Now $\frac{1}{h^2} = E_A$ and $\left(\frac{h}{LB}\right)^3 = \cos^3\theta_1$

$$\therefore \quad E_B = E_A \cos^3\theta_1$$

Similarly, $E_C = E_A \cdot \cos^3\theta_2$ and $E_D = E_A \cos^3\theta_3$ and so on.

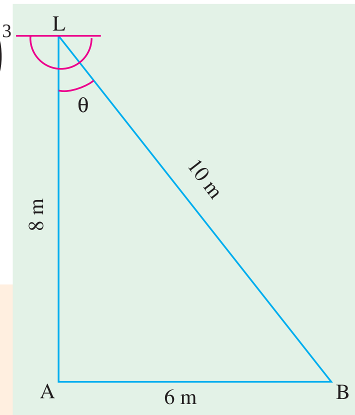

Fig. 49.8

Example 49.1. *A lamp giving out 1200 lm in all directions is suspended 8 m above the working plane. Calculate the illumination at a point on the working plane 6 m away from the foot of the lamp.* **(Electrical Technology, Aligarh Muslim Univ.)**

Solution. Luminous intensity of the lamp is

$$I = 1200/4\pi = 95.5 \text{ cd}$$

As seen from Fig. 49.8.

$$L_B = \sqrt{8^2 + 6^2} = 10 \text{ m} \; ; \cos\theta = 8/10 = 0.8$$

Now, $\quad E = I \cos\theta/r^2$

$$\therefore \quad E_B = 95.5 \times 0.8/10^2 = \mathbf{0.764 \ lm/m^2}$$

Example 49.2. *A small light source with intensity uniform in all directions is mounted at a height of 10 metres above a horizontal surface. Two points A and B both lie on the surface with point*

A directly beneath the source. How far is B from A if the illumination at B is only 1/10 as great as at A ? **(A.M.I.E.)**

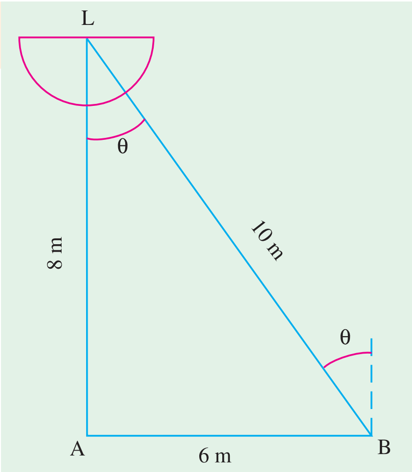

Fig. 49.9

Solution. Let the intensity of the lamp be I and the distance between A and B be x metres as shown in Fig. 49.9.

Illumination at point $A, E_A = I/10^2 = I/100$ lux

Illumination at point B,

Illumination at point B,

$$E_B = \frac{I}{10^2} \times \left[\frac{10}{\sqrt{10^2 + x^2}}\right]^2 = \frac{10\,I}{(100 + x^2)^{3/2}}$$

Since $E_B = \dfrac{E_A}{10}$,

$$\therefore \quad \frac{10\,I}{(100 + x^2)^{3/2}} = \frac{1}{10} \times \frac{I}{100}, \qquad \therefore \quad x = \mathbf{19.1\ m}$$

Example 49.3. *A corridor is lighted by 4 lamps spaced 10 m apart and suspended at a height of 5 m above the centre line of the floor. If each lamp gives 200 C.P. in all directions below the horizontal, find the illumination at the point on the floor mid-way between the second and third lamps.*

(Electrical Engineering, Bombay Univ.)

Solution. As seen from 49.10, illumination at point C is due to all the four lamps. Since point C is symmetrically situated between the lamps, illumination at this point is twice that due to L_1 and L_2.

(*i*) illumination due to $L_1 = I\cos\theta_1/L_1C^2 \quad L_1C = \sqrt{5^2 + 15^2} = 15.8$ m

$\cos\theta = 5/15.8$

illumination due to $L_1 = \dfrac{220 \times (5/15.8)}{250} = \mathbf{0.253\ lm/m^2}$

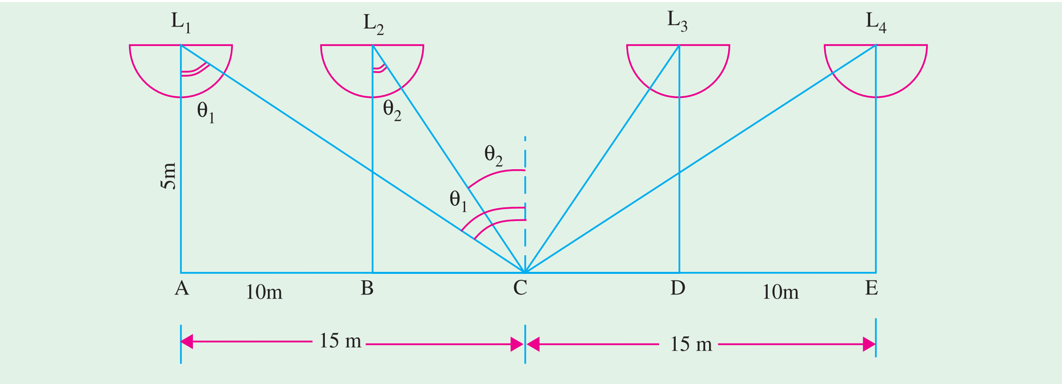

Fig. 49.10

(*ii*) $L_2C = 5/\sqrt{2}$ m ; $\theta_2 = 45°$; $\cos\theta_2 = 1/\sqrt{2}$

Illumination due to $L_2 = \dfrac{200 \times 1/\sqrt{2}}{50} = 2.83$ lm/m^2

$\therefore$ illumination at C due to L_1 and $L_2 = 3.08$ lm/m^2

Illumination at C due to all the four lamps, $E_C = 2 \times 3.08 = \mathbf{6.16\ lm/m^2}$

Example 49.4. *Two lamps A and B of 200 candela and 400 candela respectively are situated 100 m apart. The height of A above the ground level is 10 m and that of B is 20 m. If a photometer is placed at the centre of the line joining the two lamp posts, calculate its reading.*

(Electrical Technology, Gujarat Univ.)

Solution. When the illumination photometer is placed at the centre point, it will read the value of combined illumination produced by the two lamps (Fig. 49.11).

Now, $L_1C = \sqrt{10^2 + 50^2} = 51 \text{ m}$

$L_2C = \sqrt{20^2 + 50^2} = 53.9 \text{ m}$

$\cos\theta_1 = 10/51$;

$\cos\theta_2 = 20/53.9$

Illumination at point C due to lamp L_1

$$= \frac{200 \times 10}{51 \times 2600} = \mathbf{0.015\ lm/m^2}$$

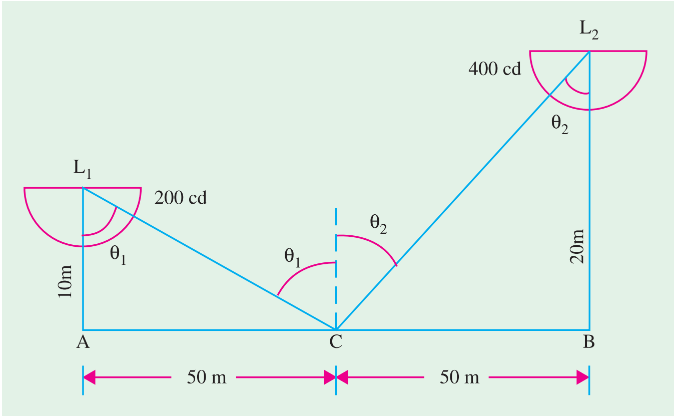

Fig. 49.11

Similarly, illumination due to lamp L_2

$$= \frac{400 \times 20/53.9}{2900} = \mathbf{0.051\ lm/m^2}$$

$\therefore \quad E_C = 0.015 + 0.051 = \mathbf{0.066\ lm/m^2\ or\ lux}$

Example 49.5. *The average luminous output of an 80-W fluorescent lamp 1.5 metre in length and 3.5 cm diameter is 3300 lumens. Calculate its average brightness. If the auxiliary gear associated with the lamp consumes a load equivalent to 25 percent of the lamp, calculate the cost of running a twin unit for 2500 hours at 30 paise per kWh.*

Solution. Surface area of the lamp $= \pi \times 0.035 \times 1.5 = 0.165 \text{ m}^2$

Flux emitted per unit area $= 3300/0.165 = 2 \times 10^4 \text{ lm/m}^2$

$$\therefore \quad B = \frac{\text{flux emitted per unit erea}}{\pi} \text{ cd/m}^2 = 2 \times \frac{10^2}{\pi} = \mathbf{6{,}382\ cd/m^2}$$

Total load of twin fitting $= 2[80 + 0.25 \times 80] = 200 \text{ W}$

Energy consumed for 2500 hr $= 2500 \times 200 \times 10^{-3} = 500 \text{ kWh}$

cost $=$ Rs. $500 \times 0.3 =$ **Rs. 150.**

Example 49.6. *A small area 7.5 m in diameter is to be illuminated by a lamp suspended at a height of 4.5 m over the centre of the area. The lamp having an efficiency of 20 lm/w is fitted with a reflector which directs the light output only over the surface to be illuminated, giving uniform candle power over this angle. Utilisation coefficient = 0.40. Find out the wattage of the lamp. Assume 800 lux of illumination level from the lamp.* **(A.M.I.E.)**

Solution. $A = \pi d^2/4 = 44.18 \text{ m}^2, \quad E = 800 \text{ lux}$

Luminous flux reaching the surface $= 800 \times 44.18 = 35{,}344$ lm

Total flux emitted by the lamp $= 35{,}344/0.4 = 88{,}360$ lm

Lamp wattage $= 88{,}360/20 =$ **4420 W**

Example 49.7. *A lamp of 100 candela is placed 1 m below a plane mirror which reflects 90% of light falling on it. The lamp is hung 4 m above ground. Find the illumination at a point on the ground 3 m away from the point vertically below the lamp.*

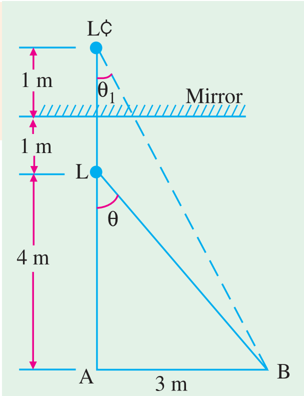

Fig. 49.12

Solution. The lamp and mirror arrangement is shown in Fig. 49.12. The lamp L produces an image L' as far behind the mirror as it is in front. Height of the image from the ground is (5 + 1) = 6m. L' acts as the secondary source of light and its candle power is $= 0.9 \times 100 = 90$ candela.

Illumination at point B equals the sum of illumination due to L and that due to L'.

$$\therefore \quad E_B = \frac{100}{(LB)^2} \times \cos\theta + \frac{90}{(L'B)^2}\cos\theta_1$$

$$= \frac{100}{5^2} \times \frac{4}{5} \times \frac{90}{45} \times \frac{6}{\sqrt{45}} = \textbf{5 lux}$$

Example. 49.8. *A light source having an intensity of 500 candle in all directions is fitted with a reflector so that it directs 80% of its light along a beam having a divergence of 15°. What is the total light flux emitted along the beam? What will be the average illumination produced on a surface normal to the beam direction at a distance of 10 m?* **(A.M.I.E.)**

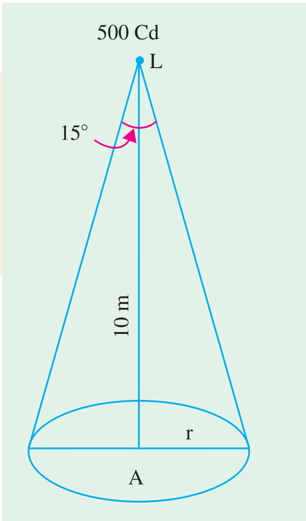

Fig. 49.13

Solution. Total flux emitted along the beam $= 0.8\,(4\pi \times 500) =$ **5,227 lm**

Beam angle, $\theta = 15°$, $l = 10$ m

Radius of the circle to be illuminated, $r = l \tan\theta/2$

$= 10 \tan 15°/2 = 1.316$ m

Area of the surface to be illuminated, $A = \pi r^2 = \pi \times 1.316^2$

$= 5.44\ \text{m}^2$

$\therefore$ Average illumination $= 5227/5.44 =$ **961 lux**

Example 49.9. *A lamp has a uniform candle power of 300 in all directions and is fitted with a reflector which directs 50% of the total emitted light uniformly on to a flat circular disc of 20 m diameter placed 20 m vertically below the lamp. Calculate the illumination (a) at the centre and (b) at the edge of the surface without the reflector. Repeat these two calculations with the reflector provided.* **(Electrical Engg., Grad I.E.T.E.)**

Solution. It should be noted that the formula $E = I\cos\theta/r^2$ will not be applicable when the reflector is used. Moreover, with reflector, illumination would be uniform.

Without Reflector

(*a*) $E = 300 \times 1/20^2 =$ **0.75 lm/m²**

(*b*) Here, $\theta = \tan^{-1}(10/20) = 26.6°$, $\cos\theta = 0.89$; $x^2 = 10^2 + 20^2 = 500$

$\therefore$ $E = 300 \times 0.89/500 =$ **0.534 lm/m²**

With Reflector

Luminous output of the lamp $= 300 \times 4\pi$ lumen

Flux directed by the reflector $= 0.5 \times 1200\,\pi = 600\,\pi$ lm

Illumination produced on the disc $= 600\,\pi/100\,\pi =$ **6 lm/m²**

It is the same at every point of the disc.

Example 49.10. *A light is placed 3 m above the ground and its candle power is 100 cos θ in any downward direction making an angle q with the vertical. If P and Q are two points on the grond, P being vertically under the light and the distance PQ being 3 m, calculate.*

(a) the illumination of the ground at P and also at Q.

(b) the total radiations sent down by the lamp.

Solution. With reference to Fig. 49.14

(*a*) C.P. along $LP = 100 \times \cos 0° = 100$ cd $\quad \therefore \quad E_P = 100/3^2 =$ **11.1 lm/m²**

C.P. along $LQ = 100 \times \cos 45° = 70.7 \quad \therefore \quad E_Q = 70.7 \times \cos 45°/18 =$ **1.39 lm/m²**

(*b*) Consider an imaginary hemisphere of radius *r* metre at whose centre lies the given lamp (Fig. 49.15).

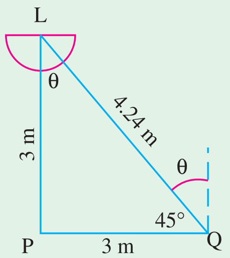

Fig. 49.14

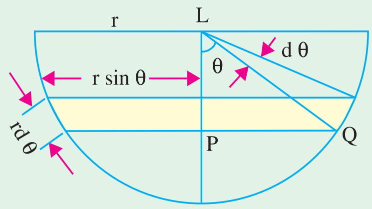

Fig. 49.15

C.P. along $LQ = 100 \cos \theta \quad \therefore \quad E_Q = 100 \cos \theta / r^2$

The area of the elementary strip at an angular distance θ from the vertical and of width $PQ = r.\,d\theta$ is $= (2\pi\, r \sin \theta) \times r.d\theta = 2\pi r^2 \sin \theta\, d\theta$.

Flux incident on the shaded area

$$= \frac{100 \cos \theta}{r^2} 2\pi\, r^2 \sin \theta.\, d\theta = 100\,\pi.\, 2 \sin \theta.\cos \theta\, d\theta = 100\,\pi \sin 2\theta\, d\theta.$$

Total flux over the hemisphere can be obtained by integrating the above expression between proper limits.

$$\therefore \qquad \text{total flux} = \int_0^{\pi/2} 100\,\pi \sin 2\theta\, d\theta = 100\,\pi \left| -\frac{\cos 2\theta}{2} \right|_0^{\pi/2} = \frac{100\,\pi}{2}$$

$$= 100\,\pi = \mathbf{314.lm}.$$

Example 49.11. *A drawing office containing a number of boards and having a total effective area of 70 m² is lit by a number of 40 W incandescent lamps giving 11 lm/W. An illumination of 80 lux is required on the drawing boards. Assuming that 60% of the total light emitted by the lamps is available for illuminating the drawing boards, estimate the number of lamps required.*

Solution. Let *N* be the number of 40 W lamps required.

Output/lamp $= 40 \times 11 = 440$ lm ; Total flux $= 440\,N$ lm

Flux actually utilized $= 0.6 \times 440\,N = 264\,N$ lm

Illumination required $= 80$ lux $= 80$ lm/m²

Total flux required at the rate of 80 lm/m² $= 80 \times 70$ lm $= 5600$ lm

$264\,N = 5600 \quad \therefore \quad N =$ **21**

Example 49.12. *A perfectly diffusing surface has a luminous intensity of 10 candles at an angle of 60º to the normal. If the area of the surface is 100 cm^2, determine the brightness and total flux radiated.*

Solution. Brightness B is defined as the luminous intensity divided by the projected area (Fig. 49.16).

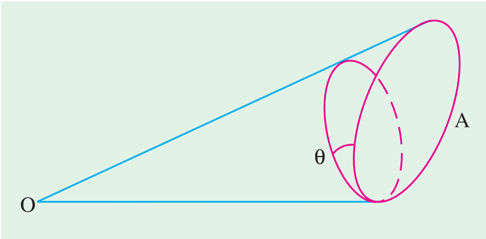

Fig. 49.16

Luminous intensity = 10 candela

Projected area = $A \cos \theta$

$= 100 \times \cos 60°$

$= 50 \text{ cm}^2$

$\therefore \quad B = 10/50 \times 10^{-4}$

$= 2 \times 10^3 \text{ cd/m}^2$

$= \mathbf{2\pi \times 10^3 \text{ lm/m}^2}$—Art. 46.4

Total flux radiated $= 2\pi \times 10^3 \times 100 \times 10^{-4}$

$= \mathbf{68.2 \text{ lm}}$

Example 49.13. *Calculate the brightness (or luminance) of snow under an illumination of **(a)** 44,000 lux and **(b)** 0.22 lux. Assume that snow behaves like a perfect diffusor having a reflection factor of 85 per cent.*

Solution. (*a*) $L = \rho E/\pi = 44{,}000 \times 0.85/\pi \text{ cd/m}^2 = \mathbf{1.19 \times 10^4 \text{ cd/m}^2}$

(*b*) $L = \dfrac{0.22 \times 0.85}{\pi} = \mathbf{5.9 \times 10^{-2} \text{ cd/m}^2}$

Example 49.14. *A 21 cm diameter globe of dense opal glass encloses a lamp emitting 1000 lumens and has uniform brightness of 4×10^3 lumen/m^2 when viewed in any direction. What would be the luminous intensity of the globe in any direction? Find what percentage of the flux emitted by the lamp is absorbed by the globe.*

Solution. Surface area of the globe $= \pi d^2 = \pi \times 21^2 = 1{,}386 \text{ cm}^2 = 0.1386 \text{ m}^2$

Flux emitted by the globe is $= 0.1386 \times 4 \times 10^3 = 554.4$ lumen

Now, 1 candela $= 4\pi$ lumens

Hence, luminous intensity of globe is $= 554.4/4\pi =$ **44 cd**

Flux absorbed by the globe is $= 1000 - 554.4 = 445.6$ lm.

$\therefore$ percentage absorption $= 445.6 \times 100/1000 =$ **44.56%**

Example 49.15. *A 2.5 cm diameter disc source of luminance 1000 cd/cm^2 is placed at the focus of a specular parabolic reflector normal to the axis. The focal length of the reflector is 10 cm, diameter 40 cm and reflectance 0.8. Calculate the axial intensity and beam-spread. Also show diagrammatically what will happen if the source were moved away from the reflector along the axis in either direction.* **(A.M.I.E. Sec. B, Winter 1991)**

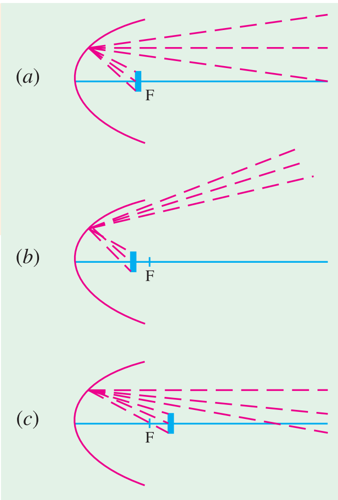

Fig. 49.17

Solution. The axial or beam intensity I depends upon

(*i*) luminance of the disc source *i.e.* L

(*ii*) aperture of the reflector *i.e.* A

(*iii*) reflectivity of the reflector *i.e.* r

$\therefore \quad I = \rho A L$ candela

Now, $\quad L = 1000 \text{ cd/cm}^2 = 10^7 \text{ cd/m}^2$

$A = \pi d^2/4 = \pi \times 0.4^2/4 = 125.7 \times 10^{-3} \text{ m}^2$

$\therefore \quad I = 0.8 \times 125.7 \times 10^{-3} \times 10^7 = \mathbf{1{,}005{,}600 \text{ cd}}$

To a first approximation, the beam spread for disc source is determined by reflector focal length and the size of the disc source. If θ is the total beam spread when the source is at the focus of the reflector [Fig. 49.17] (*a*)] then

$$\theta = 2\tan^{-1}(r/f)$$

Here, $r = 2.5/2 = 1.25$ cm ; $f = 10$ cm

$\therefore \quad \theta = 2\tan^{-1}(1.25/10) = 2 \times 7°7' = \mathbf{14°14'}$

The effect of axial movement of the source is shown in Fig. 49.17 (*b*) and (*c*).

Example 49.16. *A 22 diameter globe of opal glass encloses a lamp of uniform luminous intensity 120 C.P. Thirty per cent of light emitted by the lamp is absorbed by globe. Determine **(a)** luminance of globe **(b)** C.P. of globe in any direction.*

Solution.

(*a*) Flux emitted by source $= 120 \times 4\pi$ lm ; flux emitted by globe $= 0.7 \times 480\ \pi$ lm

$$\therefore \quad L = \frac{0.7 \times 480\ \pi}{\pi \times 0.22^2} = \mathbf{6{,}940\ lm/m^2}$$

(*b*) Since 1 candela $= 4\ \pi$ lm

∴ candle-power or luminous intensity of the globe is

$$= \frac{\text{flux in lumens}}{4\ \pi} = \frac{0.7 \times 480\ \pi}{\pi \times 4} = \mathbf{84\ cd}$$

Example 49.17. *A 0.4 m diameter diffusing sphere of opal glass (20 percent absorption) encloses an incandescent lamp with a luminous flux of 4850 lumens. Calculate the average luminance of the sphere.* **(A.M.I.E. Sec. B, Summer 1993)**

Solution. Flux emitted by the globe 80% or 4850 = 3880 lm

Surface area of the globe $= 4\pi r^2 = \pi d^2 \text{m}^2$

$$B = \frac{\text{flux emitted}}{\text{surfacr area}} = \frac{3880}{\pi \times 0.4^2} = \mathbf{7{,}720\ lm/m^2}$$

Tutorial Problem No. 49.1

1. A high-pressure mercury-vapour lamp is mounted at a height of 6 m in the middle of a large road crossing. A special reflector directs 100 C.P. maximum in a cone of 70º to the vertical line. Calculate the intensity of illumination on the road surface due to this beam of 100 C.P. ***(Electrical Engineering, Bombay Univ.)***
2. A room 6m × 4 m is illuminated by a single lamp of 100 C.P. in all directions suspended at the centre 3 m above the floor level. Calculate the illumination (*i*) below the lamp and (*ii*) at the corner of the room. ***(Mech. & Elect. Engg. : Gujarat Univ.)***
3. A lamp of 100 candle-power is placed at the centre of a room 10 m × 6m × 4 m high. Calculate the illumination in each corner of the floor and at a point in the middle of a 6 m wall at a height of 2 m from the floor. ***(Utilization of Elect. Power A.M.I.E.)***
4. A source of 5000 lumen is suspended 6.1 m. above ground. Find out the illumination (*i*) at a point just below the lamp and (*ii*) at a point 12.2 m away from the first, assuming uniform distribution of light from the source. **[(*i*) 10.7 lux (*ii*) 0.96 lux]** ***(A.M.I.E. Sec. B)***
5. Determine the average illumination of a room measuring 9.15 m by 12.2 m illuminated by a dozen 150 W lamps. The luminous efficiency of lamps may be taken as 14 lm/W and the co-efficient of utilisation as 0.35. **[79 lux]** ***(A.M.I.E. Sec. B)***
6. Two lamps are hung at a height of 9 m from the floor level. The distance between the lamps is one metre. Lamp one is of 500 candela. If the illumination on the floor vertically below this lamp is 20 lux, find the candle power of the lamp number two. **[1140 candela]** ***(Utili. of Elect. Power A.M.I.E.)***

7. Two powerful street lamps of 1,000 candela and 800 candela (assumed uniform in all directions) are mounted 12.5 m above the road level and are spaced 25 metres apart. Find the intensity of horizontal illumination produced at a point on the ground in-between the lamp posts and just below the lamp posts. **[4.07 lux, 6.86 lux, 5.69 lux]** ***(A.M.I.E.)***
8. It is required to provide an illumination of 100 lux in a factory hall 30 m by 15 m. Assume that the depreciation factor is 0.8, coefficient of utilisation is 0.4 and efficiency of lamp is 14 lm/W. Suggest the number of lamps and their ratings. The sizes of the lamps available are 100, 250, 400 and 500 W. **[40 lamps of 250 W in 5 rows]**
9. It is required to provide an illumination of 100 lm/m^2 in a workshop hall 40m $\times$ 10m and efficiency of lamp is 14 lm/W. Calculate the number and rating of lamps and their positions when trusses are provided at mutual distance of 5m. Take coefficient of utilisation as 0.4 and depreciation factor as 0.8. **[14 lamps of 750 W each]**
10. A drawing hall 30 m by 15 m with a ceiling height of 5 m is to be provided with a general illumination of 120 lux. Taking a coefficient of utilization of 0.5 and depreciation factor of 1.4, determine the number of flourscent tubes required, their spacing, mounting height and total wattage.

    Taking luminous efficiency of flourescent tube as 40 Im/W for 80 W tubes.

    [48, 24 twin-tube units each tube of 80 W; row spacing of 5 m and unit spacing of 3.75m, 3840 W] ***(Utilisation of Elect. Power, A.M.I.E.)***

49.6. Laws Governing Illumination of Different Sources

The laws applicable to the illumination produced by the following three types of sources will be considered.

(*i*) Point Source

As discussed in Art. 49.5, the law governing changes in illumination due to point source of light is $E = I \cos \theta / d^2$.

(*ii*) Line Source

Provided the line source is of infinite length and of uniform intensity, the illumination at a point lying on a surface parallel to and facing the line source is given by

$$E = \frac{\pi I}{2d} \text{ lm/m}^2$$

where I = luminous intensity normal to the line source (in candles per-meter length of the sources)

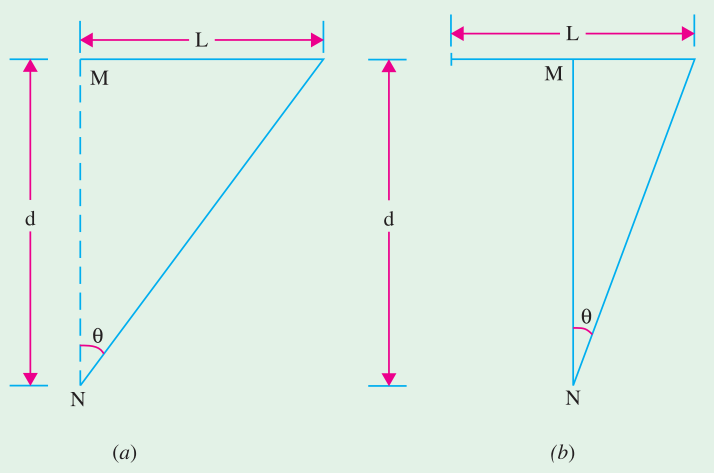

Fig. 49.18

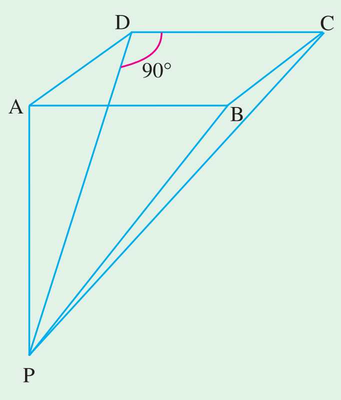

Fig. 49.19

However, in practice, the line sources are of finite length, so that the following law applies

$$E = \frac{I}{4\,d}\,(\sin 2\theta + 2\theta)\ \text{lm/m}^2 \qquad \text{—Fig. 49.18 } (a)$$

$$= \frac{I}{2\,d}\,(\sin 2\theta + 2\theta)\ \text{lm/m}^2 \qquad \text{—Fig. 49.18 } (b)$$

where I = candle power per metre length in a direction normal to the line source

$$= \frac{\Phi}{\pi^2 L}\ \text{cd/m}$$

where Φ is the total flux of the source in lumens and L is the length of the line source in metres.

(*iii*) Surface Source

Provided the surface source is of infinite area and of uniform brightness, illumination at any point facing the source is independant of the distance between the point and the surface source. Mathematically, its value is $E = \pi L$ lm/m^2 where L is the luminance of the surface source in cd/m^2.

In case the surface source is limited and rectangular in shape (Fig. 49.19), the law governing the illumination at a point P is

$$E = \frac{L}{2}\,(\alpha' \sin\beta + \beta' \sin a)$$

where $\alpha = \angle APD\ ;\ \alpha' = \angle BPC\ ;\ \beta = \angle APB\ ;\ \beta' = \angle DPC$

Note. (*i*) In case, distance d is more than 5 times the greatest dimension of the source, then irrespective of its shape, the illumination is found to obey inverse square law. This would be the case for illumination at points 5 metres or more away from a fluorescent tube of length one metre.

(*ii*) In the case of surface sources of large area, such as luminous daylights covering the whole ceiling of a large room, illumination is found to be practically constant irrespective of the height of the working place.

It may be noted that a point source produces deep shadows which may, however, be cancelled by installing a large number of fittings. Usually, glare is present. However, point sources are of great practical importance where accurate light control is required as in search-lights.

Line sources give more diffusion but cast shadows of objects lying parallel to them thus hindering vision.

Large-area surface sources though generally of low brightness, produce minimum glare but no shadows. However, the final effect is not liveliness but one of deadness.

Example 49.18. *A show case is lighted by 4 metre of architectural tubular lamps arranged in a continuous line and placed along the top of the case. Determine the illumination produced on a horizontal surface 2 metres below the lamps in a position directly underneath the centre of the 4 m length of the lamps on the assumption that in tubular lamps emit 1,880 lm per metre run. Neglect the effect of any reflectors which may be used.*

Solution. As seen in Art 49.10

$$E = \frac{I}{2d}\,(\sin 2\theta + 2\theta)\ \text{lm/m}^2 \text{ and } I = \frac{\Phi}{\pi^2 L}\ \text{cd/m}$$

As seen from Fig. 49.15

$$\theta = \tan^{-1}(L/2\,d)$$

$$= \tan{-}1(4/2) = 45°$$

$$I = 4 \times 1{,}880/\pi^2 \times 4$$

$$= \mathbf{188\ cd/m}$$

$$\therefore \quad E = \frac{188}{2\times 2}\left(\sin 90° + \frac{\pi}{2}\right) = \mathbf{121\ lm/m^2}$$

49.7. Polar Curves of C.P. Distribution

All our calculations so far were based on the tacit assumption that the light source was of equal luminous intensity or candle-power in all directions. However, lamps and other sources of light, as a rule, do not give uniform distribution in the space surrounding them.

If the actual luminous intensity of a source in various directions be plotted to scale along lines radiating from the centre of the source at corresponding angles, we obtain the polar curve of the candle power.

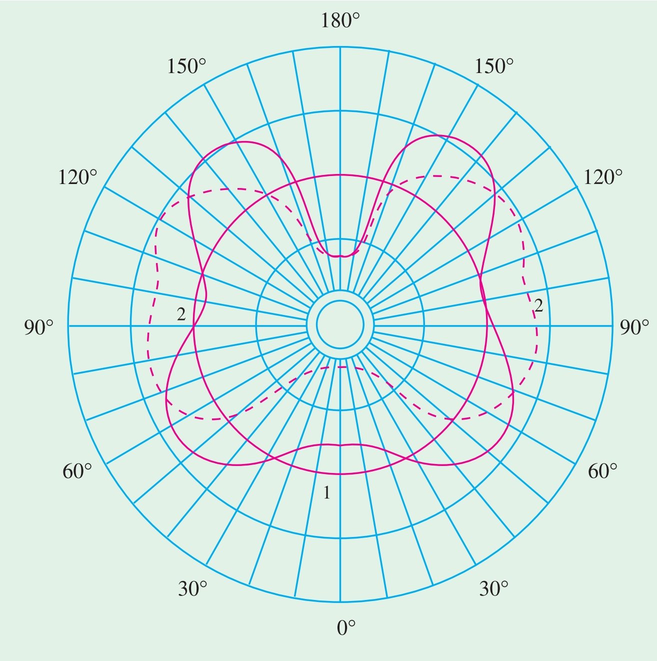

Fig. 49.20

Suppose we construct a figure consisting of large number of spokes radiating out from a point—the length of each spoke representing to some scale the candle power or luminous intensity of the source in that particular direction. If now we join the ends of these spokes by some suitable material, say, by linen cloth, then we get a surface whose shape will represent to scale the three dimensional candle power distribution of the source placed at the centre. In the ideal case of a point source having equal distribution in all directions, the surface would be spherical.

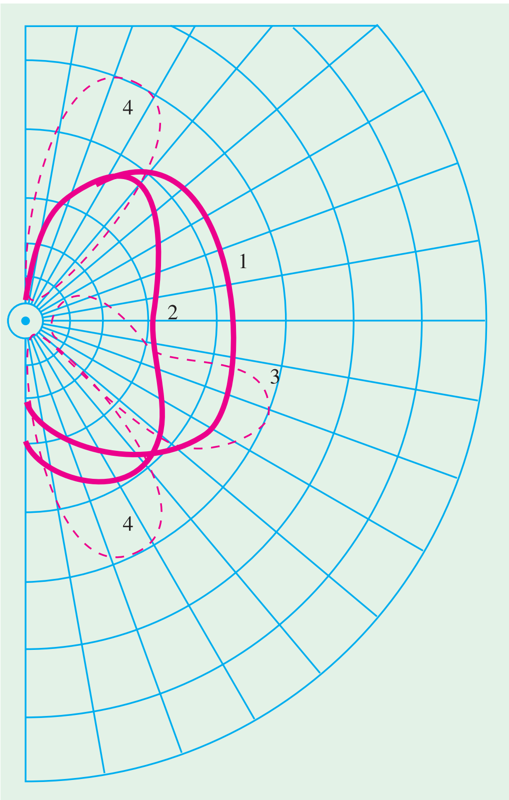

Fig. 49.21

It would be realized that it is difficult to give a graphic representation of such a 3-dimensional model in a plane surface. Therefore, as with engineering drawings, it is usual to draw only one or more elevations and a plan of sections through the centre of the source. Elevations represent c.p. distribution in the ***vertical*** plane and the plans represent c.p. distribution in ***horizontal*** plane. The number of elevations required to give a complete idea of the c.p. distribution of the source in all directions depends upon the shape of the plan *i.e.* on the horizontal distribution. If the distribution is uniform in every horizontal plane *i.e.* if the polar curve of horizontal distribution is a circle, then only one vertical curve is sufficient to give full idea of the space distribution.

In Fig. 49.20 are shown two polar curves of c.p. distribution in a vertical plane. Curve 1 is for vacuum type tungsten lamp with zig-zag filament whereas curve 2 is for gas filled tungsten lamp with filament arranged as a horizontal ring.

If the polar curve is symmetrical about the vertical axis as in the figures given below, then it is sufficient to give only the polar curve within one semicircle in order to completely define the distribution of c.p. as shown in Fig. 49.21.

The curves 1 and 2 are as in Fig. 49.20, curves 3 is for d.c. open arc with plain carbons and curve 4 is for a.c. arc with plain carbons. However, if the source and/or reflector are not symmterical about vertical axis, it is impossible to represent the space distribution of c.p. by a single polar diagram and even polar diagrams for two planes at right angles to each other give no definite idea as to the distribution in the intermediate planes.

Consider a filament lamp with a helmet-type reflector whose axis is inclined and cross-section elliptical—such reflectors are widely used for lighting shop windows. Fig. 49.22 represents the distribution of luminous intensity of such source and its reflector in two planes at right angles to each other.

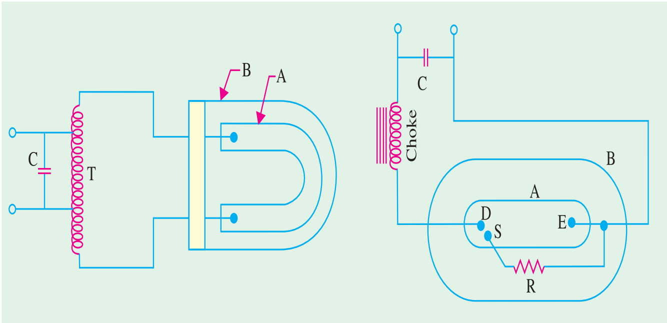

Fig. 49.22

The importance of considering the polar curves in different planes when the c.p. distribution in asymmetrical is even more strikingly depicted by the polar curves in YY plane and XX plane of a lamp with a special type of reflector designed for street lighting purposes (Fig. 49.23).

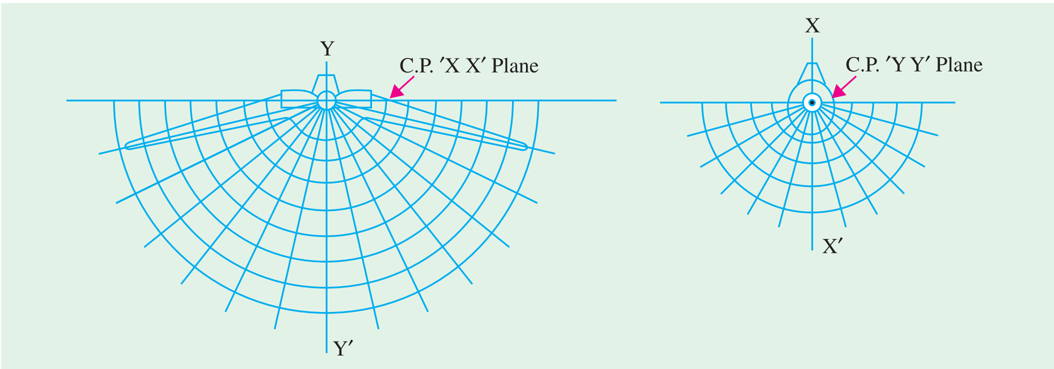

Fig. 49.23

It would be realized from above that the polar distribution of light from any source can be given any desired form by using reflectors and/or refractors of appropriate shape.

In Fig. 49.24 is shown the polar curve of c.p. distribution of a straight type of lamp in a horizontal plane.

49.8. Uses of Polar Curves

Polar curves are made use of in determining the M.S.C.P. etc. of a source. They are also used in determining the actual illumination of a surface *i.e.* while calculating the illumination in a particular direction, the c.p. in that particular direction as read from the vertical polar curve, should be employed.

49.9. Determination of M.S.C.P. and M.H.C.P. from Polar Diagrams

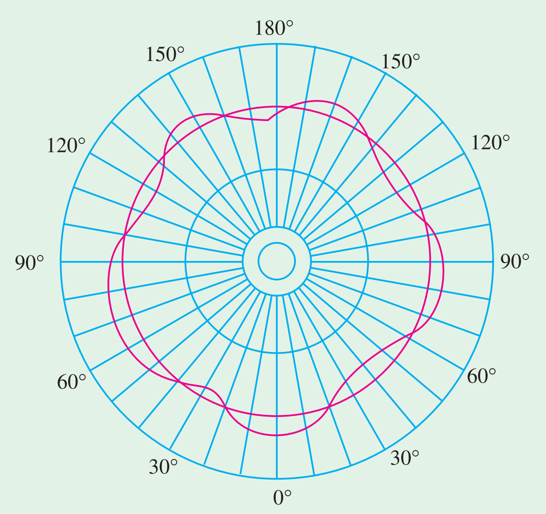

Fig. 49.24

In Fig. 49.25 (*a*) is shown the polar distribution curve of a filament lamp in a horizontal plane and the polar curve in Fig. 49.25 (*b*) represents the c.p. distribution in a vertical plane. It will be seen that the horizontal candle-power is almost uniform in all directions in that plane. However, in the vertical plane, there is a large variation in the candle power which falls to zero behind the cap of the lamp. The curve in Fig. 49.25 (*a*) has been drawn with the help of a photometer while the lamp is rotated about a vertical axis, say, 10° at a time. But the curve in Fig. 49.25 (*b*) was drawn while the lamp was rotated in a vertical plane about a horizontal axis passing through the centre of the filament.

The M.H.C.P. is taken as the mean of the readings in Fig. 49.25 (*a*). However, a more accurate result can be obtained by plotting candle power on an angular base along the rectangular axes and by determining the mean height of the curve by the mid-ordinate or by Simpson's rule.

The M.S.C.P. of the lamp can be obtained from the vertical polar curve of Fig. 49.25 (*b*) by Rousseau's construction as explained below :

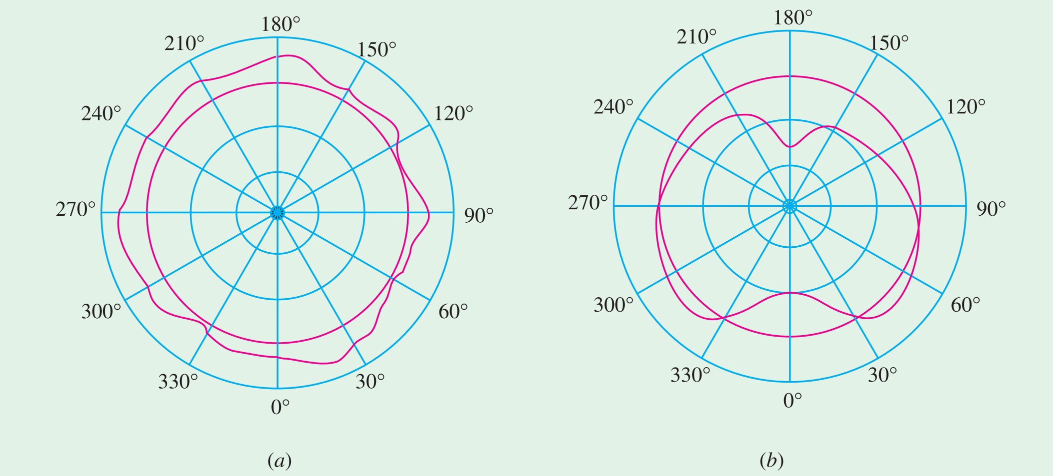

Fig. 49.25

Only half of the vertical polar curve is shown in the figure (Fig. 49.26) since it is symmetrical about the vertical axis. With *O* is the centre and radius *OR* equal to the maximum radius of the polar curve, a semi-circle *LRM* is drawn. A convenient number of points on this semi-circle (say 10° points) are projected onto any vertical plane as shown. For example, points *a*,*b*,*c* etc. are projected to *d*,*e*,*f* and so on. From point *d*, the horizontal line *dg* is drawn equal to the intercept *OA* of the polar diagram on the radius *oa*. Similarly, *eh* = *OB*, *fk* = *OC* and so on. The points *g*, *h*, *k* etc., define the Rousseau figure. The average width *w* of this figure represents the M.S.C.P. to the same scale as that of the candle powers in the polar curve. The average width is obtained by dividing the Rousseau area by the base of the Rousseau figure *i.e.* length lm which is the projection of the semi-circle *LM* on the vertical axis. The area may be determined by Simpson's rule or by using a planimeter.

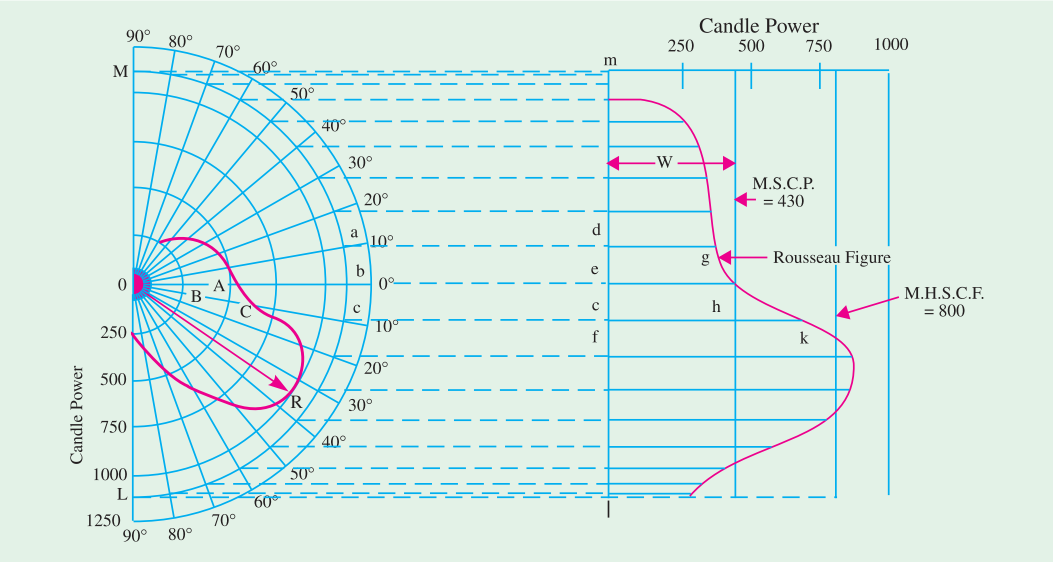

Fig. 49.26

$$\therefore \qquad \text{M.S.C.P.} = \frac{\text{area of Rousseau figure}}{\text{length of the base}}$$

As explained earlier, the M.H.C.P. of an incandescent lamp can be easily obtained by mounting the lamp with its axis vertical and taking photometer readings in the horizontal plane while the lamp is rotated about its axis in steps of 10° or so. A definite ratio exists between the M.H.C.P. and M.S.C.P. of each particular type of filament. M.S.C.P. of a lamp can be found by multiplying M.H.C.P. by a factor known as spherical reduction factor which, as defined earlier, is

$$\text{Spherical reduction factor} \quad f = \frac{\text{M.S.C.P.}}{\text{M.H.C.P.}} \qquad \therefore \quad \text{M.S.C.P.} = f \times \text{M.H.C.P.}$$

For the particular lamp considered, f = 430/80 = 0.54 (approx.)

Typical values of this factor are :

Ordinary vacuum-type tungsten lamp having zig-zag filament	0.76 – 0.78
Gas-filled tungsten lamp with filament in the form of broad shallow *V*'s	0.85 – 0.94
Gas-filled tungsten lamp with filament in the shape of a horizontal ring	1.0 – 1.2

The total lumen output is given by the relation ; lumen output = $4\pi \times$ M.S.C.P.

In the present case, lumen output = $4\pi \times 430$

= 5,405 lm

49.10. Integrating Sphere or Photometer

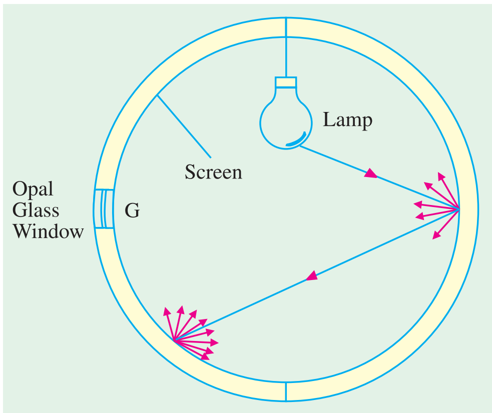

Fig. 49.27

The M.S.C.P. is usually measured by means of an integrating photometer, the most accurate form of which consists of a hollow sphere (as originally proposed by Ulbricht) whose diameter is large (at least 6 times) as compared to that of the lamp under test. The interior surface of the hollow sphere is whitened by means of a special matt white paint. When the lamp is placed inside the sphere (not necessarily at its centre) then due to successive reflections, its light is so diffused as to produce a uniform illumination over the whole surface. At some point, a small matt opal-glass window, shaded from the direct rays of the source, is made in the hollow sphere.

The brightness of the matt opal glass is proportional to that of the interior surface of the sphere. By using a suitable illumination photometer, the illumination of the window can be measured which can be used to find out the total flux emitted by the source.

$$\text{Total flux} = \text{illumination (1m/m}^2) \times \text{surface area of the sphere (m}^2)$$

$$\therefore \quad \text{M.S.C.P.} = \frac{\text{total flux}}{4\pi} \text{ candela}$$

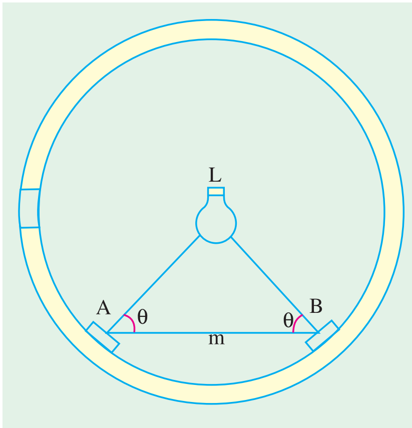

Fig. 49.28

Theory. In Fig. 49.28 is shown a light source L of luminous intensity I candela and having a total flux output of F_L placed at the centre of an integrating sphere of radius r and reflection factor ρ. Let E_A and E_B represent the illuminations at two points A and B, each of infinitely small area da and db respectively and distance m apart. We will now consider total illumination (both direct and reflected) at point A.

Obviously, $\quad E_A$ directly due to $L = I/r^2$

$\quad\quad E_B$ directly due to $L = I/r^2$

Luminous intensity of B in the direction of A is

$$I_B = \frac{\rho . E_B . A_B}{\pi} \text{ candela} \qquad \text{—Art. 45.4}$$

where $\quad A_B$ = projected area of B at right angles to the line $BA = db.\cos\theta$

$$\therefore \quad I_B = \frac{\rho . I . db \cos\theta}{\pi r^2} \text{ candela}$$

Hence, illumination of A due to B is $= \dfrac{I_B \cos\theta}{m^2} = \dfrac{\rho I . db \cos^2\theta}{\pi r^2 \times m^2}$

Now, as seen from Fig. 49.28, $\quad m = 2r\cos\theta$

$\therefore$ illumination of A due to B becomes

$$= \frac{\rho . I . db \cos^2\theta}{\pi r^2 \times 4r^2 \cos^2\theta} = \frac{\rho}{4\pi r^2} \times \frac{I}{r^2} \times db = \frac{\rho}{S} . E_B . db = \frac{\rho F_B}{D}$$

where $\quad F_B$ = flux incident on B and A = surface area of the sphere

Hence, total illumination due to first reflection $= \sum \dfrac{\rho F_B}{S} = \dfrac{\rho F_B}{S}$

Now, consider any other point C. Illumination on B due to point $C = \rho F_L/S$. The illumination on A due to C as reflected from B.

$$= \left[\rho . \left(\frac{\rho F_L}{S}\right) \times \frac{db \cos\theta}{\pi}\right] \times \frac{\cos\theta}{m^2} = \frac{\rho F_L}{S} \times \frac{\rho . db \cos\theta}{\pi} \times \frac{\cos\theta}{4r^2 \cos^2\theta}$$

$$= \frac{\rho F_L}{S} \times \frac{\rho . db}{S}$$

Total illumination due to two reflections $= \sum \dfrac{\rho F_L}{S} \times \dfrac{\rho . db}{S} = \dfrac{\rho^2 F_L}{S} \qquad (\because \Sigma ab = S)$

Continuing this way, it can be proved that total illumination at point A from all reflections from all points

$$= \frac{\rho F_L}{S} (1 + \rho^2 + \rho^3 + \ldots\ldots\ldots\ldots + \rho^{n-1}) = \frac{\rho F_L}{S} \left(\frac{1}{1-\rho}\right)$$

Hence, total illumination at A from direct and reflected lights is

$$= E_A + \frac{\rho F_L}{S}\left(\frac{1}{1-\rho}\right)$$

If A is shielded from lamp L, then its illumination is proportional to F_L because $\frac{\rho}{S}\left(\frac{1}{1-\rho}\right)$ is a constant factor. Obviously, if either brightness or illumination at one point in the sphere is measured, it would be proportional to the light output of the source. This fact is made use of while using this sphere as a globe photometer.

Example 49.19. *If an integrating sphere 0.6 m in diameter whose inner surface has a reflection coefficient of 0.8 contains a lamp producing on the portion of the sphere, screened from direct radiation, a luminance of 1000 cd/m², what is the luminous flux yield of the source ?*

(A.M.I.E. Sec. B. Summer 1986)

Solution. Obviously, the screened portion of the sphere receives light by reflection only. Reflection illumination of the screened portion is

$$E = \frac{\rho F_1}{S}\left(\frac{1}{1-\rho}\right) = \frac{0.8\, F_L}{\pi \times 0.6^2}\left(\frac{1}{1-0.8}\right) = \frac{100\, F_L}{9\pi}\ \text{lm/m}^2$$

Also $\qquad L = \rho E/\pi \qquad$ — Art. 49.4

$$\therefore \quad 1000 = \frac{100\, F_L}{9\pi} \times \frac{0.8}{\pi} \quad \text{or} \quad F_L = \mathbf{1/25\ lm}$$

49.11. Diffusing and Reflecting Surfaces : Globes and Reflectors

When light falls on polished metallic surfaces or silvered surfaces, then most of it is reflected back according to the laws of reflection *i.e.* the angle of incidence is equal to the angle of reflection. Only a small portion of the incident light is absorbed and there is always the image of the source. Such reflection is known as ***specular*** reflection.

However, as shown in Fig. 49.29 (*b*), if light is incident on coarse surfaces like paper, frosted glass, painted ceiling etc., then it is scattered or diffused in all directions, hence no image of the source is formed. Such reflection of light is called ***diffuse reflection***. A perfect diffuser is one that scatters light uniformly in all directions and hence appears equally bright from whatever direction it is viewed. A white blotting paper is the nearest approach to a diffuser.

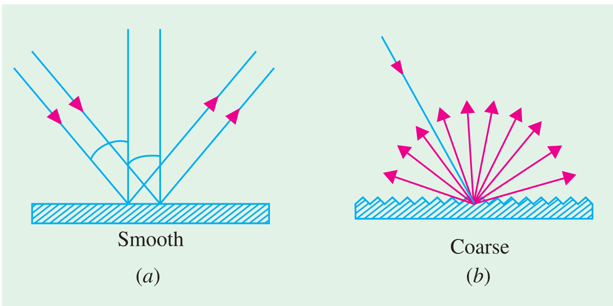

Fig. 49.29

By reflecting factor of a surface is meant the ratio = $\dfrac{\text{reflected light}}{\text{incident light}}$

It is also known as reflection ratio or coefficient of reflection of a surface.

If the light is incident on a transparent surface, then some of it is absorbed and greater percentage of it passes through and emerges on the other side.

To avoid direct glare from electric arcs and incandescent filament lamps, they are surrounded more or less completely by diffusing shades or globes. In addition, a reflector may also be embodied to prevent the escape of light in directions where it serves no useful purpose. In that case, so far as the surroundings are concerned, the diffusing globe is the source of light. Its average brilliancy is lower the more its diffusing area. Depending on the optical density, these globes absorb 15 to 40% of light emitted by the encircled bulb. The bulbs may also be frosted externally by etching or sand-blasting but internal frosting is better because there is no sharp scratching or cracks to weaken the glass.

In domestic fittings, a variety of shades are used whose main purpose is to avoid glare. Properly designed and installed prismatic glass shades and holophane type reflectors have high efficiency and are capable of giving accurate predetermined distribution of light.

Regular metallic reflection is used in search-light mirrors and for general lighting purposes. But where it is used for general lighting, the silvered reflectors are usually fluted to make the illumination as uniform as possible.

Regular cleaning of all shades, globes, and reflectors is very important otherwise the loss of light by absorption by dust etc., collected on them becomes very serious.

Various types of reflectors are illustrated in Figs. 49.30 to 49.34. Fig. 49.30 shows a holophane stiletto reflector used where extensive, intensive or focussing light distribution is required.

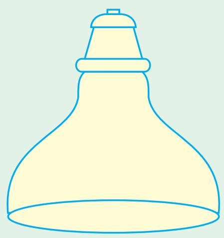

Fig. 49.30

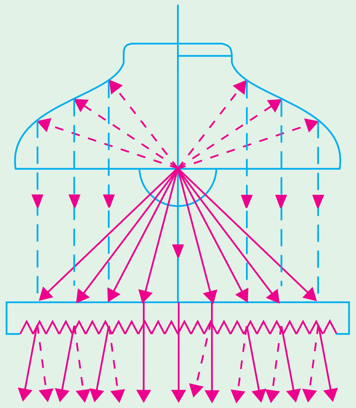

Fig. 49.31

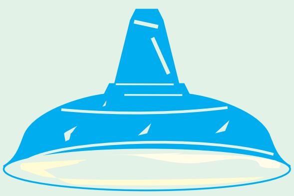

Fig. 49.32

The optical combination of a lamp, reflector and a lens plate, as shown in Fig. 49.31, provides a high degree of light control. Multiple panels can be conveniently incorporated in fittings suited to different architectural schemes.

The dispersive reflector of Fig. 49.32 is suitable for practically all classes of industrial installations. The reflector is a combination of concave and cylindrical reflecting surfaces in the form of a deep bowl of wide dispersive power. It gives maximum intensity between 0º and 45º from the vertical.

The concentrating reflector of parabolic form shown in Fig. 49.33 is suitable for situations requiring lofty installations and strongly-concentrated illumination as in public halls, foundries and power stations etc. They give maximum intensity in zones from 0º to 25º from the vertical.

Fig. 49.33

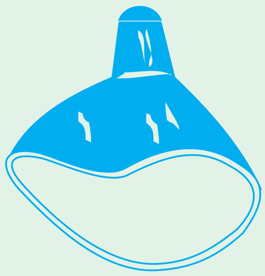

Fig. 49.34

The elliptical angle reflector shown in Fig. 49.34 is suitable for the side lighting of switchboards, show windows etc., because they give a forward projection of light in the vertical plane and spread the light in the horizontal plane.

49.12. Lighting Schemes

Different lighting schemes may be classfied as *(i)* direct lighting *(ii)* indirect lighting and *(iii)* semi-direct lighting *(iv)* semi-indirect lighting and *(v)* general diffusing systems.

(i) Direct Lighting

As the name indicates, in the form of lighting, the light from the source falls directly on the object or the surface to be illuminated (Fig. 49.35). With the help of shades and globes and reflectors of various types as disscussed in Art. 49.11, most of the light is directed in the lower hemisphere and also the brilliant source of light is kept out of the direct line of vision. Direct illumination by lamps in suitable reflectors can be supplemented by standard or bracket lamps on desk or by additional pendant fittings over counters.

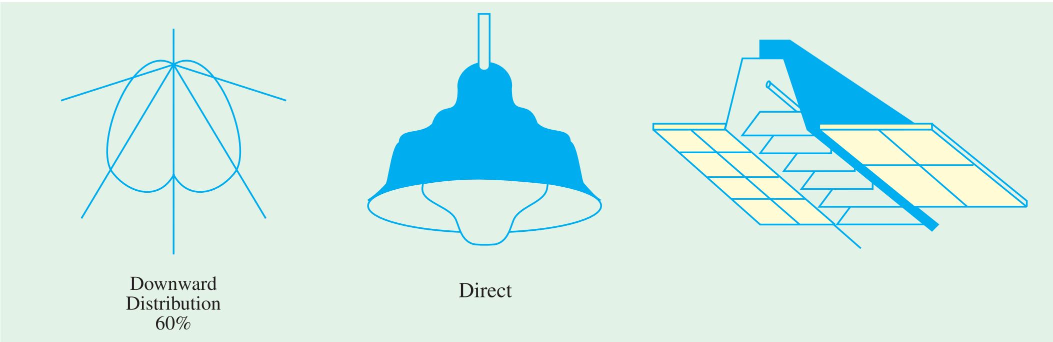

Fig. 49.35

The fundamental point worth remembering is planning any lighting installation is that sufficient and sufficiently uniform lighting is to be provided at the working or reading plane. For this purpose, lamps of suitable size have to be so located and furnished with such fittings as to give correct degree and distribution of illumination at the required place. Moreover, it is important to keep the lamps and fittings clean otherwise the decrease in effective illumination due to dirty bulbs or reflectors may amount to 15 to 25% in offices and domestic lighting and more in industrial areas as a result of a few weeks neglect.

Direct lighting, though most efficient, is liable to cause glare and hard shadows.

(ii) Indirect Lighting

In this form of lighting, light does not reach the surface directly from the source but indirectly by diffuse reflection (Fig. 49.36). The lamps are either placed behind a cornice or in suspended ***opaque*** bowls. In both cases, a silvered reflector which is corrugated for eliminating striations is placed beneath the lamp.

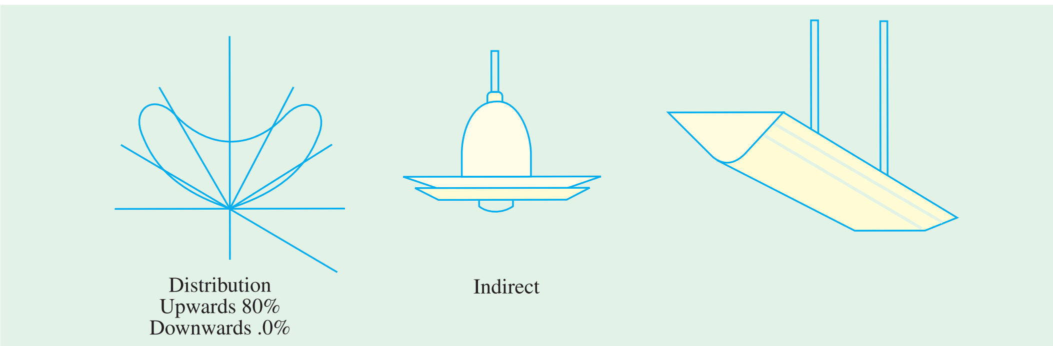

Fig. 49.36

In this way, maximum light is thrown upwards on the ceiling from which it is distributed all over the room by diffuse reflection. Even gradation of light on the ceiling is secured by careful adjustement of the position and the number of lamps. In the cornice and bowl system of lighting, bowl fittings are generally suspended about three-fourths the height of the room and in the case of cornice lighting, a frieze of curved profile aids in throwing the light out into the room to be illuminated. Since in indirect lighting whole of the light on the working plane is received by diffuse reflection, it is important to keep the fittings clean.

One of the main characteristics of indirect lighting is that it provides shadowless illumination which is very useful for drawing offices, composing rooms and in workshops especially where large machines and other obstructions would cast troublesome shadows if direct lighting were used.

However, many people find purely indirect lighting flat and monotonous and even depressive. Most of the users demand 50 to 100% more light at their working plane by indirect lighting than with direct lighting. However, for appreciating relief, a certain proportion of direct lighting is essential.

(*iii*) Semi-direct System

This system utilizes luminaries which send most of the light downwards directly on the working plane but a considerable amount reaches the ceilings and walls also (Fig. 49.37).

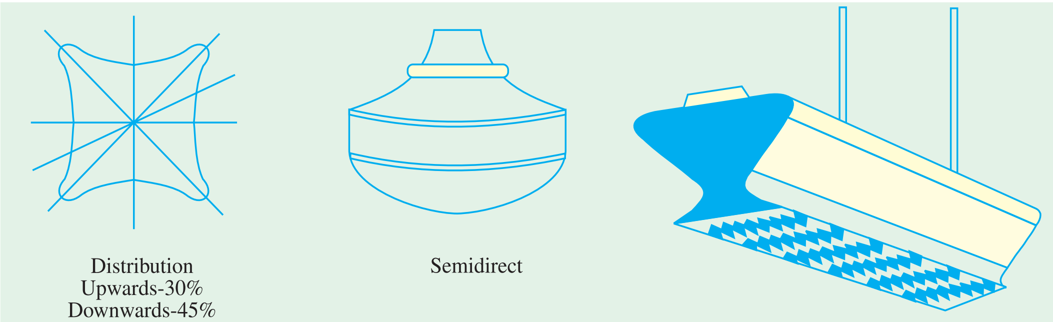

Fig. 49.37

The division is usually 30% upwards and 45% downwards. Such a system is best suited to rooms with high ceilings where a high level of uniformly-distributed illumination is desirable. Glare in such units is avoided by using diffusing globes which not only improve the brightness towards the eye level but improve the efficiency of the system with reference to the working plane.

(*iv*) Semi-indirect Lighting

In this system which is, in fact, a compromise between the first two systems, the light is partly received by diffuse reflection and partly direct from the source (Fig. 49.38). Such a system, therefore, eliminates the objections of indirect lighting mentioned above. Instead of using opaque bowls with reflectors, translucent bowls without reflector are used. Most of the light is, as before, directed upwards to the ceiling for diffuse reflection and the rest reaches the working plane directly except for some absorption by the bowl.

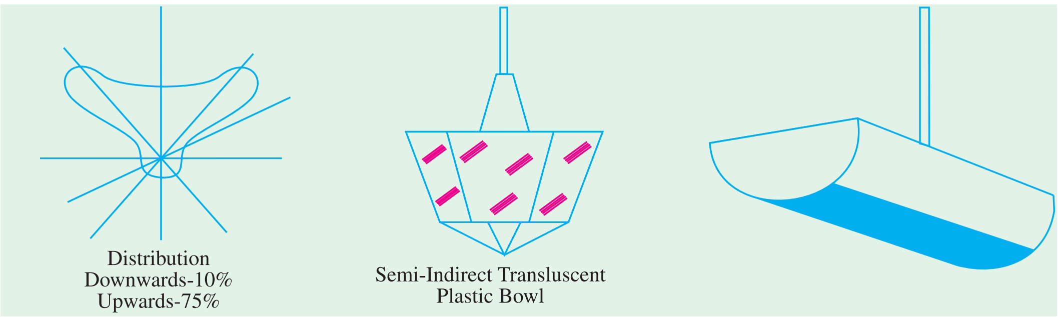

Fig. 49.38

(v) General Diffusing System

In this system, luminaries are employed which have almost equal light distribution downwards and upwards as shown in Fig. 49.39.

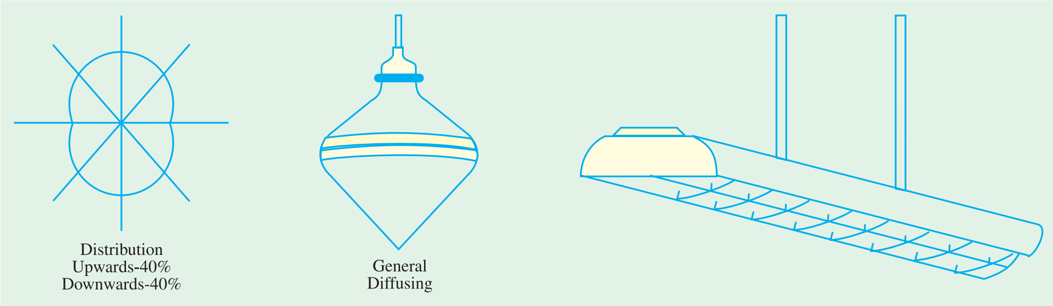

Fig. 49.39

49.13. Illumination Required for Different Purposes

There has been a steady movement towards higher intensities for artificial illumination during the last few decades. The movement is likely to continue because the highest intensities in average installations are much less than those of the diffused daylight. The human eye posses a tremendous power of accommodation and it can work comfortably within an enormous range of illuminations.

For example, at full noon, sun provides about 120,000 lm/m^2, diffuse day-light near a window is of the order of 600 lm/m^2 (value varying widely) and full moon-light gives 0.1 to 0.3 lm/m^2. For reading, usually 20 to 30 lm/m^2 is generally considered sufficient, though daylight illumination is much higher.

Some persons can read without much strain even when illumination is as low as 3 lm/m^2. Because of this, it is difficult to lay down definite values of illumination for various purposes but the following summary will be found useful :

Purpose and Places	*lm/m^2*
Precision work, displays, tasks requiring rapid discrimination	above 500
Extra fine machine work, around needles of sewing machines, fine engraving, inspection of fine details having low contrast	200-500
Proof-reading, drawing, sustained reading, fine assembling, skilled bench-work	100-200
Drawing offices, art exhibition, usual reading	60-100
In museums, drill halls, for work of simple nature not involving close attention to fine details	40-60
Usual observation as in bed-rooms, waiting rooms, auditoriums and general lighting in factories	20-40
Hospital wards, yards, railway platforms and corridors	5-10

49.14. Space/Height Ratio

It is given by the ratio : $\dfrac{\text{horizontal distance between two lamps}}{\text{mounting height of lamps}}$

This ratio depends on the nature of the polar curve of a lamp ***when used along with its reflector***. A reflector has tremendous influence on the shape of the polar curve of the lamp, hence the value of space/height ratio, in fact, depends entirely on the type of reflector used. For obtaining uniform illumination on the working plane, it is essential to choose a correct value for this ratio.

In other words, it means that a reflector gives uniform illumination for a definite value of this ratio only. The ratio may be found easily if the polar curve of the type of fixture used is known. For reflectors normally used in indoor lighting, the value of this ratio lies between 1 and 2.

49.15. Design of Lighting Schemes and Lay-outs

A well-designed lighting scheme is one which

(*i*) provides adequate illumination (*ii*) avoids glare and hard shadows (*iii*) provides sufficiently uniform distribution of light all over the working plane.

Before explaining the method of determining the number, size and proper arrangement of lamps in order to produce a given uniform illumination over a certain area, let us first consider the following two factors which are of importance in such calculations.

49.16. Utilization Factor or Coefficient of Utilization (η)

It is the ratio of the lumens actually received by a particular surface to the total lumens emitted by a luminous source.

$$\therefore \qquad \eta = \frac{\text{lumens actually received on working plane}}{\text{lumens emitted by the light source}}$$

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

1. the type of lighting system, whether direct or indirect etc.
2. the type and mounting height of the fittings
3. the colour and surface of walls and ceilings and
4. to some extent on the shape and dimensions of the room.

For example, for direct lighting, the value of η varies between 0.4 and 0.6 and mainly depends on the shape of the room and the type and mounting height of fittings but very little on the colour of walls and ceiling. For indirect lighting, its value lies between 0.1 and 0.35 and the effect of walls and ceiling, from which light is reflected on the working plane, is much greater. Exact determination of the value of utilization factor is complicated especially in small rooms where light undergoes multiple reflections.

Since the light leaving the lamp in different directions is subjected to different degrees of absorption, the initial polar curve of distribution has also to be taken into account. Even though manufacturers of lighting fittings supply tables giving utilization factors for each type of fitting under specified conditions yet, since such tables apply only to the fittings for which they have been compiled, a good deal of judgment is necessary while using them.

49.17. Depreciation Factor (*p*)

This factor allows for the fact that effective candle power of all lamps or luminous sources deteriorates owing to blackening and/or accumulation of dust or dirt on the globes and reflectors etc. Similarly, walls and ceilings etc., also do not reflect as much light as when they are clean. The value of this factor may be taken as 1/1.3 if the lamp fittings are likely to be cleaned regularly or 1/1.5 if there is much dust etc.

$$p = \frac{\text{illumination under actual condtions}}{\text{illumination when everything is perfectly clean}}$$

Since illumination is specified in lm/m^2, the area in square metre multiplied by the illumination required in lm/m^2 gives the total useful luminous flux that must reach the working plane. Taking into consideration the utilization and depreciation or maintenance factors, the expression for the gross lumens required is

$$\text{Total lumens,} \qquad \Phi = \frac{E \times A}{\eta \times p}$$

where E = desired illumination in lm/m^2 ; A = area of working plane to be illuminated in m^2
p = depreciation or maintenance factor ; η = utilization factor.

The size of the lamp depends on the number of fittings which, if uniform distribution is required, should not be far apart. The actual spacing and arrangement is governed by space/height values and by the layout of ceiling beams or columns. Greater the height, wider the spacing that may be used, although the larger will be the unit required. Having settled the number of units required, the lumens per unit may be found from (total lumens/number of units) from which the size of lamp can be calculated.

Example 49.20. *A room 8 m × 12 m is lighted by 15 lamps to a fairly uniform illumination of 100 lm/m^2. Calculate the utilization coefficient of the room given that the output of each lamp is 1600 lumens.*

Solution. Lumens emitted by the lamps = 15 × 1600 = 24,000 lm

Lumens received by the working plane of the room = 8 × 12 × 100 = 9600 lm

Utilization coefficient = 9600/24,000 = **0.4 or 40%.**

Example 49.21. *The illumination in a drawing office 30 m × 10 m is to have a value of 250 lux and is to be provided by a number of 300-W filament lamps. If the coefficient of utilization is 0.4 and the depreciation factor 0.9, determine the number of lamps required. The luminous efficiency of each lamp is 14 lm/W.* **(Elect. Drives & Utilization, Punjab Univ. Dec. 1994)**

Solution. $\Phi = EA/\eta p$; E = 250 lm/m^2, A = 30 × 10 = 300 m^2; η = 0.4, p = 0.9

$\therefore$ Φ = 250 × 300/0.4 × 0.9 = 208,333 lm

Flux emitted/lamp = 300 × 14 = 4200 lm; No. of lamps reqd.= 208,333/4200 = **50.**

Example 49.22. *Find the total saving in electrical load and percentage increase in illumination if instead of using twelve 150 W tungsten-filament lamps, we use twelve 80 W fluorescent tubes. It may be assumed that **(i)** there is a choke loss of 25 per cent of rated lamp wattage **(ii)** average luminous efficiency throughout life for each lamp is 15 lm/W and for each tube 40 lm/W and **(iii)** coefficient of utilization remains the same in both cases.*

Solution. Total load of filament lamps = 12 × 150 = 1800 W

Total load of tubes = 12 (80 + 0.25 × 80) = 1200 W

Net saving in load = 1800 – 1200 = **600 W**

If A is the room area and η the corfficient of utilization, then

illumination with lamps, $E_1 = \dfrac{12 \times 150 \times 15\eta}{A}$ = **27,000 η/A lm/m^2**

illumination with tubes, $E_2 = \dfrac{12 \times 80 \times 40\eta}{A}$ = **38,400 η/A lm/m^2**

increase in illumination $= \dfrac{38,400 - 27,000}{27,000}$ = **0.42 or 42%**

Example 49.23. *A football pitch 120 m × 60 m is to be illuminated for night play by similar banks of equal 1000 W lamps supported on twelve towers which are distributed around the ground to provide approximately uniform illumination of the pitch. Assuming that 40% of the total light emitted reaches the playing pitch and that an illumination of 1000 lm/m^2 is necessary for television purposes, calculate the number of lamps on each tower. The overall efficiency of the lamp is to be taken as 30 lm/W.* **(Elect. Technology-I, Bombay Univ.)**

Solution. Area to be illuminated = 120 × 60 = 7,200 m^2

Flux required $= 7{,}200 \times 1{,}000 = 7.2 \times 10^6$ lm

Since only 40% of the flux emitted reaches the ground, the total luminous flux required to be produced is $= 7.2 \times 10^6/0.4 = 18 \times 10^6$ lm

Flux contributed by each tower bank $= 18 \times 10^6/12 = 1.5 \times 10^6$ lm

Output of each 1000-W lamp $= 30 \times 1000 = 3 \times 10^4$ lm

Hence, number of such lamps on each tower is $= 1.5 \times 10^6/3 \times 10^4 =$ **50**

Example 49.24. *Design a suitable lighting scheme for a factory 120 m × 40 m with a height of 7 m. Illumination required is 60 lux. State the number, location and mounting height of 40 W fluorescent tubes giving 45 lm/W.*

Depreciation factor = 1.2 ; utilization factor = 0.5

(Electric Drives & Util. Punjab Univ. 1993)

Solution. $\Phi = \dfrac{60 \times 120 \times 40}{0.5 \times (1/1.2)} = 691{,}200$ lm; Flux per tube $= 45 \times 40 =$ **1800 lm.**

No. of fluorescent tubes reqd. = 691,200/1800 = 384. If twin-tube fittings are employed, then number of such fittings required. = 384/2 = **192.**

These can be arranged in 8 rows of 24 fittings each. Assuming that the working plane is 1 metre above the floor level and the fittings are fixed 1 metre below the ceiling, we get a space/height factor of unity both along the length as well as width of the factory bay.

Example 49.25. *A drawing hall in an engineering college is to be provided with a lighting installation. The hall is 30 m × 20 m × 8 m (high). The mounting height is 5 m and the required level of illumination is 144 lm/m². Using metal filament lamps, estimate the size and number of single lamp luminaries and also draw their spacing layout. Assume :*

Utilization coefficient = 0.6; maintenance factor = 0.75; space/height ratio=1

lumens/watt for 300-W lamp = 13,lumens/watt for 500-W lamp = 16.

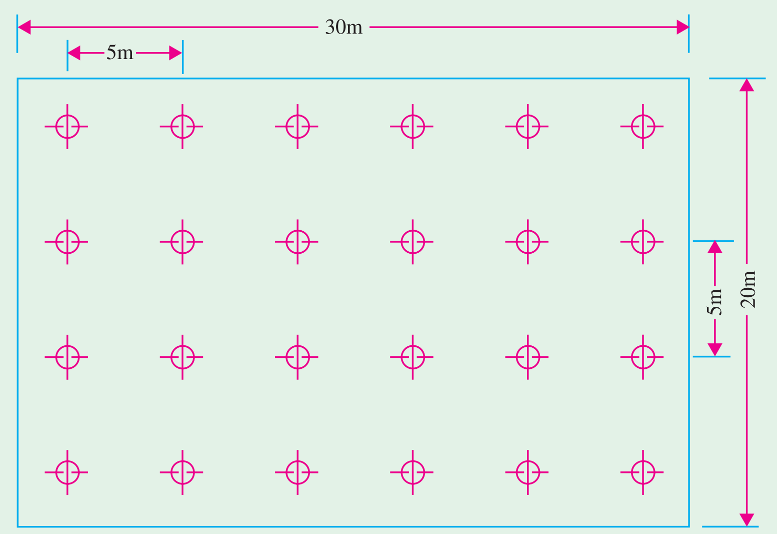

Fig. 49.40

Solution. Flux is given by $\Phi = EA/\eta p = 30 \times 20 \times 144/0.6 \times 0.75 = 192{,}000$ lm

Lumen output per 500-W lamp = 500 × 16 = 8,000

∴ No. of 500-W lamps required = 192,000/8000 = **24**

Similarly, No. of 300-W lamps required = 192,000/3900 = **49**

The 300-W lamps cannot be used because their number cannot be arranged in a hall of 30 m × 20 m with a space/height ratio of unity. However, 500-W lamps can be arranged in 4 rows of 6 lamps each with a spacing of 5 m both in the width and the length of the hall as shown in Fig. 49.40.

Example 49.26. *Estimate the number and wattage of lamps which would be required to illuminate a workshop space 60×15 metres by means of lamps mounted 5 metres above the working plane. The average illumination required is about 100 lux.*

Coefficient of utilization=0.4 ; Luminous efficiency=16 lm/W.

Assume a spacing/height ratio of unity and a candle power depreciation of 20%.

(Utilization of Electrical Energy, Madras Univ.)

Solution. Luminous flux is given by $\Phi = \dfrac{EA}{\eta p} = \dfrac{100 \times (60 \times 15)}{0.4 \times 1/1.2} = 27 \times 10^4$ lm

Total wattage reqd. $= 27 \times 10^4/16 =$ **17,000 W**

For a space/height ratio of unity, only three lamps can be mounted along the width of the room. Similarly, 12 lamps can be arranged along the length of the room. Total number of lamps required is $12 \times 3 =$ **36**. Wattage of each lamp is = 17,000/36 = 472 W. We will take the nearest standard lamp of **500 W**. These thirty-six lamps will be arranged as shown in Fig. 49.41.

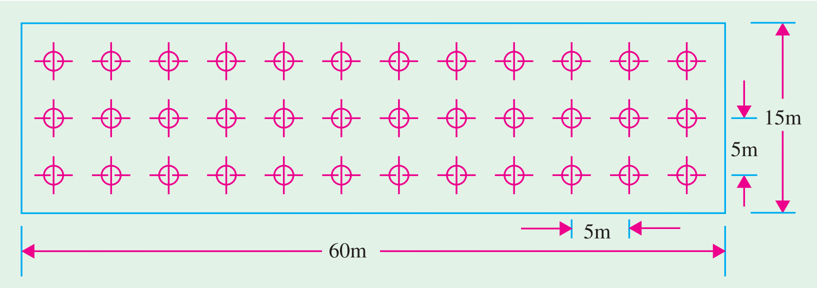

Fig. 49.41

Example 49.27. *A drawing hall 40 m $\times$ 25 m $\times$ 6 high is to be illuminated with metal-filament gas-filled lamps to an average illumination of 90 lm/m^2 on a working plane 1 metre above the floor. Estimate suitable number, size and mounting height of lamps. Sketch the spacing layout.*

Assume coefficient of utilization of 0.5, depreciation factor of 1.2 and spacing/height ratio of 1.2

Size of lamps	*200 W*	*300 W*	*500 W*
Luminous efficiency (in lm/W)	*16*	*18*	*20*

(Elect. Technology, Bombay Univ.)

Solution. Total flux required is $\Phi = \dfrac{40 \times 25 \times 90}{0.5 \times 1/1.2} = 216{,}000$ lm

Lumen output of each 200-W lamp is 3200 lm, of 300-W lamp is 5,400 lm and of 500-W lamp is 10,000 lm.

No. of 200-W lamps reqd. $= \dfrac{216{,}000}{3{,}200} =$ **67**; No. of 300-W lamps reqd.$= \dfrac{216{,}000}{5{,}400} =$ **40**

No. of 500-W lamps reqd. = 216,000/ 10,000 = **22**

With a spacing/height ratio of 1.2, it is impossible to arrange both 200-W and 300-W lamps. Hence, the choice falls on 500-W lamp. If instead of the calculated 22, we take 24 lamps of 500 wattage, they can be arranged in four rows each having six lamps as shown in Fig. 49.42. Spacing along the length of the hall is 40/6 = 6.67 m and that along the width is 25/4 = 6.25 m.

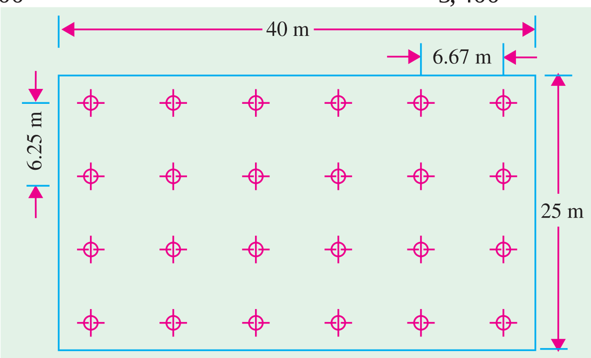

Fig. 49.42

Since mounting height of the lamps is 5 m above the working plane, it gives a space/height ratio of 6.7/5 = 1.5 along the length and 6.25/5 = 1.4 along the width of the hall.

Example 49.28. *A school classroom, 7 m × 10 m × 4 m high is to be illuminated to 135 lm/m² on the working plane. If the coefficient of utilization is 0.45 and the sources give 13 lumens per watt, work out the total wattage required, assuming a depreciation factor of 0.8 . Sketch roughly the plan of the room, showing suitable positions for fittings, giving reasons for the positions chosen.*

Solution. Total flux required is $\Phi = EA/\eta p$

Now $E = 135\ \text{lm/m}^2$;

$A = 7 \times 10 = 70\ \text{m}^2$;

$\eta = 0.45$; $p = 0.8$

$F = 135 \times 7 \times 10/0.45 \times 0.8 = 26{,}250$ lm

Total wattage reqd. = 26,250/13 = **2020 W**

Taking into consideration the dimensions of the room, light fitting of 200 W would be utilized.

No. of fittings required = 2020/200 = **10**

As shown in Fig. 49.43, the back row of fittings has been located 2/3 m from the rear wall so as to (*i*) provide adequate illumination on the rear desk and (*ii*) to minimise glare from paper because light would be incident practically over the shoulders of the students. The two side fittings help eliminate shadows while writing. One fitting has been provided at the chalk board end of the classroom for the benefit of the teacher. The fittings should be of general diffusing pendant type at a height of 3 m from the floor.

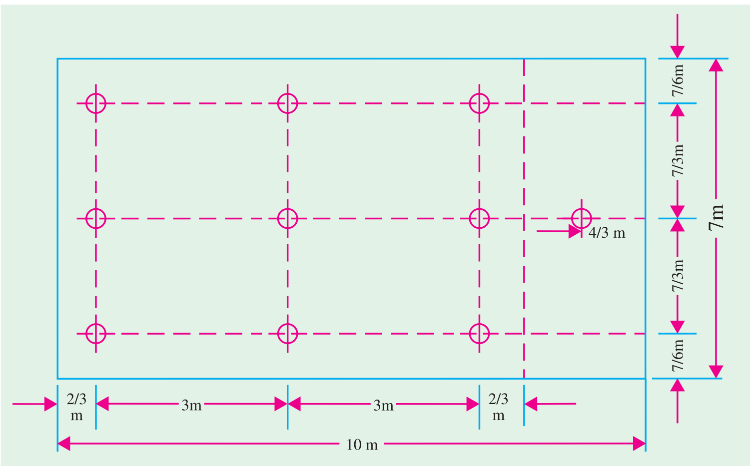

Fig. 49.43

Example 49.29. *A hall 30 m long and 12 m wide is to be illuminated and the illumination required is 50 lm/m². Calculate the number, the wattage of each unit and the location and mounting height of the units, taking a depreciation factor of 1.3 and utilization factor of 0.5, given that the outputs of the different types of lamp are as under :*

Watts :	*100*	*200*	*300*	*500*	*1000*
Lumens :	*1615*	*3650*	*4700*	*9950*	*21500*

(Utili. of Elect. Power, A.M.I.E.)

Solution. Area to be illuminated, $A = 30 \times 12 = 360\ \text{m}^2$

Illumination required, $E = 50\ \text{lm/m}^2$, $p = 1/1.3$, $\eta = 0.5$

Now, $\Phi = EA/\eta p = 50 \times 360/0.5 \times (1/1.3) = 46{,}800$ lm

If 100-W lamps are used, No. reqd. = 46,800/1615 = 29

If 200-W lamps are used, No. reqd. = 46,800/3650 = 13

If 300-W lamps are used, No. reqd. = 6,800/4700 = 10

If 500-W lamps are used, No. reqd. = 46,800/9950 = 5

If 1000-W lamps are used, No. reqd. = 46,800/21500 = 2

If we take the mounting height of 5 m, then 300 W lamps would be suitable. The No. of lamps required would be 10, arranged in two rows, each row having 5 lamps thus giving a spacing of 6 m in lengths as well as width and space/height ratio of 6/5 = 1.2.

If we use lamps of low power, their number would be large thereby increasing the number of fittings and hence cost. Lamps of higher voltage would be few in number but will not give a desirable space/height ratio.

Tutorial Problem No. 49.2

1. A room 30 m × 15 m is to be illuminated by 15 lamps to give an average illumination of 40 lm/m^2. The utilization factor is 4.2 and the depreciation factor is 1.4. Find the M.S.C.P. of each lamp.

[561 cd] (*Elect. Technology-1. Bombay Univ.*)

2. A factory space of 33 m × 13 m is to be illuminated with an average illumination of 72 lm/m^2 by 200 W lamps. The coefficient of utilization is 0.4 and the depreciation factor is 1.4. Calculate the number of lamps required. The lumen output of a 200-W lamp is 2,730 lm.

[40] (*Elect. Technology-I, Bombay Univ.*)

3. A drawing hall 30 m × 15 m with a ceiling height of 5 m is to be provided with an illumination of 120 lux. Taking the coefficient of utilization of 0.5, depreciation factor of 1.4, determine the No. of fluorescent tubes required and their spacing, mounting height and total wattage. Take luminous efficiency of fluorescent tube as 40 lm/W for 80-W tube. (*A.M.I.E. Sec. B, Summer*)

4. A room 40 m × 15 m is to be illuminated by 1.5 m 80-W fluorescent tubes mounted 3.5 m above the working plane on which an average illumination of 180 lm/m^2 is required. Using maintenance factor of 0.8 and the utilization factor of 0.5, design and sketch a suitable layout. The 80-W fluorescent tube has an output of 4,500 lm. (*Electrical Technology, Bombay Univ.*)

5. A hall is to be provided with a lighting installation. The hall is 30 m × 20 m × 8 m (high). The mounting height is 5 m and the required level of illumination is 110 lux. Using metal filament lamps, estimate the size and number of single lamp luminaries and draw their spacing layout. Assume depreciation factor = 0.8, utilization coefficient = 0.6 and space/height ratio = 1.

Watt :	200	300	500
Lumen/watt :	10	12	12.3

[24 lamps, 500 W] (*Services & Equipment-II, Calcutta Univ.*)

6. It is required to provide an illumination of 100 lux in a factory hall 30 m × 12 m. Assume that the depreciation factor is 0.8, the coefficient of utilization 0.4 and the efficiency of proposed lamps 14 lm/W. Calculate the number of lamps and their disposition.

(*Utilization of Elect. Energy, Madras Univ.*)

7. Define the terms : (*i*) Lux (*ii*) Luminous Flux (*iii*) Candle Power.

A workshop 100 m × 50 m is to be illuminated with intensity of illumination being 50 lux. Design a suitable scheme of lighting if coefficient of utilization = 0.9 ; Depreciation factor = 0.7 and efficiency of lamps = 80 lm/W. Use 100-W lamps. (*Electrical Engineering-III, Poona Univ.*)

49.18. Floodlighting

It means ‘flooding’ of large surfaces with the help of light from powerful projectors. Flooding is employed for the following purposes :

1. For aesthetic purposes as for enhancing the beauty of a building by night *i.e.* flood lighting of ancient monuments, religious buildings on important festive occassions etc.
2. For advertising purposes *i.e.* flood lighting, huge hoardings and commercial buildings.
3. For industrial and commercial purposes as in the case of railway yards, sports stadiums and quarries etc.

Usually, floodlight projectors having suitable reflectors fitted with standard 250-, 500-, or 1,000-watt gas-filled tungsten lamps, are employed. One of the two typical floodlight installations often used is as shown in Fig. 49.44 (*a*). The projector is kept 15 m to 30 m away from the surface to be floodlighted and provides approximately parallel beam having beam spread of 25° to 30°. Fig. 49.44 (*b*) shows the case when the projector cannot be located away from the building. In that case, an asymmetric reflector is used which directs more intense light towards the top of the building.

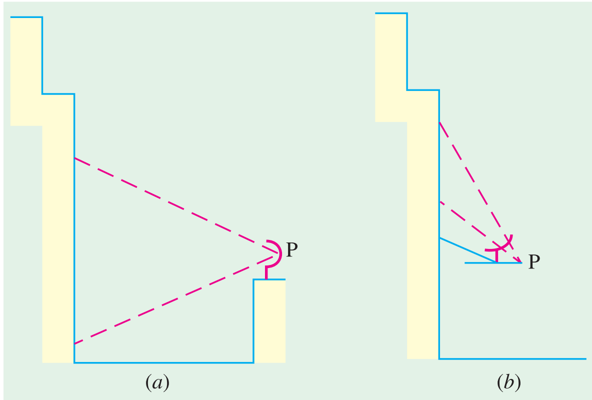

Fig. 49.44

The total luminous flux required to floodlight a building can be found from the relation, $\Phi = EA/\eta \times p$.

However, in the case of flood-lighting, one more factor has to be taken into account. That factor is known as waste-light factor (W). It is so because when several projectors are used, there is bound to be a certain amount of overlap and also because some light would fall beyond the edges of the area to be illuminated. These two factors are taken into account by multiplying the theoretical value of the flux required by a waste-light factor which has a value of nearly 1.2 for regular surfaces and about 1.5 for irregular objects like statues etc. Hence, the formula for calculation of total flux required for floodlighting purposes is

$$\Phi = \frac{EAW}{\eta p}$$

Example 49.30. *It is desired to floodlight the front of a building 42 m wide and 16 m high. Projectors of 30° beam spread and 1000-W lamps giving 20 lumen/watt are available. If the desired level of illumination is 75 lm/m² and if the projectors are to be located at ground level 17 m away, design and show a suitable scheme. Assume the following :*

Coefficient of utilization = 0.4 ; Depreciation factor = 1.3; Waste-light factor = 1.2.

(Electrical Power-II ; M.S. Univ. Baroda)

Solution. $\Phi = \dfrac{EAW}{\eta p}$

Here $E = 75 \text{ lm/m}^2$; $A = 42 \times 16 = 672 \text{ m}^2$; $W = 1.2$; $\eta = 0.4$; $p = 1/1.3$

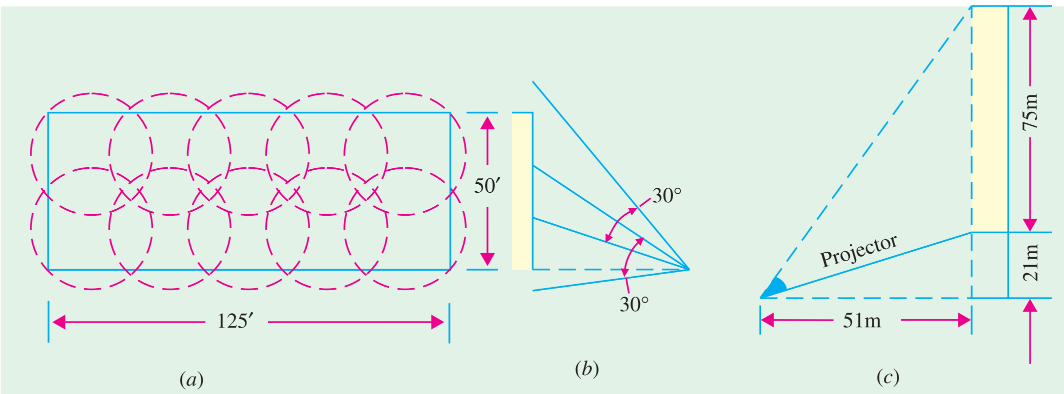

Fig. 49.45

$$\therefore \qquad \Phi = \frac{7.5 \times 672 \times 1.2}{0.4 \times 1/1.3} = 196{,}500 \text{ lm}$$

Lumen output of each 1,000-W lamp = 1,000 × 20 = 20,000 lm

No. of lamps required = 196,500/20,000 = **10.**

With a beam spread* of 30°, it is possible to cover the whole length and width of the building by arranging the 10 projectors in two rows as shown in Fig. 49.45 (*a*).

Example 49.31. *Estimate the number of 1000-W floodlight projectors required to illuminate the up per 75 m of one face of a 96 m tower of width 13 m if approximate initial average luminance is to be 6.85 cd/m². The projectors are mounted at ground level 51m from base of the tower. Utilization factor is = 0.2; reflection factor of wall = 25% and efficiency of each lamp = 18 lm/W.*

(A.M.I.E. Sec. B., Winter 1992)

Solution. $B = 6.85 \text{ cd/m}^2$ Now, $B = \rho E/\pi \text{ cd/m}^2$ —Art 49.4

$\therefore \quad E = pB/\rho = 6.85\,\pi/0.25 = 27.4\,\pi \text{ lm/m}^2$

Area to be floodlighted $= 13 \times 75 = 975 \text{ m}^2$

$\therefore$ flux required $= 27.4\,\pi \times 975$ lm

Taking utilization factor into account, the flux to be emitted by all the lamps

$= 27.4\,\pi \times 975/0.2$ lm

Flux emitted by each lamp $= 18 \times 1000 = 18{,}000$ lm

$$\therefore \text{ No. of lamps reqd.} = \frac{27.4\,\pi \times 975}{0.2 \times 18{,}000} = \mathbf{24 \text{ (approx.)}}$$

49.19. Artificial Sources of Light

The different methods of producing light by electricity may, in a board sense, be divided into three groups.

1. By ***temperature incandescence***. In this method, an electric current is passed through a filament of thin wire placed in vacuum or an inert gas. The current generates enough heat to raise the temperature of the filament to luminosity.

Incandescent tungsten filament lamps are examples of this type and since their output depends on the temperature of their filaments, they are known as ***temperature radiators***.

2. By establishing an arc between two carbon electrodes. The source of light, in their case, is the incandescent electrode.

3. ***Discharge Lamps***. In these lamps, gas or vapour is made luminous by an electric discharge through them. The colour and intensity of light *i.e.* candle-power emitted depends on the nature of the gas or vapour only. It should be particularly noted that these discharge lamps are luminiscent-light lamps and do not depend on temperature for higher efficiencies. In this respect, they differ radically from incandescent lamps whose efficiency is dependent on temperature. Mercury vapour lamp, sodium-vapour lamp, neon-gas lamp and fluorescent lamps are examples of light sources based on discharge through gases and vapours.

49.20. Incandescent Lamp

An incandescent lamp essentially consists of a fine wire of a high-resistance metal placed in an evacuated glass bulb and heated to luminosity by the passage of current through it. Such lamps were

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* It indicates the divergence of a beam and may be defined as the angle within which the minimum illumination on a surface normal to the axis of the beam is 1/10th of the maximum.

produced commercially for the first time by Edison in 1879. His early lamps had filaments of carbonized paper which were, later on, replaced by carbonized bamboo. They had the disadvantage of negative temperature coefficient of resistivity. In 1905, the metallized carbon-filament lamps were put in the market whose filaments had a positive temperature coefficient of resistivity (like metals). Such lamps gave 4 lm/W.

An incandescent lamp

At approximately the same time, osmium lamps were manufactured which had filaments made of osmium which is very rare and expensive metal. Such lamps had a very fair maintenance of candle-power during their useful life and an average efficiency of 5 lm/W. However, osmium filaments were found to be very fragile.

In 1906 tantalum lamps having filaments of tantalum were produced which had an initial efficiency of 5 lm/watt.

All these lamps were superseded by tungsten lamps which were commercially produced in about 1937 or so. The superiority of tungsten lies mainly in its ability to withstand a high operating temperature without undue vaporisation of the filament. The necessity of high working temperature is due to the fact that the amount of visible radiation increases with temperature and so does the radiant efficiency of the luminous source. The melting temperature of tungsten is 3655°K whereas that of osmium is 2972°K and that of tantalum is 3172°K. Actually, carbon has a higher melting point than tungsten but its operating temperature is limited to about 2073°K because of rapid vaporization beyond this temperature.

In fact, the ideal material for the filament of incandescent lamps is one which has the following properties :

1. A high melting and hence operating temperature
2. A low vapour pressure
3. A high specific resistance and a low temperature coefficient
4. Ductility and
5. Sufficient mechanical strength to withstand vibrations.

Since tungsten possesses practically all the above mentioned qualities, it is used in almost all modern incandescent lamps. The earlier lamps had a square-cage type filament supported from a central glass stem enclosed in an evacuated glass bulb. The object of vacuum was two fold :

(*a*) to prevent oxidation and

(*b*) to minimize loss of heat by convection and the consequent lowering of filament temperature. However, vacuum favoured the evaporation of the filament with the resulting blackening of the lamp so that the operating temperature had to be kept as low as 2670° K with serious loss in luminous efficiency.

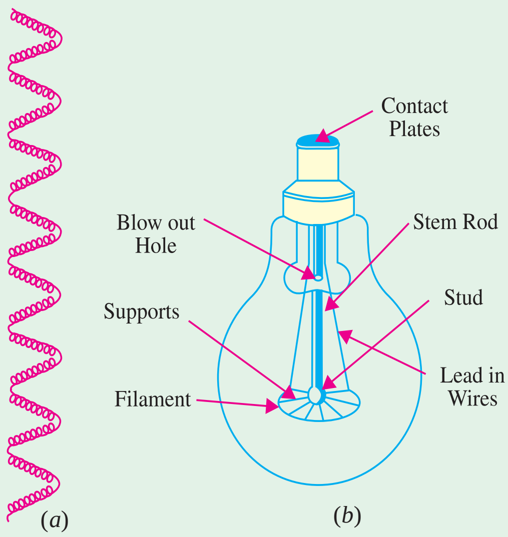


Fig. 49.46

It was, later on, found that this difficulty could be solved to a great extent by inserting a chemically inert gas like nitrogen or argon. The presence of these gases within the glass bulb decreased the evaporation of the filament and so lengthened its life. The filament could now be run at a relatively higher temperature and hence higher luminous efficiency could be realized. In practice, it was found that an admixture of 85% argon and about 15 percent nitrogen gave the best results.

However, introduction of gas led to another difficulty *i.e.* loss of heat due to convection which offsets the additional increase in efficiency. However, it was found that for securing greater efficiency, a concentrated filament having a tightly-wound helical construction was necessary. Such a coiled filament was less exposed to circulating gases, its turns supplying heat to each other and further the filament was mechanically stronger. The latest improvement is that the coiled filament is itself 'coiled' resulting in 'coiled-coil' filament Fig. 49.46 (*a*) which leads to further concentrating the heat, reducing the effective exposure to gases and allows higher temperature operation, thus giving greater efficiency. The construction of a modern coiled-coil gas-filled filament lamp is shown in Fig. 49.46 (*b*). The lamp has a 'wreath' filament *i.e.* a coiled filament arranged in the form of a wreath on radial supports.

A electric filament is a metallic wire, usually made of tungsten, when heated to luminance by passing electricity, radiates light

49.21. Filament Dimensions

There is found to be a definite relation between the diameter of a given filament and the current. Consider a filament operating at a fixed temperature and efficiency. Then since no heat is being utilized for further raising the temperature, all the heat produced in a given time is mostly lost by radiation (if vacuum is good). In other words,

Heat produced per second = heat lost per second by radiation.

$$\text{Now, power intake} = I^2 R = I^2 \times \frac{\rho l}{A} = \frac{I^2 \rho l}{\pi d^2/4} = I^2\left(\frac{4\rho l}{\pi d^2}\right)$$

where, I = filament current in amperes, l = filament length

A = filament cross-section, d = filament diameter

r = resistivity of filament material at the working temperature.

Heat radiated per second from the surface is proportional to the area of the surface and emissivity of the material

$\therefore$ heat lost/second $\propto$ surface area $\times$ emissivity σ

$$\therefore \quad I^2 (4rl/\pi d^2) \propto l \times \pi d \times \sigma \quad \text{or} \quad I^2 \propto d^3 \qquad \ldots(i)$$

$$\therefore \quad I \propto d^{1.5} \quad \text{or} \quad d \propto I^{2/3}$$

In general, for two filaments of the same material working at the same temperature and efficiency, the relation as seen from (*i*) above is

$$\left(\frac{I_1}{I_2}\right)^2 = \left(\frac{d_1}{d_2}\right)^3$$

It would be noticed that the above expressions are similar to those concerning fusing current of a given material under stated conditons (Preece's Rule).

Moreover, for two filaments working at the same temperature, the flux per unit area is the same. Denoting their lengths by l_1 and l_2 and their diameters by d_1 and d_2 respectively, we have, Lumen output $\propto l_1 d_1 \propto l_2 d_2$ or $l_1 d_1 = l_2 d_2$ = constant.

Example 49.32. *If the filament of a 32 candela, 100-V lamp has a length l and diameter d, calculate the length and diameter of the filament of a 16 candela 200-V lamp, assuming that the two lamps run at the same intrinsic brilliance.*

Solution. Using the above relation $32 \propto l_1 d_1$ and $16 \propto l_2 d_2$

$$\therefore \quad l_2 d_2 = \frac{1}{2} l_1 d_1$$

Assuming that the power intakes of the two lamps are proportional to their outputs, we have

$$32 \propto 100\, I_1 \text{ and } 16 \propto 200\, I_2 \qquad \therefore \quad I_2 = I_1 \times (16/200) \times (100/32) = \frac{1}{4} I_1$$

$$\text{Also } I_1 \propto d_1^{3/2} \text{ and } I_2 \propto d_2^{3/2} \qquad \therefore \quad (d_2/d_1)^{3/2} = I_2/I_1 = \frac{1}{4}$$

$$\therefore \quad d_2 = 0.4\, d_1 \text{ (approx.)}$$

$$\therefore \quad l_2 = \frac{1}{2} l_1 \times (d_1/d_2) = \frac{1}{2} \times (1/0.3968) \times l_1 = 1/26\, l_1.$$

Actually, this comparison is not correct because a thicker filament can be worked at a somewhat higher temperature than a thinner one.

Example 49.33. *An incandescent lamp has a filament of 0.005 cm diameter and one metre length. It is required to construct another lamp of similar type to work at double the supply voltage and give half the candle power. Assuming that the new lamp operates at the same brilliancy, determine suitable dimensions for its filament.* **(Elect. Technology, Utkal Univ.)**

Solution. Let I_1 and I_2 be the luminous intensities of the two lamps. Then

$$I_1 \propto l_1 d_1 \text{ and } l_2 \propto l_2 d_2 \qquad \therefore \quad \frac{l_2 d_2}{l_1 d_1} = \frac{I_2}{I_1} = \frac{1}{2} \text{ or } l_2 d_2 = \frac{1}{2} l_1 d_1$$

Assuming that the power intakes of the two lamps are proportional to their outputs, we have

$$I_1 \propto V_1 i_1 \text{ and } I_2 \propto V_2 i_2 \qquad \therefore \quad \frac{V_2 i_2}{V_1 i_1} = \frac{I_2}{I_1}$$

$$\therefore \quad i_2 = i_1 (V_1/V_2)(I_2/I_1) = i_1 \times \frac{1}{2} \times \frac{1}{2} = \frac{1}{4} i_1 \qquad \text{Now, } i_1 \propto d_1^{3/2} \text{ and } i_2 \propto d_2^{3/2}$$

$$\therefore \quad (d_2/d_1)^{3/2} = (i_2/i_1) = \frac{1}{4} \qquad \therefore \quad d_2 = 0.3968\, d_1$$

$$\therefore \quad l_2 = \frac{1}{2} l_1 \frac{d_1}{d_2} = \frac{1}{2} l_1 \times \left(\frac{1}{0.3968}\right) = 1.26\, l_1$$

Now, d_1 = **0.005 cm ;** l_1 = **100 cm**

$\therefore$ d_2 = 0.3968 × 0.005 = **0.001984 cm.** l_2 = 1.26 × 100 = **126 cm.**

Example 49.34. *A 60 candle power, 250-V metal filament lamp has a measured candle power of 71.5 candela at 260 V and 50 candela at 240 V.*

(a) *Find the constant for the lamp in the expression $C = aV^b$ where C = candle power and V = voltage.*

(*b*) *Calculate the change of candle power per volt at 250 V. Determine the percentage variation of candle power due to a voltage variation of æ 4% from the normal value.* **(A.M.I.E. Sec. B)**

Solution. (*a*) $C = aV^b \quad \therefore \quad 71.5 = a \times 260^b$ and $50 = a \times 240^b$

$\therefore \quad 71.5/50 = (260/240)^b$, b = **4.5**

Substituting this value of b in the above equation, we get

$a = 50/240^{4.5}$, $\quad a = \mathbf{0.98 \times 10^{-9}}$

Hence, the expression for the candle power of the lamp becomes $C = 0.98 \times 10^{-9}\, V^{4.5}$ candela

(*b*) Differentiating the above expression and putting V = 250 V, we get

$$\frac{dC}{dV} = 0.98 \times 10^{-9} \times 4.5 \times 250^{3.5} = \mathbf{4.4 \text{ candela per volt}}$$

When voltage increases by 4%, $C_2/C_1 = 1.04^{4.5}$

% change in candle power $= \dfrac{C_2 - C_1}{C_1} \times 100 = (1.04^{4.5} - 1) \times 100 = 19.3$

When voltage falls by 4%, $C_2/C_1 = 0.96^{4.5}$

$\therefore$ % change in candle power $= (0.96^{4.5} - 1) \times 100 = \mathbf{-16.8}$

49.22. Incandescent Lamp Characteristics

The operating characteristics of an incandescent lamp are materially affected by departure from its normal working voltage. Initially, there is a rapid heating up of the lamp due to its low thermal capacity, but then soon its power intake becomes steady. If the filament resistance were not dependent on its temperature, the rate of generation of heat would have been directly proportional to the square of voltage applied across the lamp. However, because of (*i*) positive temperature coefficient of resistance and (*ii*) complex mechanism of heat transfer from filament to gas, the relations between the lamp characteristics and its voltage are mostly experimental. Some of the characteristics of gas-filled lamps are given below.

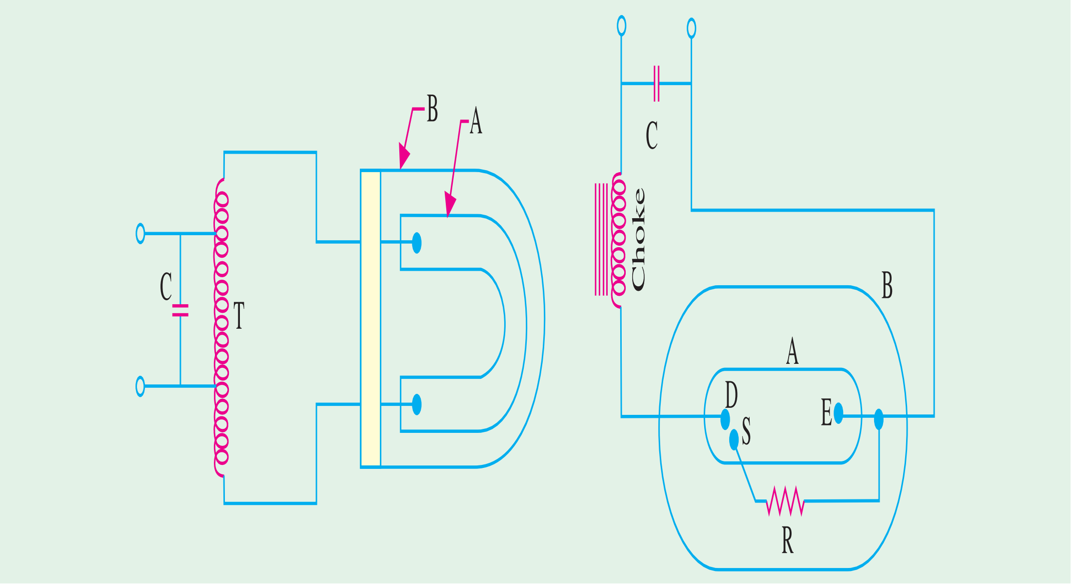


Fig. 49.47

(*i*) It is found that candle power or lumen output of the lamp varies with the voltage as lumen output $\propto V^{3.3}$.

(*ii*) Variation of lumen output in terms of current is given by : lumen output $\propto I^5$

(*iii*) Life of the lamp is given by : life $\propto 1/V^{13}$

(*iv*) Wattage is given by $W \propto V^{1.43}$

(*v*) Its lumen/watt is given by : lm/watt $\propto V^2$

The characteristic curves are plotted in Fig. 49.47. The life characteristic is very revealing. Even a small undervoltage considerably increases its life whereas overvoltage of as small a value as 5% shortens its life by 50%.

49.23. Clear and Inside-frosted Gas-filled Lamps

The advantages of clear glass-filled lamps are that they facilitate light control and are necessary for use in lighting units where accurate distribution is required such as in flood-lights for buildings, projectors and motor-car headlights. However, they produce hard shadows and glare from filaments. Inside-frosted gas-filled lamps have luminous output nearly 2 per cent less than clear glass lamps of the same rating, but they produce softer shadows and practically eliminate glare from filaments. Such lamps are ideal for use in industrial open fittings located in the line of sight at low mounting heights and in diffuse fittings of opal glass type in order to avoid the presence of filament striations on the surface of the glassware etc.

Another new type of incandescent lamp is the inside-silica coated lamp which, due to the fine coating of silica on the inside of its bulb, has high diffusion of light output. Hence, the light from the filament is evenly distributed over the entire bulb surface thus eliminating the noticeably-bright spot around the filament area of an inside-frosted lamp. Such lamps are less glaring, soften shadows and minimize the brightness of reflections from specular (shiny) surfaces.

49.24. Discharge Lamps

In all discharge lamps, an electric current is passed through a gas or vapour which renders it luminous. The elements most commonly used in this process of producing light by gaseous conduction are neon, mercury and sodium vapours. The colours (*i.e.* wavelength) of light produced depends on the nature of gas or vapour. For example, the neon discharge yields orange-red light of nearly 6,500 A.U. which is very popular for advertising signs and other spectacular effects. The pressure used in neon tubes is usually from 3 to 20 mm of Hg. Mercury-vapour light is always bluish green and deficient in red rays, whereas sodium vapour light is orange-yellow.

Discharge lamps are of two types. The first type consists of those lamps in which the colour of light ***is the same as produced by the discharge through the gas or vapour***. To this group belong the neon gas lamps, mercury vapour (M.V.) and sodium vapour lamps. The other type consists of vapour lamps which use the phenomenon of fluorescence. In their case, the discharge through the vapour produces ultra-violet waves which cause fluorescence in certain materials known as phosphors. The radiations from the mercury discharge (especially 2537 A° line) impinge on these phosphors which absorb them and then re-radiate them at longer wave-lengths of visible spectrum. The inside of the fluorescent lamp is coated with these phosphors for this purpose. Different phosphors have different exciting ranges of frequency and give lights of different colours as shown in table 49.2.

Table 49.2

Phosphor	*Lamp Colour*	*Exciting range A°*	*Emitted wavelenght A°*
Calcium Tangstate	Blue	2200 - 3000	4400
Zinc Silicate	Green	2200 - 2960	5250
Cadmium Borate	Pink	2200 - 3600	6150
Cadmium Silicate	Yellow-pink	2200 - 3200	5950

49.25. Sodium Vapour Lamp

Sodium vapour lamp

One type of low-pressure sodium-vapour lamp along with its circuit connection is shown in Fig. 49.48. It consists of an inner U-tube A made of a special sodium-vapour-resisting glass. It houses the two electrodes and contains sodium together with the small amount of neon-gas at a pressure of about 10 mm of mercury and one per cent of argon whose main function is to reduce the initial ionizing potential. The discharge is first started in the neon gas (which gives out redish colour). After a few minutes, the heat of discharge through the neon gas becomes sufficient to vaporise sodium and then discharge passes through the sodium vapour. In this way, the lamp starts its normal operation emitting its characteristic yellow light.

The tungsten-coated electrodes are connected across auto-transformer *T* having a relatively high leakage reactance. The open-circuit voltage of this transformer is about 450 V which is sufficient to initiate a discharge through the neon gas. The leakage reactance is used not only for starting the current but also for limiting its value to safe limit. The electric discharge or arc strikes immediately after the supply is switched on whether the lamp is hot or cold. The normal burning position of the lamp is horizontal although two smaller sizes of lamp may be burnt vertically. The lamp is surrounded by an outer glass envelope *B* which serves to reduce the loss of heat from the inner discharge tube *A*. In this way, *B* helps to maintain the necessary high temperature needed for the operation of a sodium vapour lamp irrespective of draughts. The capacitor *C* is meant for improving the power factor of the circuit.

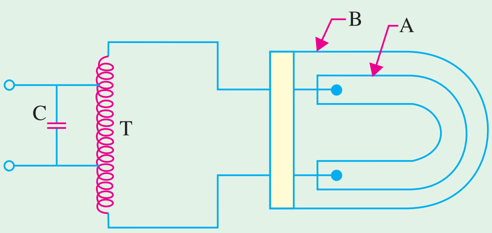


Fig. 49.48

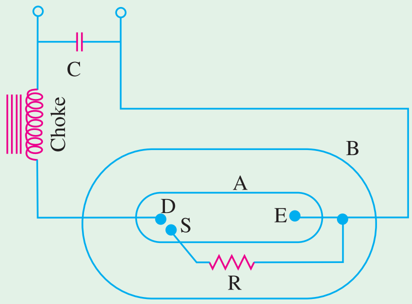


Fig. 49.49

The light emitted by such lamps consists entirely of yellow colour. Solid objects illuminated by sodium-vapour lamp, therefore, present a picture in monochrome appearing as various shades of yellow or black.

49.26. High-pressure Mercury Vapour Lamp

Like sodium-vapour lamp, this lamp is also classified as electric discharge lamp in which light is produced by gaseous conduction. Such a lamp usually consists of two bulbs — an arc-tube containing the electric discharge and an outer bulb which protects the arc-tube from changes in temperature. The inner tube or arc tube *A* is made of quartz (or hard glass) the outer bulb *B* of hard glass. As shown in Fig. 49.49, the arc tube contains a small amount of mercury and argon gas and houses three electrodes *D*, *E* and *S*. The main electrodes are *D* and *E* whereas *S* is the auxiliary starting electrode. *S* is connected through a high resistance *R* (about 50 kΩ) to the main electrode situated at the outer end of the tube. The main electrodes consist of tungsten coils with electron-emitting coating or elements of thorium metal.

When the supply is switched on, initial discharge for the few seconds is established in the argon gas between *D* and *S* and then in the argon between *D* and *E*. The heat produced due to this discharge through the gas is sufficient to vaporise mercury. Consequently, pressure inside *A* increases to about one or two atmospheres and the p.d. across *D* and *E* grows from about 20 to 150 V, the operation taking about 5-7 minutes. During this time, discharge is established through the mercury vapours which emit greenish-blue light.

The choke serves to limit the current drawn by the discharge tube *A* to a safe limit and capacitor *C* helps to improve the power factor of the circuit.

True colour rendition is not possible with mercury vapour lamps since there is complete absence of red-light from their radiations. Consequently, red objects appear black, all blues appear mercury-spectrum blue and all greens the mercury-spectrum green with the result that colour values are distorted.

Correction for colour distortion can be achieved by

1. Using incandescent lamps (which are rich in red light) in combination with the mercury lamps.
2. Using colour-corrected mercury lamps which have an inside phosphor coat to add red colour to the mercury spectrum.

Stroboscopic (Flickering) effect in mercury vapour lamps is caused by the 100 on and off arc strikes when the lamps are used on the 50-Hz supply. The effect may be minimized by

1. Using two lamps on lead-lag transformer
2. Using three lamps on separated phases of a 3-phase supply and
3. Using incandescent lamps in combination with mercury lamps.

In the last few years, there has been tremendous improvement in the construction and operation of mercury-vapour lamps, which has increased their usefulness and boosted their application for all types of industrial lighting, floodlighting and street lighting etc. As compared to an incandescent lamp, a mercury-vapour lamp is (*a*) smaller in size (*b*) has 5 to 10 times longer operating life and (*c*) has 3 times higher efficiency *i.e.* 3 times more light output for given electrical wattage input.

Typical mercury-vapour lamp applications are :

1. High-bay industrial lighting — where high level illumination is required and colour rendition is not important.
2. Flood-lighting and street-lighting
3. Photochemical applications — where ultra-violet output is useful as in chlorination, water sterilization and photocopying etc.
4. For a wide range of inspection techniques by ultra-violet activation of fluorescent and phosphorescent dyes and pigments.
5. Sun-tan lamps — for utilizing the spectrum lines in the erythemal region of ultra-violet energy for producing sun-tan.

49.27. Fluorescent Mercury-vapour Lamps

Basically, a fluorescent lamp consists of a long glass tube internally coated with a suitable fluorescent powder. The tube contains a small amount of mercury along with argon whose function is to facilitate the starting of the arc. There are two sealed-in electrodes at each end of the tube. Two basic types of electrodes are used in fluorescent lamps :

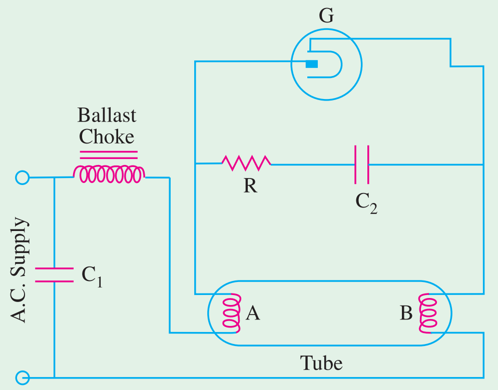


Fig. 49.50

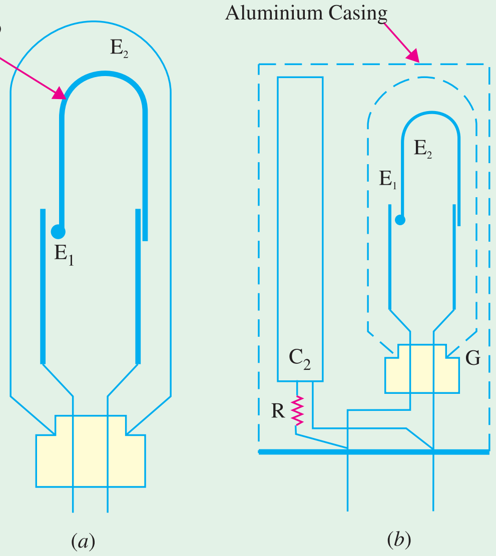


Fig. 49.51

1. The coated-coil tungsten wire type. This type is used in standard pre-heat, rapid-start, instant-start lamps etc.

2. The inside-coated metal cylinder type which operates at a lower and more even temperature than the tungsten type and is called 'cold cathode'.*

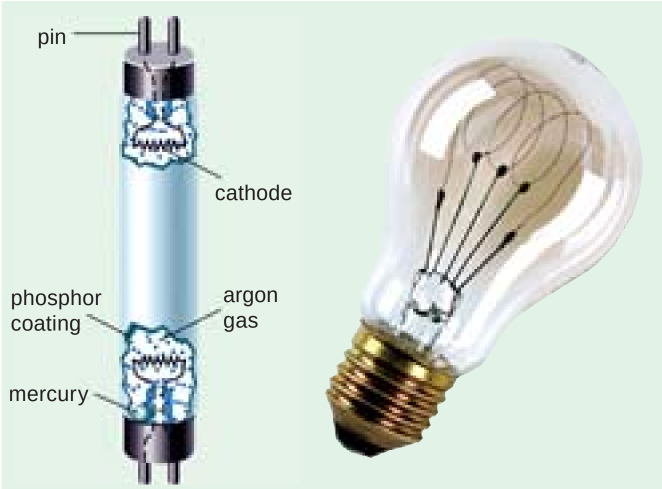
Circuits employed for the control of fluorescent lamps can be divided into two main groups ***(i)*** switch-start circuits and ***(ii)*** startless circuits requiring no starter. There are two types of starters ***(a)*** glow type — which is a voltage-operated device and ***(b)*** thermal switch — which is a current-operated device. Fig. 49.50 shows a flourescent tube fitted with a glow starter *G*. As shown separately in Fig. 49.51 (*a*), the glow switch consists of two electrodes enclosed in a glass bulb filled with a mixture of helium and hydrogen or argon or neon at low pressure. One electrode E_1 is fixed whereas the other E_2 is movable and is made of a U-shaped bimetallic strip. To reduce radio interference, a small capacitor C_2 is connected across the switch. The resistor *R* checks capacitor surges and prevents the starter electrodes or contacts from welding together. The complete starter switch along with the capacitor and resistor is contained in an aluminium casing is shown in Fig. 49.51 (*b*). Normally, the contacts are open and when supply is switched on, the glow switch receives almost full mains voltage**. The voltage is sufficient to start a glow discharge between the two electrodes E_1 and E_2 and the heat generated is sufficient to bend the bimetallic strip E_2 till it makes contact with the fixed electrode E_1, thus closing the contacts. This action completes the main circuit through the choke and the lamp electrodes *A* and *B* (Fig. 49.50). At the same time, since the glow between E_1 and E_2 has been shorted out, the bimetallic strip cools and the contacts E_1 and E_2 open. By this time, lamp electrodes *A* and *B* become heated to incandescence and the argon gas in their immediate vicinity is ionized. Due to opening of the glow switch contacts, a high inductive e.m.f. of about 1000 volts is induced in the choke. This voltage surge is sufficient to initiate a discharge in the argon gas lying between electrodes *A* and *B*. The heat thus produced is sufficient to vaporize mercury and the p.d. across the fluorescent tube falls to about 100 or 110 V which is not sufficient to restart the glow in

* A cold cathode fluorescent lamp requires higher operating voltage than the other type. Although cold cathode lamps have less efficiency, they have much longer life than other lamps.

** It is so because only the small discharge current flows and voltage drop across the choke is negligible.

G. Finally, the discharge is established through the mercury vapour which emits ultra-violet radiations. These radiations impinge on the fluorescent powder and make it emit visible light.

The function of the capacitor C_1 is to improve the power factor of the circuit. It may be noted that the function of the highly-inductive choke (also called ballast) is ***(i)*** to supply large potential for starting the arc or discharge and ***(ii)*** to limit the arc current to a safe value.



A fluorescent lamp radiates more light compared to an incandescent filament bulb, for the same amount of power consumed

49.28. Fluorescent Lamp Circuit with Thermal Switch

The circuit arrangement is shown in Fig. 49.52. The switch has a bimetallic strip close to a resistance *R* which produces heat. The switch is generally enclosed in hydrogen-filled glass bulb *G*. The two switch electrodes E_1 and E_2 are normally closed when the lamp is not in operation. When normal supply is switched on, the lamp filament electrodes *A* and *B* are connected together through the thermal switch and a large current passes through them. Consequently, they are heated to incandescence. Meanwhile heat produced in resistance *R* causes the bimetallic strip E_2 to break contact. The inductive surge of about 1000 V produced by the choke is sufficient to start discharge through mercury vapours as explained in Art. 49.27. The heat produced in *R* keeps the switch contacts E_1 and E_2 open during the time lamp is in operation.

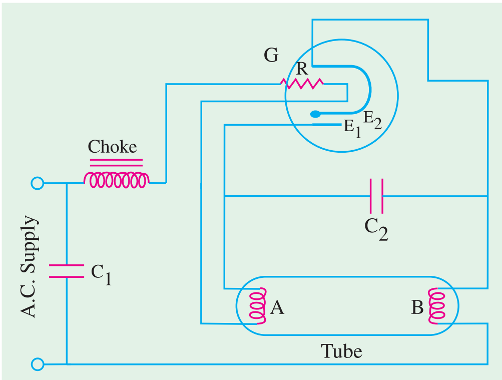


Fig. 49.52

49.29. Startless Fluorescent Lamp Circuit

Such a circuit (Fig. (49.53) which does not require the use of a starter switch is commercially known as 'instant-start' or 'quick-start'. In this case, the normal starter is replaced by a filament heating transformer whose secondaries *SS* heat up the lamp electrodes *A* and *B* to incandescence in a fraction of a second. This combination of pre-heating and application of full supply voltage across lamp electrodes *A* and *B* is sufficient to start ionization in the neighbourhood of the electrodes which further spreads to the whole tube. An earthed strip *E* is used to ensure satisfactory starting.

The advantages of startless method are

1. It is almost instantaneous starting.
2. There is no flickering and no false starts.
3. It can start and operate at low voltage of 160-180 V.
4. Its maintenance cost is lower due to the elimination of any starter-switch replacements.
5. It lengthens the life of the lamp.

49.30. Stroboscopic Effect of Fluorescent Lamps

Stroboscopic or flickering effect produced by fluorescent lamps is due to the periodic fluctuations in the light output of the lamp caused by cyclic variations of the current on a.c. circuits. This phenomenon creates multiple-image appearance of moving objects and makes the movement appear jerky. In this connection, it is worth noting that

1. This flicker effect is more pronounced at lower frequencies.
2. Frequency of such flickers is twice the supply frequency.
3. The fluorescent powder used in the tube is slightly phosphorescent, hence stroboscopic effect is reduced to some extent due to after-glow.

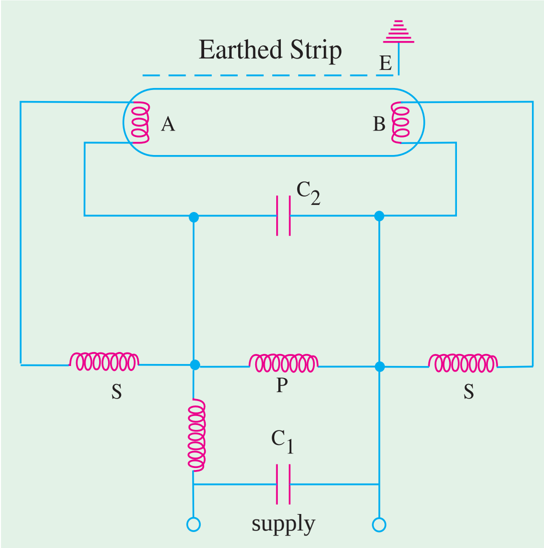


Fig. 49.53

Stroboscopic effect is very troublesome in the following cases :

1. When an operator has to move objects very quickly particularly those having polished finish. These objects would appear to move with jerky motion which over a long period would produce visual fatigue.
2. In the case of rotating machines whose frequency of rotation happens to be a multiple of flicker frequency, the machines appear to decrease in speed of rotation or be stationary. Sometimes the machines may even seem to rotate in the opposite direction.

Some of the methods employed for minimizing stroboscopic effect are given below :

1. By using three lamps on the seperate phases of a 3-phase supply. In this case, the three light waves reaching the working plane would overlap by 120° so that the resultant fluctuation will be very much less than from a single fluorescent lamp.
2. By using a 'twin lamp' circuit on single-phase supply as shown in Fig. 49.54, one of the chokes has a capacitor in series with it and the lamp. In this way, a phase displacement of nearly 120° is introduced between the branch currents and also between the two light waves thereby reducing the resultant fluctuation.
3. By operating the lamps from a high frequency supply. Obviously, stroboscopic effect will entirely disappear on d.c. supply.

49.31. Comparison of Different Light Sources

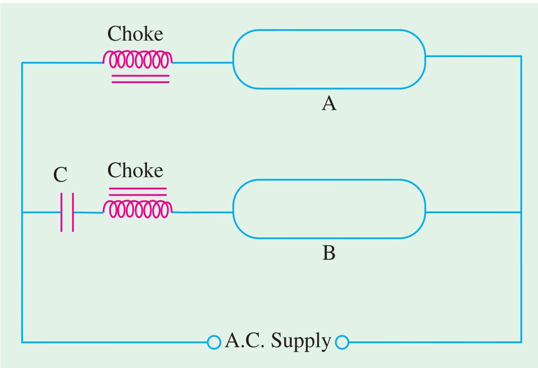


Fig. 49.54

1. Incandescent Lamps. They have instantaneous start and become momentarily off when the supply goes off. The colour of their light is very near the natural light. Their initial cost of installation is minimum but their running cost is maximum. They work equally well both on d.c. and a.c. supply and frequent switching does not affect their life of operation. Change of supply voltage affects their efficiency, output and life in a very significant way. They have an average working life of 1000 hours and luminous efficiency of 12 lm/W. Since their light has no stroboscopic effects, the incandescent lamps are suitable for domestic, industrial, street lighting and floodlights etc. They are available in a wide range of voltage ratings and, hence are used in automobiles, trains, emergency lights, aeroplanes and signals for railways etc.

2. Flourescent Lamps. They have a reaction time of one second or a little more at the start. They go off and restart when the supply is restored. The colour of their light varies with the phosphor coating. Their initial cost of installation is maximum but running cost is minimum. Since stroboscopic effect is present, they are suitable for semi-direct lighting, domestic, industrial, commercial, roads and halls etc. Change in voltage affects their starting although light output does not change as remarkably as in the case of incandescent lamps. Colour of their light changes with the different phosphor coating on the inner side of the tube. Frequent switching affects their life period. They have quite high utility but their voltage rating is limited. Hence, their use is confined to mains voltage or complicated inverter circuits which convert 12 V d.c. into high volt d.c.. They have an average working life of 4000 hours and a luminous efficiency of 40 lm/W.

3. Mercury Vapour Lamps. They take 5 to 6 minutes for starting. They go off and cannot be restarted after the recovery of the voltage till the pressure falls to normal. They suffer from high colour distortion. Their initial cost of installation is high but lesser than that of flourescent lamps. Their running cost is much less than incandescent lamps but higher than flourescent tubes for the same levels of illumination. Stroboscopic effect is present in their light. They are suitable for open space like yards, parks and highway lighting etc. Change in voltage effects their starting time and colour of radiations emitted by them. Switching does not affect their life period. They have very limited utility that too on mains voltage. They are suitable for vertical position of working. They have an average working life of 3000 hours and an efficiency of 40 lm/W.

4. Sodium Vapour Lamps. They have a starting time of 5 to 6 minutes. They go off and cannot be restarted after the recovery of the voltage till its value falls to the normal value. The colour of their light is yellowish and produces colour distortion.Their initial cost of installation is maximum although their running cost is less than for filament lamps but more than for flourescent lamps. They have stroboscopic effect and are suitable for use in open spaces, highways and street lighting etc. Change in voltage affects their starting time and colour of their radiations. They work on a.c. voltage and frequent switching affects their life. They are not suitable for local lighting. The colour of their light cannot be changed. They are very suitable for street lighting purposes. Their position of working is horizontal. They have a working life of about 3000 hours and efficiency of 60-70 lm/W.

Tutorial Problem No. 49.3

1. Explain $\cos^3 \phi$ law. *(J.N. University, Hyderabad, November 2003)*
2. A lamp of 500 candle power is placed at the centre of a room,(20 m × 10 m × 5 m.) Calculate the illumination in each corner of the floor and a point in the middle of a 10 m wall at a height of 2 m from floor. *(J.N. University, Hyderabad, November 2003)*
3. Enumerate the various factors, which have to be considered while designing any lighting scheme. *(J.N. University, Hyderabad, November 2003)*
4. Prove that 1 candle/sq. feet = ($\pi fl - L$.) *(J.N. University, Hyderabad, November 2003)*
5. A lamp giving 300 c.p. in all directions below the horizontal is suspended 2 metres above the centre of a square table of 1 metre side. Calculate the maximum and minimum illumination on the surface of the table. *(J.N. University, Hyderabad, November 2003)*
6. Explain the various types of lighting schemes with relevant diagrams. *(J.N. University, Hyderabad, November 2003)*
7. Discuss inverse square law? Corire law of Illustration. *(J.N. University, Hyderabad, November 2003)*

8. A lamp fitted with 120 degrees angled cone reflector illuminates circular area of 200 meters in diameter.The illumination of the disc increases uniformly from 0.5 metre-candle at the edge to 2 meter-candle at the centre.
Determine :
(*i*) the total light received (*ii*) Average illumination of the disc (*iii*) Average c.p. of the source.
(J.N. University, Hyderabad, November 2003)
9. Discuss the flood lighting with suitable diagrams. *(J.N. University, Hyderabad, November 2003)*
10. Explain the measurement techniques used for luminous intensity.
(J.N. University, Hyderabad, November 2003)
11. Write short notes on :
(*i*) Bunsen photometer head (*ii*) Lummer-Brodherm photometer head (*iii*) Flicker photometer head.
(J.N. University, Hyderabad, November 2003)
12. What do you understand by polar curves as applicable to light source? Explain.
(J.N. University, Hyderabad, November 2003)
13. Mean spherical Candlepower. *(J.N. University, Hyderabad, April 2003)*
14. Explain how you will measure the candlepower of a source of light.
(J.N. University, Hyderabad, April 2003)
15. Explain the Rosseau's construction for calculating M.S.C.P. of a lamp.
(J.N. University, Hyderabad, April 2003)
16. What do you mean by International Luminosity curve? Explain.
(J.N. University, Hyderabad, April 2003)
17. Explain in detail the primary standard of luminous intensity with relevant diagram.
(J.N. University, Hyderabad, April 2003)
18. Explain with sketches the constructional features of a filament lamp.
(J.N. University, Hyderabad, April 2003)
19. Explain how the standard lamps canbe calibrated w.r.t. primary and secondary standards.
(J.N. University, Hyderabad, April 2003)
20. Briefly explain the various laboratory standards used in Illumination.
(J.N. University, Hyderabad, April 2003)
21. Write short notes on :
(*a*) High pressure mercury vapour lamp (*i*) M.A. Type (*ii*) M.T. Type
(*b*) Mercury fluorescent lamp.
(J.N. University, Hyderabad, April 2003)
22. Explain with connection diagram the operation of the low pressure fluorescent lamp and state its advantage. *(J.N. University, Hyderabad, April 2003)*
23. Explain clearly the following :
Illumination, Luminous efficiency, MSCP, MHCP and solid angle.
(J.N. University, Hyderabad, December 2002/January 2003)
24. A small light source with uniform intensity is mounted at a height of 10 meters above a horizontal surface. Two points A and B both lie on the surface with point A directly beneath the source. How far is B from A if the illumination at B is only 1/15th of that at A?
(J.N. University, Hyderabad, December 2002/January 2003)
25. Discuss the : (*i*) Specular reflection principle (*ii*) Diffusion principle of street lighting.
(J.N. University, Hyderabad, December 2002/January 2003)
26. Determine the height at which a light source having uniform spherical distribution should be placed over a floor in order that the intensity of horizontal illumination at a given distance from its vertical line may be greatest. *(J.N. University, Hyderabad, December 2002/January 2003)*
27. What is a Glare? *(J.N. University, Hyderabad, December 2002/January 2003)*
28. With the help of a neat diagram, explain the principle of operation of fluorescent lamp.
(J.N. University, Hyderabad, December 2002/January 2003)

29. A machine shop 30 m long and 15 m wide is to have a general illumination of 150 lux on the work plane provided by lamps mounted 5 m above it. Assuming a coefficient of utilization of 0.55, determine suitable number and position of light. Assume any data if required.
(J.N. University, Hyderabad, December 2002/January 2003)

30. Laws of illumination. *(J.N. University, Hyderabad, December 2002/January 2003)*

31. Working principle of sodium vapour lamp.
(J.N. University, Hyderabad, December 2002/January 2003)

32. Explain the principle of operation of sodium vapour lamp and its advantages.
(J.N. University, Hyderabad, December 2002/January 2003)

33. A corridor is lighted by lamps spaced 9.15 m apart and suspended at a height of 4.75 m above the centre line of the floor. If each lamp gives 100 candle power in all directions, find the maximum and minimum illumination on the floor along the centre line. Assume and data if required.
(J.N. University, Hyderabad, December 2002/January 2003)

34. Discuss the laws of illumination and its limitations in practice.
(J.N. University, Hyderabad, December 2002/January 2003)

35. State the functions of starter and choke in a fluorescent lamp.
(J.N. University, Hyderabad, December 2002/January 2003)

36. Mercury Vapour Lamp. *(J.N. University, Hyderabad, December 2002/January 2003)*

37. Describe briefly (*i*) conduit system (*ii*) C.T.S. system of writing.
(Bangalore University, January/February 2003)

38. With a neat circuit diagram, explain the two way control of a filament lamp.
(Belgaum Karnataka University, February 2002)

39. With a neat sketch explain the working of a sodium vapour lamp.
(Belgaum Karnataka University, February 2002)

40. Mention the different types of wiring. With relevant circuit diagrams and switching tables, explain two-way and three-way control of lamps.
(Belgaum Karnataka University, January/February 2003)

41. With a neat sketch explain the working of a fluorescent lamp.
(Belgaum Karnataka University, January/February 2003)

OBJECTIVE TESTS – 49

1. Candela is the unit of
(*a*) flux
(*b*) luminous intensity
(*c*) illumination
(*d*) luminance.

2. The unit of illuminance is
(*a*) lumen
(*b*) cd/m^2
(*c*) lux
(*d*) steradian.

3. The illumination at various points on a horizontal surface illuminated by the same source varies as
(*a*) $\cos^3\theta$
(*b*) $\cos\theta$
(*c*) $1/r^2$
(*d*) $\cos^2\theta$.

4. The M.S.C.P. of a lamp which gives out a total luminous flux of 400 π lumen is .... candela.
(*a*) 200
(*b*) 100
(*c*) 50
(*d*) 400.

5. A perfect diffuser surface is one that
(*a*) diffuses all the incident light
(*b*) absorbs all the incident light
(*c*) transmits all the incident light
(*d*) scatters light uniformly in all directions.

6. The direct lighting scheme is most efficient but is liable to cause
(*a*) monotony
(*b*) glare
(*c*) hard shadows
(*d*) both (*b*) and (*c*).

7. Total flux required in any lighting scheme depends inversely on
(*a*) illumination

(b) surface area
(c) utilization factor
(d) space/height ratio.

8. Floodlighting is NOT used for .... purposes.
(a) reading
(b) aesthetic
(c) advertising
(d) industrial.

9. Which of the following lamp has minimum initial cost of installation but maximum running cost ?
(a) incandescent
(b) fluorescent
(c) mercury vapour
(d) sodium vapour.

10. An incandescent lamp can be used
(a) in any position
(b) on both ac and dc supply
(c) for street lighting
(d) all of the above.

11. The average working life of a fluorescent lamp is about....................... hours.
(a) 1000
(b) 4000
(c) 3000
(d) 5000.

12. The luminous efficiency of a sodium vapour lamp is about .... lumen/watt.
(a) 10
(b) 30
(c) 50
(d) 70

13. Which of the following statements is correct?
(a) Light is a form of heat energy
(b) Light is a form of electrical energy
(c) Light consists of shooting particles
(d) Light consists of electromagnetic waves

14. Luminous efficiency of a fluorescent tube is
(a) 10 lumens/watt
(b) 20 lumens/watt
(c) 40 lumens/watt
(c) 60 lumens/watt

15. Candela is the unit of which of the following?
(a) Wavelength
(b) Luminous intensity
(c) Luminous flux
(d) Frequency

16. Colour of light depends upon
(a) frequency
(b) wave length
(c) both (a) and (b)
(d) speed of light

17. Illumination of one lumen per sq. metre is called ....
(a) lumen metre
(b) lux
(c) foot candle
(d) candela

18. A solid angle is expressed in terms of ....
(a) radians/metre
(b) radians
(c) steradians
(d) degrees

19. The unit of luminous flux is ....
(a) watt/m^2
(b) lumen
(c) lumen/m^2
(d) watt

20. Filament lamps operate normally at a power factor of
(a) 0.5 lagging
(b) 0.8 lagging
(c) unity
(d) 0.8 leading

21. The filament of a GLS lamp is made of
(a) tungsten
(b) copper
(c) carbon
(d) aluminium

22. Find diameter tungsten wires are made by
(a) turning
(b) swaging
(c) compressing
(d) wire drawing

23. What percentage of the input energy is radiated by filament lamps?
(a) 2 to 5 percent
(b) 10 to 15 percent
(c) 25 to 30 percent
(d) 40 to 50 percent

24. Which of the following lamps is the cheapest for the same wattage?
(a) Fluorescent tube
(b) Mercury vapour lamp
(c) GLS lamp
(d) Sodium vapour lamp

25. Which of the following is not the standard rating of GLS lamps?
(a) 100 W
(b) 75 W
(c) 40 W
(d) 15 W

26. In houses the illumination is in the range of
(a) 2–5 lumens/watt
(b) 10–20 lumens/watt

(*c*) 35–45 lumens/watt
(*d*) 60–65 lumens/watt

27. ''The illumination is directly proportional to the cosine of the angle made by the normal to the illuminated surface with the direction of the incident flux''. Above statement is associated with
(*a*) Lambert's cosine law
(*b*) Planck's law
(*c*) Bunsen's law of the illumination
(*d*) Macbeth's law of illumination

28. The colour of sodium vapour discharge lamp is
(*a*) red
(*b*) pink
(*c*) yellow
(*d*) bluish green

29. Carbon arc lamps are commonly used in
(*a*) photography
(*b*) cinema projectors
(*c*) domestic lighting
(*d*) street lighting

30. Desired illumination level on the working plane depends upon
(*a*) age group of observers
(*b*) whether the object is stationary or moving
(*c*) Size of the object to be seen and its distance from the observer
(*d*) whether the object is to be seen for longer duration or shorter duration of time
(*e*) all above factors

31. On which of the following factors dies the depreciation or maintenance factor depend?
(*a*) Lamp cleaning schedule
(*b*) Ageing of the lamp
(*c*) Type of work carried out at the premises
(*d*) All of the above factors

32. In lighting installating using filament lamps 1% voltage drop results into
(*a*) no loss of light
(*b*) 1.5 percent loss in the light output
(*c*) 3.5 percent loss in the light output
(*d*) 15 percent loss in the light output

33. For the same lumen output, the running cost of the fluorescent lamp is
(*a*) equal to that of filament lamp
(*b*) less than that of filament lamp
(*c*) more than that of filament lamp
(*d*) any of the above

34. For the same power output
(*a*) high voltage rated lamps will be more sturdy
(*b*) low voltage rated lamps will be more sturdy
(*c*) both low and high voltage rated lamps will be equally sturdy

35. The cost of a fluorescent lamp is more than that of incandescent lamp because of which of the following factors?
(*a*) More labour is required in its manufacturing
(*b*) Number of components used is more
(*c*) Quantity of glass used is more
(*d*) All of the above factors

36. Filament lamp at starting will take current
(*a*) less than its full running current
(*b*) equal to its full running current
(*c*) more than its full running current

37. A reflector is provided to
(*a*) protect the lamp
(*b*) provide better illumination
(*c*) avoid glare
(*d*) do all of the above

38. The purpose of coating the fluorescent tube from inside with white power is
(*a*) to improve its life
(*b*) to improve the appearance
(*c*) to change the colour of light emitted to white
(*d*) to increase the light radiations due to secondary emissions

39. .... will need lowest level of illumination.
(*a*) Audiotoriums
(*b*) Railway platform
(*c*) Displays
(*d*) Fine engravings

40. Due to moonlight, illumination is nearly
(*a*) 3000 lumens/m^2
(*b*) 300 lumens/m^2
(*c*) 30 lumens/m^2
(*d*) 0.3 lumen/m^2

41. Which of the following instruments is used for the comparison of candle powers of different sources?
(*a*) Radiometer
(*b*) Bunsen meter
(*c*) Photometer
(*d*) Candle meter

42. .... photometer is used for comparing the lights of different colours?
(*a*) Grease spot
(*b*) Bunsen
(*c*) Lummer brodhum
(*d*) Guilds flicker

43. In the fluorescent tube circuit the function of choke is primarily to
(*a*) reduce the flicker

(b) minimise the starting surge
(c) initiate the arc and stabilize it
(d) reduce the starting current

44. ...... cannot sustain much voltage fluctuations.
(a) Sodium vapour lamp
(b) Mercury vapour lamp
(c) Incandescent lamp
(d) Fluorescent lamp

45. The function of capacitor across the supply to the fluorescent tube is primarily to
(a) stabilize the arc
(b) reduce the starting current
(c) improve the supply power factor
(d) reduce the noise

46. ...... does not have separate choke
(a) Sodium vapour lamp
(b) Fluorescent lamp
(c) Mercury vapour lamp
(d) All of the above

47. In sodium vapour lamp the function of the leak transformer is
(a) to stabilize the arc
(b) to reduce the supply voltage
(c) both (a) and (b)
(d) none of the above

48. Most affected parameter of a filament lamp due to voltage change is
(a) wattage
(b) life
(c) luminous efficiency
(d) light output

49. In electric discharge lamps for stabilizing the arc
(a) a reactive choke is connected in series with the supply
(b) a condenser is connected in series to the supply
(c) a condenser is connected in parallel to the supply
(d) a variable resistor is connected in the circuit

50. For precision work the illumination level required is of the order of
(a) 500-1000 lumens/m^2
(b) 200-2000 lumens/m^2
(c) 50-100 lumens/m^2
(d) 10-25 lumens/m^2

51. ...... is a cold cathode lamp.
(a) Fluorescent lamp
(b) Neon lamp
(c) Mercury vapour lamp
(d) Sodium vapour lamp

52. In case of ...... least illumination level is required.
(a) skilled bench work
(b) drawing offices
(c) hospital wards
(d) find machine work

53. For normal reading the illumination level required is around
(a) 20-40 lumens/m^2
(b) 60-100 lumens/m^2
(c) 200-300 lumens/m^2
(d) 400-500 lumens/m^2

54. In electric discharge lamps light is produced by
(a) cathode ray emission
(b) ionisation in a gas or vapour
(c) heating effect of current
(d) magnetic effect of current

55. A substance which change its electrical resistance when illuminated by light is called ....
(a) photoelectric
(b) photovoltaic
(c) phatoconductive
(d) none of the above

56. In case of ...... power factor is the highest.
(a) GLS lamps
(b) mercury arc lamps
(c) tube lights
(d) sodium vapour lamps

57. A mercury vapour lamp gives ..... light.
(a) white
(b) pink
(c) yellow
(d) greenish blue

58. Sometimes the wheels of rotating machinery, under the influence of fluorescent lamps appear to be stationary. This is due to the
(a) low power factor
(b) stroboscopic effect
(c) fluctuations
(d) luminescence effect

59. Which of the following bulbs operates on least power?
(a) GLS bulb
(b) Torch bulb
(c) Neon bulb
(d) Night bulb

60. The flicker effect of fluorescent lamps is more pronounced at
(a) lower frequencies
(b) higher frequencies
(c) lower voltages
(d) higher voltages

61. Which of the following application does not need ultraviolet lamps?
(*a*) Car lighting
(*b*) Medical purposes
(*c*) Blue print machine
(*d*) Aircraft cockpit dashboard lighting

62. Which gas can be filled in GLS lamps?
(*a*) Oxygen
(*b*) Carbon dioxide
(*c*) Xenon
(*d*) Any inert gas

ANSWERS

1. (*b*)	**2.** (*c*)	**3.** (*a*)	**4.** (*b*)	**5.** (*d*)	**6.** (*d*)	**7.** (*c*)	**8.** (*a*)	**9.** (*a*)	**10.** (*d*)
11. (*b*)	**12.** (*d*)	**13.** (*d*)	**14.** (*d*)	**15.** (*b*)	**16.** (*c*)	**17.** (*b*)	**18.** (*c*)	**19.** (*b*)	**20.** (*c*)
21. (*a*)	**22.** (*d*)	**23.** (*b*)	**24.** (*c*)	**25.** (*b*)	**26.** (*d*)	**27.** (*a*)	**28.** (*c*)	**29.** (*b*)	**30.** (*e*)
31. (*d*)	**32.** (*c*)	**33.** (*b*)	**34.** (*b*)	**35.** (*d*)	**36.** (*c*)	**37.** (*d*)	**38.** (*d*)	**39.** (*b*)	**40.** (*d*)
41. (*c*)	**42.** (*d*)	**43.** (*c*)	**44.** (*c*)	**45.** (*c*)	**46.** (*a*)	**47.** (*c*)	**48.** (*b*)	**49.** (*a*)	**50.** (*a*)
51. (*b*)	**52.** (*c*)	**53.** (*b*)	**54.** (*b*)	**55.** (*c*)	**56.** (*a*)	**57.** (*d*)	**58.** (*b*)	**59.** (*b*)	**60.** (*a*)
61. (*a*)	**62.** (*d*)								

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