1

Illumination

1.1. INTRODUCTION

- **Light** is *a form of electromagnetic energy radiated from a body which is capable of being perceived by the human eye.* The sensation of light results from a flow of energy into the eye and the light will appear to vary if the rate of this flow of energy varies. Light radiations form only a very small part of the complete range of electromagnetic radiations. Light can be of different colours, which depend on the wavelength of the radiation causing it.
- Light can be described as a *vibratory motion*, which is transmitted in the form of waves through space. Visible light travels in the form of transverse waves of electromagnetic oscillations. The speed of all electromagnetic waves is 3×10^8 m/s in free space. The wavelength and frequency are different for different waves. The velocity with which these waves travel is related to the wavelength and frequency, by the relation : $v = \lambda f$

The complete range of waves along with their frequency and wavelength is illustrated in Fig. 1.1.

Fig. 1.2 shows the light emitted together with its colour for the wavelengths within the visible spectrum.

Since the wavelengths of light are very short, smaller unit of length called Angstrom Unit (AU) named after a Sweedish scientist is used.

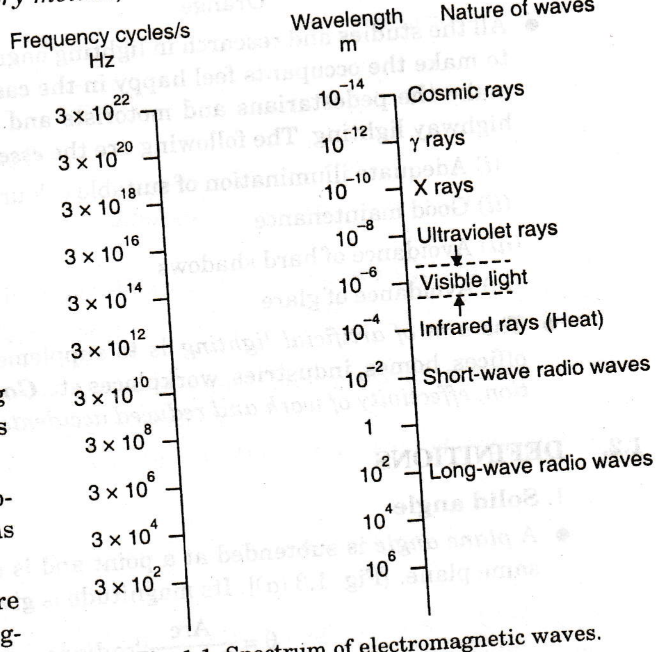

Fig. 1.1. Spectrum of electromagnetic waves.

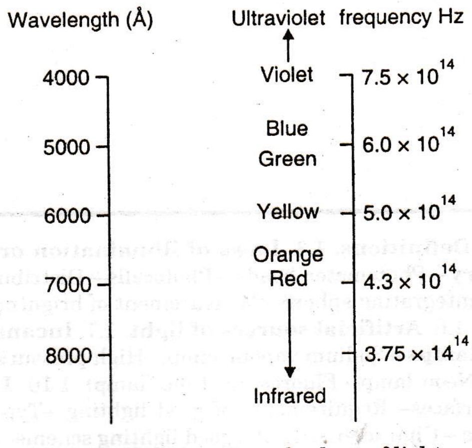

Fig. 1.2. Wavelength and colour of light.

Angstrom Unit (Å) = 10^{-10} m

Another smaller unit is *micron* (1 micron = 10^{-6} m).

A list of colours with their wavelengths is given below :

Colour	*Wavelengths*
Violet	4100 Å
Blue	4700 Å
Green	5500 Å
Yellow	5800 Å
Red	6000 Å
Orange	6100 Å

- All the studies and research in lighting engineering try to achieve a good lighting scheme to make the occupants feel happy in the case of interior design and factory lighting and make the pedestarians and motorists and other road users comfortable in the case of highway lighting. The following are the *essentials of any good lighting system :*

  (*i*) Adequate illumination of suitable colour on the working surfaces.

  (*ii*) Good maintenance

  (*iii*) Avoidance of hard shadows

  (*iv*) Avoidance of glare.

- The *aim of artificial lighting* is to supplement the daylight or to replace it in modern offices, homes, industries, workplaces etc. ***Good illumination*** *ensures increased production, effectivity of work and reduced accidents.*

1.2. DEFINITIONS

1. Solid angle

- A *plane angle* is subtended at a point and is enclosed by two straight lines lying in the same plane. [Fig. 1.3 (*a*)]. Its magnitude is given by,

$$\theta = \frac{\text{Arc}}{\text{Radius}} \text{ 'radians'}$$

The largest angle subtended at a point is 2π radians.

A *radian* is the angle subtended by an arc of a circle whose length equals the radius of the circle.

- ***Solid angle*** is the *angle generated by the surface passing through the point in space and the periphery of the area [Fig. 1.3(b)].* It is denoted by ω, expressed in '*steradians*' and is given by the *ratio of the area of the surface to the square of the distance between the area and the point,*

i.e., $$\omega = \frac{\text{Area}}{(\text{Radius})^2} = \frac{A}{r^2}$$

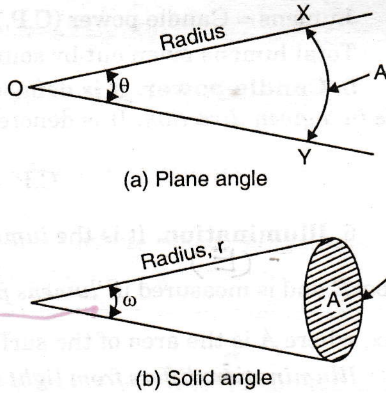

Fig. 1.3. Plane angle and solid angle.

The largest solid angle subtended at a point is due to a sphere at its centre, and is equal to $\frac{4\pi r^2 \text{ (Area of sphere)}}{r^2}$ $= 4\pi$ steradians.

Relationship between ω and θ is obtained as follows :

Consider a curved surface of a spherical segment *ABC* of height *h* and radius *r* (Fig. 1.4).

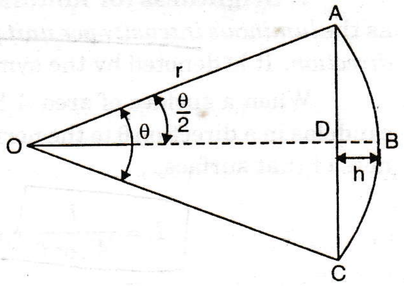

Fig. 1.4. Relation between solid and plane angles.

Surface area of segment $ABC = 2\pi rh$

Here, $h(BD) = OB - OD = r - r\cos\frac{\theta}{2} = r\left(1 - \cos\frac{\theta}{2}\right)$

$\therefore$ Surface area of segment $ABC = 2\pi r^2\left(1 - \cos\frac{\theta}{2}\right)$

$$\text{Solid angle, } \omega = \frac{\text{Surface area}}{(\text{Radius})^2} = \frac{2\pi r^2\left(1 - \cos\frac{\theta}{2}\right)}{r^2}$$

$$= 2\pi\left(1 - \cos\frac{\theta}{2}\right) \qquad \text{...(1.1)}$$

1. **Light.** *The radiant energy from a hot body which produces the visual sensation upon the human eye is called* ***light.***

It is denoted by the symbol *Q*, expressed in lumen-hours (analogous to watt-hours)

2. **Luminous flux.** *The total quantity of light energy emitted per second from a luminous body is called* ***luminous flux.*** (F)

It is represented by the symbol *F* and measured in *lumens.* The concept of luminous flux assists us to specify the output and efficiency of a given light source.

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

It is denoted by the symbol *I* and is measured in '*candela*' (cd) or *lumens/stearadian i.e.,* $I = \frac{F}{\omega}$ lumens/steradian or candela, where ω in the solid angle).

4. **Lumen.** It is the unit of luminous flux and is defined as the *amount of luminous flux given out in a space represented by one unit solid angle by a source having an intensity of one candle power in all directions.*

i.e., Lumens = Candle power (C.P.) × Solid angle (ω)

Total lumens given out by source of one candela is 4π lumens.

5. **Candle power.** It is defined as the *number of lumens emitted by a source in a unit solid angle in a given direction.* It is denoted by symbol C.P.

i.e.,
$$\text{C.P.} = \frac{\text{Lumens}}{\omega}$$

6. **Illumination.** It is the *luminous flux received by a surface per unit area.* It is denoted by

(E)

symbol E and is measured in *'lumens per square metre' or lux or 'metre-candle' (i.e.,* $E = \frac{F}{A}$ lumens/m² or lux, where A is the area of the surface).

Illumination differs from light very much, though generally these terms are used more or less synonymously. Strictly speaking *light is the cause and illumination is the result of the light* on the surfaces on which it falls. Thus illumination makes surfaces more or less bright with a certain colour and it is this brightness and colour which the eye sees and interprets as something useful or pleasant or otherwise.

(L)

7. **Brightness (or luminance).** Brightness of a surface is defined as the *luminous intensity per unit projected area of the surface in the given direction.* It is denoted by the symbol L.

When a surface of area A has an effective luminous intensity of I candelas in a direction θ to the normal (Fig. 1.5), then luminance or brightness of that surface,

$$\boxed{L = \frac{I}{A\cos\theta}} \text{ candela/square metre (Cd/m}^2\text{)}$$

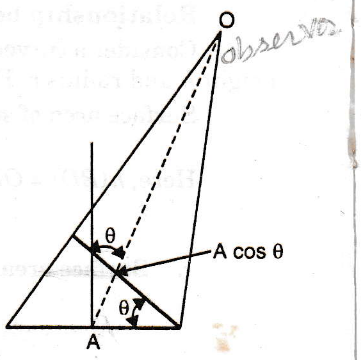

Fig. 1.5

A *"uniform diffuse source"* is one in which the *intensity per unit projected area is the same from all directions of view.*

• ***Relation between I, L and E :***

Consider a uniform diffuse spherical source with radius r metres and luminous intensity I candela.

Then,
$$L = \frac{I}{\pi r^2}$$

and,
$$E = \frac{I}{4\pi r^2} \times 4\pi = \frac{I}{r^2}$$

$$\therefore \qquad \boxed{E = \pi L} \qquad \text{...(1.2)}$$

8. **Mean horizontal candle power (M.H.C.P.).** It is defined as the *mean of candle power in all directions in the horizontal plane containing the source of light.*

9. **Mean spherical candle power (M.S.C.P.).** It is defined as the *mean of candle powers in all directions and in all planes from the source of light.*

10. **Mean hemi-spherical candle power.** It is defined as the *mean of all candle powers in all directions above or below the horizontal plane passing through the source of light.*

11. **Reduction factor.** Reduction factor of a source of light is the *ratio of its mean spherical candle power to its mean horizontal candle power, i.e.,*

$$\text{Reduction factor} = \frac{\text{M.S.C.P.}}{\text{M.S.H.P.}}.$$

MHCP

12. **Lamp efficiency.** It is defined as the *ratio of the luminous flux to the power input.* It is expressed in *lumens per watt.*

13. **Specific consumption.** It is defined as the *ratio of power input to the average candle power.* It is expressed in *watts per candle.*

14. **Space-height ratio.** It is defined as the *ratio of horizontal distance between adjacent lamps and height of their mountings.*

15. **Utilisation factor (UF).** The *ratio of total lumens reaching the working plane to total lumens given out by the lamp* is called *utilisation factor (or co-efficient of utilisation).*

16. **Maintenance factor (MF).** It is the *ratio of illumination under normal working conditions to the illumination when the things are perfectly clean.*

17. **Depreciation factor.** This is merely the reverse of the maintenance factor and is defined as the *ratio of initial metre-candles to the ultimate maintained metre-candles on the working plane.* It value is *more than unity.*

18. **Waste light factor.** Whenever a surface is illuminated by a number of sources of light, there is always a certain amount of waste of light on account of overlapping and falling of light outside at the edges of the surface. The effect is taken into account by multiplying the theoretical value of lumens required by 1.2 for rectangular areas and 1.5 for irregular areas and objects such as statues, monuments etc.

19. **Absorption factor.** In the places where atmosphere is full of smoke fumes, such as in foundries, there is a possibility of absorption of light. *The ratio of total lumens available after absorption to the total lumens emitted by the source of light is called the* **absorption factor.** Its values varies from unity for clean atmosphere to 0.5 for foundries.

20. **Beam factors.** The ratio of lumens in the beam of a projector to the lumens given out by lamps is called the *beam factor.* This factor takes into account the absorption of light by reflector and front glass of the projector lamp. Its value varies from 0.3 to 0.6.

21. **Reflection factor.** When a ray of light impinges on a surface it is reflected from the surface at an angle of incidence, as shown in Fig. 1.6. A certain portion of incident light is absorbed by the surface. The ratio of reflected light to the incident light is called the *'reflection factor'.* It is *always less than unity.*

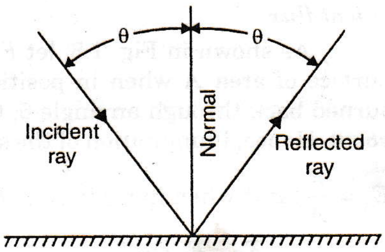

Fig. 1.6

22. **Glare.** The opening of the pupil in the human eye is controlled by the iris. If a bright object comes into the view of the eye, large amount of light produces an intense image on the retina and the iris automatically protects the eye by contracting the pupil, thus reducing the intensity of the image. When the eye is towards another object which is less bright as compared to the bright object already in the field of view, the iris will contract reducing the amount of light received on the retina from every object in the field of view and making it difficult to see the object desired. At the same time, the portion of the retina which received image of the bright object remains fatigued. This phenomenon is called ***"Glare"***, and is familiar in connection with motor-car head lights.

In other wards, **"glare"** *may be defined as the brightness within the field of vision of such a character as to cause annoyance, discomfort, interference with vision or eye-fatigue.*

1.3. LAWS OF ILLUMINATION OR LUMINANCE

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

illuminatin

1. E is *directly proportional to the luminous intensity* (I) of the source. In other words, $E \propto I$.

2. **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, $E \propto \dfrac{1}{r^2}$.

Proof: Consider surface areas A_1 and A_2 at distances r_1 and r_2 respectively from the point source S of luminous intensity I and *normal* to the rays as shown in Fig. 1.7. Let the solid angle subtended be ω.

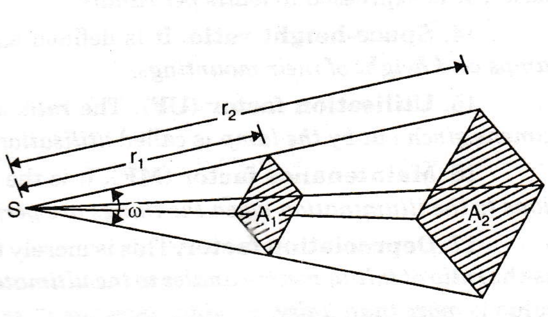

Fig. 1.7. Inverse square law.

Total luminous flux radiated

$$= I\omega \text{ lumens}$$

Illumination of the surface of area A_1

$$E_1 = \frac{I\omega}{A_1} = \frac{I\omega}{\omega r_1^2} = \frac{I}{r_1^2} \text{ lumens per unit area}$$

Similarly, illumination on the surface of area A_2,

$$E_2 = \frac{I\omega}{A_2} = \frac{I\omega}{\omega r_2^2} = \frac{I}{r_2^2} \text{ lumens per unit area.}$$

Hence the *illumination of a surface is inversely proportional to the square of the distance between the surface and the light source provided that the distance between the surface and the source is sufficiently large so that source can be regarded as a point source.*

3. **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.*

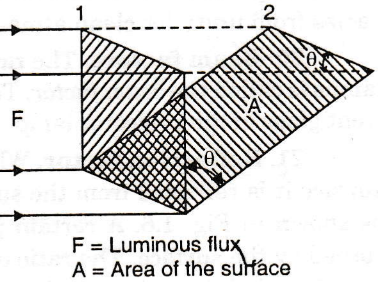

Fig. 1.8. Lambert's cosine law.

As shown in Fig. 1.8, let F 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 flux incident on it is $F \cos \theta$. Hence, illumination of the surface when in position 1 is

$E_1 = \dfrac{F}{A}$. But when in position 2, $E_2 = \dfrac{F\cos\theta}{A}$

$$\therefore \quad E_2 = E_1 \cos\theta$$

Combining all these factors together, we get

$$\boxed{E = \frac{I\cos\theta}{r^2}}. \text{ The unit is lumens per unit area.}$$

Example 1.1. *A 250 V lamp has a total flux of 1500 lumens and takes a current of 0.4 A. Calculate :*

(*i*) *Lumens per watt.* (*ii*) *M.S.C.P. per watt.*

Solution. Given : $V = 250$ volts ; $F = 1500$ lumens ; $I = 0.4$ A

Mean spherical candle power of lamp,

$$\text{M.S.C.P.} = \frac{F}{4\pi} = \frac{1500}{4\pi} = 119.4$$

$$(i)\ \textbf{Lumens per watt} = \frac{\text{Output of lamp in lumens}}{\text{Wattage of lamp in watts}} = \frac{1500}{250 \times 0.4} = 15. \quad \textbf{(Ans.)}$$

$MSCP = \frac{F}{4\pi}$

(*ii*) **M.S.C.P. per watt** $= \frac{\text{M.S.C.P. of lamp}}{\text{Wattage of lamp}} = \frac{119.4}{250 \times 0.4} =$ **1.194. (Ans.)**

Example 1.2. *A 0.3 metre diameter diffusing sphere of opal glass having 15% absorption, encloses an incandescent lamp with a luminous flux of 4500 lumens. Calculate average luminance of the sphere.*

Solution. *Given :* $d = 0.3$ m ; Lamp = 4500 lumens

Flux 1 emitted by the sphere, $F_{sphere} = (1 - 0.15) \times 4500 = 3825$ lumens

Surface area of the sphere $= 4\pi r^2 = 4\pi \times \left(\frac{0.3}{2}\right)^2 = 0.2827 \text{ m}^2$

$\therefore$ Average luminance of sphere $= \frac{F_{sphere}}{\text{Surface area of sphere}}$

$= \frac{3825}{0.2827} =$ **13530 lumens/m². (Ans.)**

Example 1.3. *A filament lamp of 500 W is suspended at a height of 4.5 metres above the working plane and gives uniform illumination over an area of 6 m diameter. Assuming an efficiency of the reflector as 70% and efficiency of lamp as 0.8 watt per candle power, determine the illumination on the working plane.*

$\eta_{lamp} = \frac{\text{luminous flux}}{\text{power input}}$

Solution. Wattage of the filament lamp = 500 W

Height of the lamp above the working plane = 4.5 m

Diameter of the uniformly illuminated area = 6 m

Efficiency of reflector = 70%

Efficiency of lamp = 0.8 W per candle power

Illumination on the working plane :

Candle power of the lamp $= \frac{500}{0.8} = 625$ C.P.

Luminous output of lamp $= 4\pi \times 625 = 2500\,\pi$ lumens

Flux emitted by the reflector = Efficiency of reflector × Total luminous output of the lamp

$= 0.7 \times 2500\,\pi = 1750\,\pi$ lumens

Area of working plane $= \frac{\pi}{4} \times (6)^2 = 9\pi \text{ m}^2$.

$\therefore$ Illumination on the working plane $= \frac{1750\,\pi}{9\,\pi} =$ **194.44 Lumens/m². (Ans.)**

Example 1.4. *The candle power of a lamp is 120. A plane surface is placed at a distance of 2.5 metres from this lamp. Calculate the illumination on the surface when it (i) normal, (ii) inclined to 45°, and (iii) Parallel to rays.*

Solution. (*i*) $E = \frac{\text{C.P.}}{d^2} = \frac{120}{(2.5)^2} =$ **19.2 lux. (Ans.)**

(*ii*) $E = \frac{\text{C.P.}}{d^2} \times \cos 45° = \frac{120}{(2.5)^2} \times \cos 45° =$ **13.58 lux. (Ans.)**

(*iii*) $E = 0$, since the rays of light are parallel to the surface, they cannot illuminate it. **(Ans.)**

Example 1.5. *Derive the relation to find the illumination at any point on the plane surface due to light source suspended at height h from the plane surface.*

Solution. Refer to Fig. 1.9. Consider a point P on the plane surface AB where illumination due to light source S of candle power C.P. at a height h from the surface AB is to be determined.

Let d be the distance between source S and point P.

Then, $\cos\theta = \dfrac{h}{d}$ or $d = \dfrac{h}{\cos\theta}$

Illumination at point P, by laws of illumination

$$= \frac{\text{C.P.}}{d^2}\cos\theta = \frac{\text{C.P.}}{(h/\cos\theta)^2}\cos\theta = \frac{\text{C.P.}}{h^2}\cos^3\theta,$$

and illumination at any point O, *vertically below the source of light*

$$= \frac{\text{C.P.}}{h^2}.$$

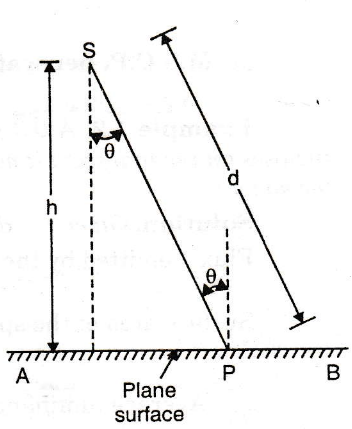

Fig. 1.9

Hence *illumination at any point on a plane is* $\cos^3\theta$*-times of illumination at a point just vertically below the light source, where* θ *is the angle between the normal to the surface at the point and rays of light.*

Example 1.6. *A 500 W lamp having M.S.C.P. of 800 is suspended 3 m above the working plane :*

(*i*) *Illumination directly below the lamp at the working plane.*

(*ii*) *Lamp efficiency.*

(*iii*) *Illumination at a point 2.4 m away on the horizontal plane from vertically below the lamp.*

Solution. Wattage of the lamp = 500 W

M.S.C.P. of the lamp, $I = 800$

Height of the lamp, $h = 3$ m

(*i*) **Illumination directly below the lamp at the working plane :**

Illumination directly below the lamp,

$$E_A = \frac{I}{h^2} = \frac{800}{3^2} = \mathbf{88.9\ lux.}\quad \textbf{(Ans.)}$$

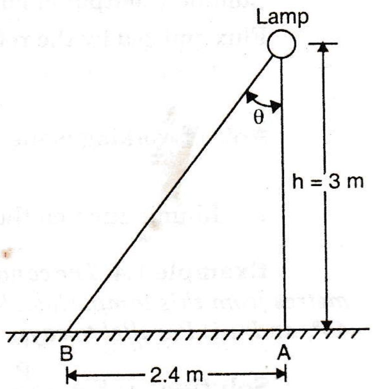

Fig. 1.10

(*ii*) **Lamp efficiency :**

$$\text{Lamp efficiency} = \frac{\text{Luminous flux}}{\text{Power input}} = \frac{4\pi \times \text{M.S.C.P.}}{500} = \frac{4\pi \times 800}{500}$$

$$= \mathbf{20.1\ lumens/watt.}\quad \textbf{(Ans.)}$$

(*iii*) **Illumination at a point 2.4 m away :**

Illumination at a point 2.4 m away on the horizontal plane from vertically below the lamp,

$$E_B = \frac{I}{h^2}\cos^3\theta$$

Here, $$\cos\theta = \frac{3}{\sqrt{3^2 + 2.4^2}} = 0.7808$$

$\therefore$ $$E_B = \frac{800}{3^2} \times (0.7808)^3 = \mathbf{42.3\ lux.}\quad \textbf{(Ans.)}$$

Example 1.7. *A lamp with reflector is mounted 10 m above the centre of a circular area of 20 m diameter. If the combination of the lamp and reflector gives a uniform C.P. of 800 over the circular area, determine the maximum and minimum illumination produced on the area.*

(Panjab University)

Solution. Candle power of the lamp, C.P. = 800

Height of the lamp, $h = 10$ m

Diameter of the circular area = 20 m

The *maximum illumination* will occur *directly below the lamp i.e.*, at point A and

$$= \frac{\text{C.P.}}{h^2} = \frac{800}{10^2} = \mathbf{8\ lux.}\quad \textbf{(Ans.)}$$

The minimum illumination will occur at the periphery of the circular area *i.e.*, at point B and

$$= \frac{\text{C.P.}}{h^2}\cos^3\theta$$

$$= \frac{800}{10^2} \times \left(\frac{10}{\sqrt{10^2 + 10^2}}\right)^3 = \mathbf{2.83\ lux.}\quad \textbf{(Ans.)}$$

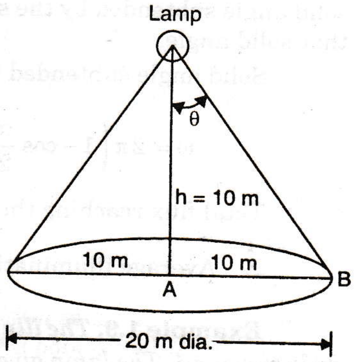

Fig. 1.11

Example 1.8. *A lamp having a uniform C.P. of 300 in all directions is provided with a reflector which directs 60 per cent of the total light uniformly on to a circular area of 12 m diameter. The lamp is 5 m above the area. Calculate :*

(*i*) *The illumination at the centre and edge of the surface with and without reflector.*

(*ii*) *The average illumination over the area without the reflector.*

Solution. Candle power of the lamp C.P. = 300

Height of the lamp, $h = 5$ m

Efficiency of the reflector = 60%

(*i*) **The illumination at the centre without reflector.**

The illumination at the centre

$$= \frac{\text{C.P.}}{h^2} = \frac{300}{5^2} = \mathbf{12\ lux.}\quad \textbf{(Ans.)}$$

The illumination at the edge of the surface with and without the reflector :

The illumination at the edge of the surface *without reflector.*

$$= \frac{\text{C.P.}}{h^2}\cos^3\theta = \frac{300}{5^2} \times \left(\frac{5}{\sqrt{5^2 + 6^2}}\right)^3$$

$= \mathbf{3.15\ lux.}$ **(Ans.)**

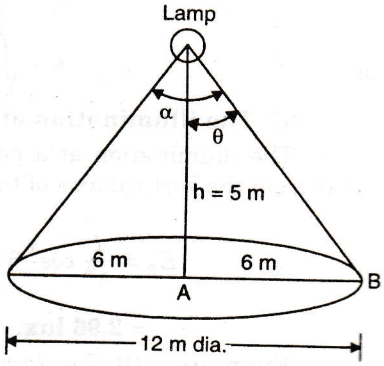

Fig. 1.12

Comparison of different light sources :

The comparison of incandescent lamps, fluorescent lamps, mercury vapour lamps and sodium vapour lamps is given below :

S. No.	*Aspect*	***Incandescent lamps***	***Fluorescent lamps***	***Mercury vapour lamps***	***Sodium vapour lamps***
1.	*Starting*	They have instantaneous start and become momentarily off when supply goes off.	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.	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 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.
2.	*Colour of light*	Very near the natural.	Varies with the phosphor coating.	They suffer from colour distortion.	Yellowish, colour distortion is produced.
3.	*Installation cost ; running cost*	Minimum ; maximum.	maximum ; minimum.	High but lesser than that of fluorescent lamps ; Much less than incandescent lamps but higher than fluorescent tubes.	Maximum, less than for filament lamps but more than for fluorescent lamps.
4.	*Average life*	1000 hours.	4000 hours.	3000 hours.	3000 hours.
5.	*Efficiency*	10 lm/W.	40 lm/W.	40 lm/W.	60 – 70 lm/W.
6.	*Stroboscopic effect*	No.	Yes.	Yes	Yes
7.	*Applications*	Automobiles, trains, emergency lights, aeroplanes, signals for railways ; domestic, industrial street lighting and flood lights etc.	• Semidirect lighting, domestic, industrial, commercial, roads and halls etc. • Their use is confined to mains voltage or complicated inverter circuits which convert 12 V D.C. into high voltage D.C.	• Suitable for open space like yards, parks and highway lighting etc. • Suitable for vertical position of working.	Very suitable for street lighting purposes ; their position of working is horizontal (*Not* suitable for local lighting).

1.10. LIGHTING SCHEMES

1.10.1. Diffusing and Reflecting Surfaces

When light falls on polished metallic surfaces or silvered surfaces, then most of it is reflected back according to the laws of reflection [Fig. 1.46 (*a*)] *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.***

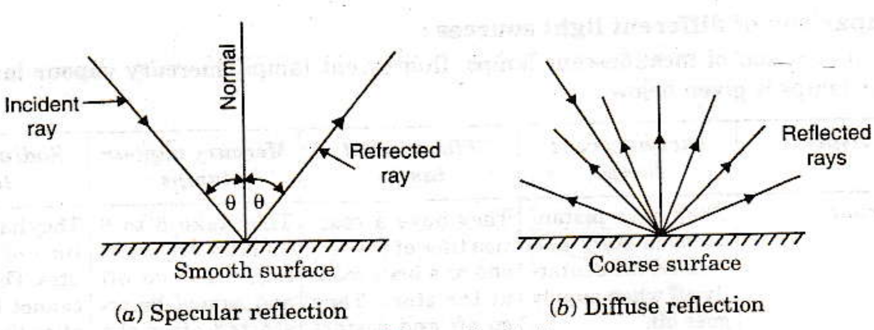

Fig. 1.46. Types of reflections.

If the light is incident on coarse surfaces like paper, frosted glass, painted ceiling etc. then it is scattered in all directions [Fig. 1.46 (*b*)], 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'.*

The *ratio of reflected light energy to the incident light energy is known as* **reflection factor** (also known as *reflection ratio* or coefficient of reflection of a surface).

- Perfect mirror surfaces and perfect diffusing surfaces are ideals that do not exist in nature. *The reflection from any surface is partly specular and partly diffuse*, the proportion varying widely. A surface that is almost free from mirror reflection is called a *mat* surface.

1.10.2. Requirements of Good Lighting

Good lighting is one which provides *visual comfort.* Visual comfort enhances the efficiency of a workman.

Usually good lighting is often confused with high illumination levels. The factors which are to considered are *minimum glare* and *brightness-contrast.*

- Light sources should be properly shielded by luminaries and mounted above the normal line of sight. Reflected glare is to be avoided, by mounting luminaries with respect to equipment, so that the reflected glare is directed away from the observer. Use of diffusing absorbing fixers reduce glare.

1.10.3. Types of Lighting Schemes

A good lighting scheme results in an attractive and commanding presence of objects and enhances the architectural style of the interior of a building. Due to the comfortable illumination, people would be in a position to do their work quickly, accurately and easily.

Different lighting schemes may be *classified* as follows :

1. Direct lighting
2. Semi-direct lighting
3. Semi-indirect lighting
4. Indirect lighting
5. General diffusing lighting.

Fig. 1.47 shows different types of lighting arrangements.

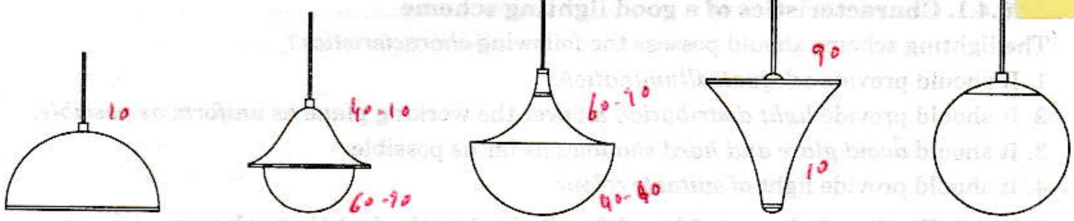

Fig. 1.47. Different types of lighting arrangements.

1. **Direct lighting.** Refer to Fig. 1.47 (*a*).

- It is most commonly used type of lighting scheme.
- In this system more than 90% of total light flux is made to fall directly on the working plane with the help of deep reflectors.
- Direct lighting, though most efficient, is *liable to cause glare and hard shadows.*
- It is mainly used for *industrial and general outdoor lighting.*

2. **Semi-direct lighting.** Refer to Fig. 1.47 (*b*).

- In this system 60 to 90% of the total light flux is made to fall downwards directly with the help of semi-direct reflectors, remaining light is to be used to illuminate the ceiling and walls.
- 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.

3. **Semi-indirect lighting.** Refer to Fig. 1.47 (*c*).

- In this system 60 to 90% of the total light flux is made to fall downwards directly with the help of semi-direct reflectors.
- It is mainly used for *indoor light decoration purposes.*

4. **Indirect lighting.** Refer to Fig. 1.47 (*d*).

- In this system more than 90% of total light flux is thrown upwards to the ceiling for diffuse reflection by using inverted or bowl reflectors. In such a system the ceiling acts as the light source, and the glare is reduced to minimum.
- This system provides a *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.

5. **General diffusing lighting.** Refer to Fig. 14.7 (*e*)

- In this lighting system lamps made of diffusing glass are used which give nearly equal illumination in all directions.

1.10.4. Design of Lighting Scheme

1.10.4.1. Characteristics of a good lighting scheme

The lighting scheme should possess the following *characteristics* :

1. It should provide *adequate illumination.*
2. It should provide *light distribution* all over the working plane as *uniform as possible.*
3. It should *avoid glare and hard shadows* as far as possible.
4. It should provide light of *suitable colour.*

1.10.4.2. Factors to be considered for designing the lighting scheme

While designing the lighting scheme the following *factors* should be considered :

1. Intensity of illumination.
2. Selection of luminaires.
3. Size of the room.
4. Mounting height and spacing of fittings.
5. Conditions of use.

1. **Intensity of illumination.** The intensity of illumination required for different types of work differ. The recommended levels of illumination for various occupancies is shown in Table 1.1 below :

Table 1.1. Recommended levels of illumination

S. No.	*Occupancy*	*Illumination (lux)*
1.	*Factories and Workshops*	
	(*i*) Rough work, *e.g.,* frame assembly of heavy machinery	150
	(*ii*) Medium work, *e.g.,* machined parts, engine assembly, vehicle body assembly	300
	(*iii*) Fine work, *e.g.,* radio and telephone equipment, type-writer and office machinery assembly	700
	(*iv*) Very fine work, *e.g.,* assembly of very small precision mechanisms, instruments	1500
2.	*Power Houses*	
	(*i*) Boiler house, turbine house, conveyor house, switchgear and transformer chambers	100
	(*ii*) Control rooms	300
3.	*Offices*	
	(*i*) Reception	150
	(*ii*) Conference room, general offices, typing rooms	300
	(*iii*) Drawing offices	400
4.	*Schools and Colleges*	
	(*i*) Classrooms, lecture halls, workshops, library reading tables, laboratories	300
	(*ii*) Sewing rooms, drawing halls, art rooms	500
	(*iii*) Common room, stairs	150
5.	*Hospitals*	
	(*i*) Waiting rooms, wards, casualty	150
	(*ii*) Dispensaries, laboratories, operation theatres (general)	300
	(*iii*) Operation table	Special lighting

6.	*Hotels and Restaurants*	
	(*i*) Reception, dining rooms, bedrooms, lounges, stairs	150
	(*ii*) Accounts, writing desk, dressing table	300
7.	*Shops*	
	(*i*) General areas	300
	(*ii*) Stock areas	150
	(*iii*) Shop window	Special lighting
8.	*Houses*	
	(*i*) Living room-general	150
	(*ii*) Living room-home work or sustained reading	300
	(*iii*) Kitchen, bedrooms, bathrooms etc.	150
9.	*Storage places*	
	(*i*) Loading and unloading	40
	(*ii*) General stores	100
	(*iii*) Stores of very small items	300
10.	*Sport grounds*	
	(*i*) Stadium	300
	(*ii*) Football field	200
	(*iii*) Tennis court	400
11.	*Canteens*	200

2. **Selection of luminaires :**

A luminaire (light fitting) is the apparatus which distributes, filters or transforms the light given by a lamp or lamps. It includes all the items necessary for fixing and protecting these lamps and for connecting them to the supply circuit.

- The choice of lamps for different types of occupancies differ.
  — Tubular fluorescent lamps or tungsten filament lamps can be used when lighting is to be done in small premises.
  — In case of large premises, the lighting can be carried out by using high intensity sources such as mercury or sodium discharge lamps.
- The linear output of the lamps can also be modified by using suitable reflectors and diffusers. Depending upon the type of illumination required (direct, indirect, diffusing etc.) the type of reflector is decided.

3. **Size of the room :**

The lumen output of the sources is not fully utilized at the work place. Part of it is lost in the fittings. Some part is directed to the walls and ceiling where part will be absorbed and part reflected. This is taken into account by a factor known as **"utilisation factor"** or **"coefficient of utilisation"**.

Coefficient of utilization depends on the following *factors :*

(*i*) Lumen output of the fitting,

(*ii*) Size and shape of the room,

(*iii*) Reflection factors of walls and ceiling,

(*iv*) Height of the ceiling,

(*v*) Arrangement of the fitting etc.

Co-efficient of utilisation for different fittings is given in Table 1.2.

Table 1.2. Co-efficeint of utilization for different fittings

S. No.	*Type of fittings*	*Utilisation factor*	
		Big rooms with light coloured walls and ceilings	*Small rooms with dark walls and ceilings*
1.	*Standard direct reflectors*	0.64	0.24
2.	*Fluorescent lamp fittings*	0.64	0.24
3.	*Semi-direct fittings*	0.56	0.20
4.	*Enclosed sphere or diffusing fittings*	0.56	0.15
5.	*Indirect fittings*	0.40	0.09

4. **Mounting height and spacing of fittings.** The term "general lighting" implies that the illumination at working level should not vary substantially throughout the room. Therefore, it is apparent that the fitting for general lighting should be so placed that the illumination received from each fitting overlaps and builds up that of its neighbours. *The distance of a light source from the wall should be equal to one half the distance between two adjacent light sources. Also distance between light fittings should not exceed 1.5 times the mounting height.*

5. **Conditions of use.** Conditions of use of light fitting vary with different types of installations. Dust and dirt of the surroundings may get deposited on the light fittings and hence deteriorate the lamp efficiency. If regular periodic cleaning is adopted and assuming good atmospheric conditions the value of ***"maintenance factor"*** may be taken as 0.8. But for dusty and dirty atmosphere, the factor may be as low as 0.4. Another term ***"depreciation factor"*** is also used which is the *reciprocal of maintenance factor* (*i.e.*, Depreciation factor = 1/Maintenance factor).

1.10.5. Method of Lighting Calculations

Out of several methods employed for lighting calculations, some of them are :

1. Watt per square metre method.
2. Lumen or light flux method.
3. Point-to-point or Inverse-square law method.

1. **Watt per square method :**

- This method is *very handy for rough calculation or checking.*
- It consists in making an allowance of watts per square metre of area to be illuminated according to the illumination desired on the assumption of an average figure of overall efficiency of the system.

2. **Lumen or light flux method.** This method is applicable to those cases where the sources of light are such as to produce an approximate uniform illumination over the working plane or where an average value is required.

Total lumens received on working plane

= No. of lamps × wattage of each lamp × efficiency of each lamp (in terms of lumens/watt) × coefficient of utilisation × maintenance factor.

3. **Point-to-point or inverse-square law method :**

- *This method is applicable where the illumination at a point due to one or more sources of light is required, the candle power of the sources in the particular direction under consideration being known.*

- When a polar curve of lamp and its reflector giving candle powers of the lamp in different directions is known, the illumination at any point within the range of the lamp can be calculated from the inverse square law. If two and more than two lamps are illuminating the same working plane, the illumination due to each can be calculated and added.
- This method is not much used (because of its complicated and cumbersome applications) ; it is employed only in some special problems, such as *flood lighting, yard lighting etc.*

1.10.6. Calculation of Illumination

The following empirical formula can be used to calculate the illumination :

$$N = \frac{E \times A}{O \times UF \times MF} \quad ...(1.6)$$

where, N = Number of fittings needed,

E = Required illumination (lux),

A = Working area (square metres),

O = Luminous flux produced per lamp (lumens),

UF = Utilisation factor (or co-efficient of utilisation), and

MF = Maintenance factor.

The luminous flux of different types of lamps is given in the table 1.3 given below :

Table 1.3. Luminous flux of various types of lamps

Discription of the lamp			*Lumen efficiency per watt.*	*Lumen output at 230 volts*
1.	*Fluorescent lamp* :	80 watts—5 ft. warm white	58	4640
		40 watts—4 ft. warm white	60	2400
		20 watts—2 ft. warm white	46	920
2.	*Incandescent lamp* :	40 watts	10	400
		60 watts	12	720
		100 watts	13.80	1380
		150 watts	14	2100
		200 watts	14.75	2950
		300 watts	16	4800
		500 watts	16.9	8450
		1000 watts	19	19000
3.	*Mercury discharge lamps* :	80 watts	31	2480
		125 watts	31	3875
		250 watts	35	8750
		400 watts	39	15600
4.	*Sodium discharge lamps* :	45 watts	50	2250
		60 watts	57	3420
		85 watts	65	5525
		140 watts	70	9800

√ **Example 1.24.** *A small assembly shop 16 m long, 10 m wide, and 3 m upto trusses is to be illuminated to a level of 200 lux. The utilization and maintenance factors are 0.74 and 0.8 respectively. Calculate the number of lamps required to illuminate the whole area if the lumen output of the lamp selected is 3000 lumens.*

Solution. Working area, $A = 16 \text{ m} \times 10 \text{ m} = 160 \text{ m}^2$

Required illumination, $E = 200$ lux

Lumens output of one lamp, $O = 3000$ lumens

Utilization factor, $UF = 0.74$

Maintenance factor, $MF = 0.8$.

Number of lamps required, N :

$$N = \frac{E \times A}{O \times UF \times MF} \quad \text{...[Eqn. (1.6)]}$$

$$= \frac{200 \times 160}{3000 \times 0.74 \times 0.8} = 18. \quad \textbf{(Ans.)}$$

Example 1.25. *An office 25 m × 12 m is illuminated by 40 W incandescent lamps of lumen output 2700 lumens. The average illumination required at the work place is 200 lux. Calculate the number of lamps required to be fitted in the office. Assume utilization and depreciation factors as 0.65 and 1.25 respectively.*

Solution. Working area, $A = 25 \text{ m} \times 12 \text{ m} = 300 \text{ m}^2$

Required illumination, $E = 200$ lux

Lumens output of the lamp, $O = 2700$ lumens

Utilization factor, $UF = 0.65$

Depreciation factor, $= 1.25$

∴ Maintenance factor, $MF = \frac{1}{1.25} = 0.8$

Number of lamps required, N :

$$N = \frac{E \times A}{O \times UF \times MF} = \frac{200 \times 300}{2700 \times 0.65 \times 0.8} = 4.3. \quad \textbf{(Ans.)}$$

Example 1.26. *An illumination of 25 lux is to be produced on the floor of a room 12 m × 9 m. 18 lamps are required to produce this illumination in the room, if 50% of the emitted light falls on the floor. What is the power of the lamp in candela ?*

Assume maintenance factor as unity.

Solution. *Given* : $E = 25$ lux ; $A = 12 \times 9 = 108 \text{ m}^2$; $N = 18$ lamps ; $UF = 0.5$; $MF = 1$.

We know that, $$N = \frac{E \times A}{O \times UF \times MF} \quad \text{or} \quad 18 = \frac{25 \times 108}{O \times 0.5 \times 1}$$

∴ Lumen output the lamp, $O = \frac{25 \times 108}{18 \times 0.5 \times 1} = 300$ lumens

Hence, *power of the lamp in candela* $= \frac{300}{4\pi} = \textbf{24 cd.}$ **(Ans.)**

√ **Example 1.27.** *A football pitch 120 m × 60 m is to be illuminated for night play by similar bank 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 percent of the total light emitted reaches the playing pitch and that illumination of 1000 lm/m² 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.* **(Bombay University)**

Solution. *Given* : $A = 120 \times 60 = 7200\ m^2$; Rating of each lamp = 1000 W ; No. of towers = 12 ; Percent of total light reaching the working plane = 40% ; E = 1000 lm/m² ; luminous efficiency of each lamp = 30 lm/W.

Number of lamps on each tower :

Total luminous flux required to be produced $= \frac{E \times A}{0.4} = \frac{1000 \times 7200}{0.4} = 18 \times 10^6$ lm

Luminous flux contributed by each tower $= \frac{18 \times 10^6}{12} = 1.5 \times 10^6$ lm

Output of each 1000 W lamp $= 30 \times 1000 = 30000$ lm

∴ No. of 1000 W lamps on each tower $= \frac{15 \times 10^6}{3000} =$ **50. (Ans.)**

Example 1.28. *It is desired to illuminate a drawing hall with an average illumination of about 250 lux. The area of the hall is 30 m × 20 m. The lamps are to be fitted at 5 m height. Find out the number and size of incandescent lamps required for an efficiency of 12 lumens/watt. Utilisation factor = 0.4 and maintenance factor = 0.85.*

Solution. *Given* : $E = 250$ lux ; $A = 30 \times 20 = 600\ m^2$; $UF = 0.4$; $MF = 0.85$

Gross lumens required $= \frac{E \times A}{UF \times MF} = \frac{250 \times 600}{0.4 \times 0.85} = 441176$

∴ Total wattage required $= \frac{441176}{12} = 36765$ W

Taking 8 lamps along the length giving a spacing of $\frac{30}{8}$ m *i.e.,* 3.75 m lengthwise and 5 lamps along width giving spacing of $\frac{20}{5}$ m *i.e.,* 4 m width wise.

∴ Total number of lamps $= 8 \times 5 =$ **40. (Ans.)**

Wattage of each lamp $= \frac{36765}{40} \approx$ **1000 W. (Ans.)**

These 40 lamps will be arranged as shown in Fig. 1.48.

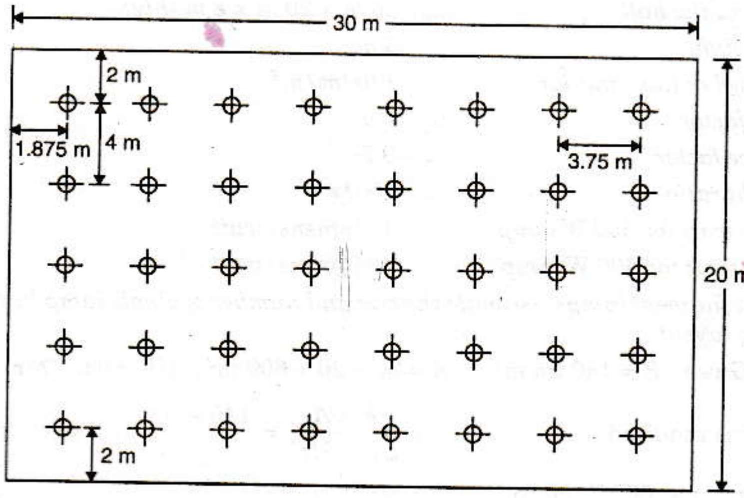

Fig. 1.48

Example 1.29. *Estimate the number and wattage of lamps which would be required to illuminate a workshop space 60 m × 15 m by means of lamps mounted 5 metres above the working plane. The average illumination required is 100 lux. Coefficient of utilisation = 0.42 ; Maintenance factor = 0.8 ; Luminous efficiency = 16 lm/W ; space-height ratio = unity.* **(Madras University)**

Solution. *Given* : $A = 60 \times 15 = 900\ m^2$; $E = 100$ lux ; $UF = 0.42$; $MF = 0.78$;

Luminous efficiency = 16 lm/W

Gross lumens required $= \dfrac{E \times A}{UF \times MF} = \dfrac{100 \times 900}{0.42 \times 0.78} = 274725$ 0.8

Total wattage required $= \dfrac{274725}{16} = 17170$ 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 $= 12 \times 3 = 36$

Wattage of each lamp $= \dfrac{17170}{36} = 477$ W

We will take the nearest standard lamp of **500 W.** The arrangement of the lamps will be as shown in the Fig. 1.49.

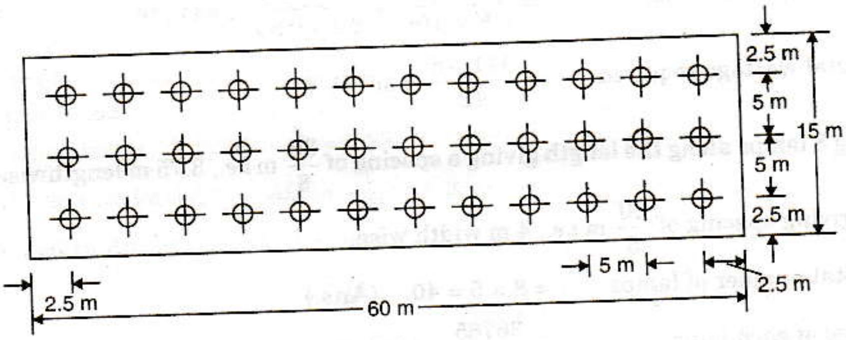

Fig. 1.49

Example 1.30. *The following data relate to the lighting scheme of an engineering college :*

Dimensions of the hall	...	*30 m × 20 m × 8 m (high)*
Mounting height	...	*5 m*
Required level of illumination	...	*140 lm / m²*
Utilisation factor	...	*0.6*
Maintenance factor	...	*0.75*
Space-height ratio	...	*Unity*
Lumens per watt for 300 W lamp	...	*13 lumens / watt*
Lumens per watt for 500 W lamp	...	*16 lumens / watt*

Using metal filament lamps, estimate the size and number of single lamp luminaries and also draw their spacing layout.

Solution. *Given* : $E = 140\ lm/m^2$; $A = 30 \times 20 = 600\ m^2$; $UF = 0.6$; $MF = 0.75$

Gross lumens required $= \dfrac{E \times A}{UF \times MF} = \dfrac{140 \times 600}{0.6 \times 0.75} = 186667$ lm

Lumen output per 500 W lamp $= 500 \times 16 = 8000$

$\therefore$ No. of 500 W lamps required $= \dfrac{186667}{8000} = 24$

Similarly, no. of 300 W lamps required $= \dfrac{186667}{300 \times 13} = 48$

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 length and width of the hall as shown in Fig. 1.50.

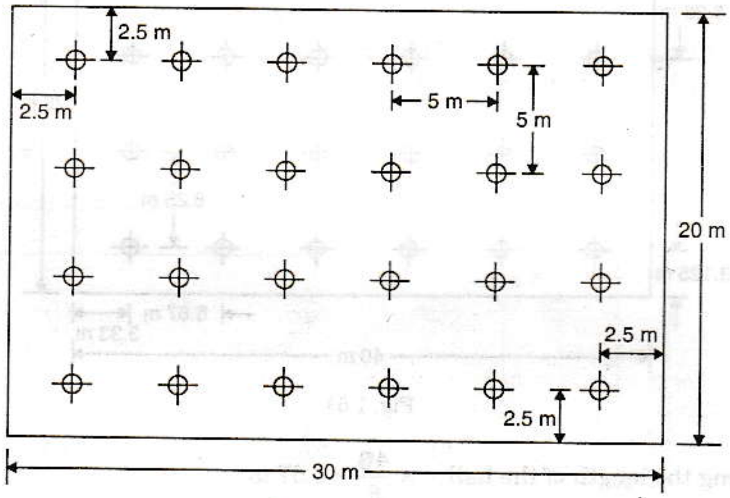

Fig. 1.50

Example 1.31. *A drawing hall 40 m × 25 m × 6 m is to be illuminated with metal filament gas-filled lamps to an average illumination of 90 lm / m² 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 utilisation of 0.5, depreciation factor of 1.2 and space-height ratio of 1.2.*

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

(Bombay University)

Solution. *Given* : $A = 40 \times 25 = 1000\ \text{m}^2$; $E = 90\ \text{lm/m}^2$; $UF = 0.5$, $MF = \dfrac{1}{DF} = \dfrac{1}{1.2}$;

Space-height ratio = 1.2.

Grass lumens required $= \dfrac{E \times A}{UF \times MF} = \dfrac{90 \times 1000}{0.5 \times (1/1.2)} = 216000$ lm

Lumen output of each 200 W lamp $= 200 \times 16 = 3200$ lm

Lumen output of each 300 W lamp $= 300 \times 18 = 5400$ lm

Lumen output of each 500 W lamp $= 500 \times 20 = 10000$ lm

No. of 200 W lamps required $= \dfrac{216000}{3200} = 67$

No. of 300 W lamps required $= \dfrac{216000}{5400} = 40$

No. of 500 W lamps required $= \dfrac{216000}{10000} = 22$

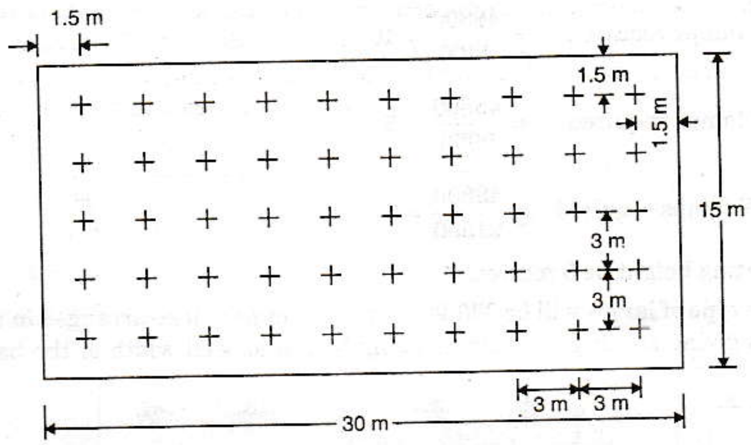

Fig. 1.53

1.11. STREET LIGHTING

The street lighting entails the following *main objectives :*

(*i*) To make the traffic and obstructions on the road clearly visible in order to promote safety and convenience.

(*ii*) To enhance the community value of the street.

(*iii*) To make the street more attractive.

The following two general principles are employed in the design of street lighting installations :

1. Diffusion principle.
2. Specular reflection principle.

1. **Diffusion principle :**

- In this case the lamps fitted with suitable reflectors are employed. The design of the reflectors is such that they may *direct the light downwards and spread as uniformly as possible over the surface of the road.* In order to avoid glare the reflectors are made to have a cut-off between 30° to 45° so that the filament is not visible except underneath it.
- The diffusing nature of the road surface causes the reflection of a certain proportion of the incident light in the direction of the observer, and therefore the road surface appears bright to the observer.
- For calculating the illumination at any point on the road surface, point-to-point or inverse-square law method is employed. Over certain proportions of the road the surface is illuminated from two lamps and the resultant illumination is the sum of the illuminations due to each lamp.

2. **Specular reflection principle :**

- Here, the reflectors are curved upwards so that the light is thrown on the road at a very large angle of incidence. In this method, the requirement of a pedestrian, who requires to see objects in his immediate neighbourhood, is also fulfilled.
- This method is *more economical*, in comparison to diffusion method of lighting. However, it has the demerit that it *produces glare* for the motorists.

Illumination level, mounting height and types of lamps for street lighting :

- In *class A installations* (*e.g.*, important shopping centres and road junctions) the illumination level of 30 lm/m^2 is required, whereas for *poorly lighted suburban streets*, illumination level of 4 lm/m^2 is sufficient. For an *average well lighted street* an illumination level of 8 to 15 lm/m^2 is required.
- Normal spacing for standard lamps is 50 metres with a *mounting height of 8 metres.*
- For street lighting purposes, mercury vapour and sodium discharge lamps have been found to have certain particular advantages ; the most important of these is the *low power consumption for a given amount of light*, which inspite of the higher cost of the lamps, makes the overall cost of an installation with discharge lamps less than that employing filament lamps.

— The colour and monochromatic nature of light produced by discharge lamps does not matter much in street light installations.

- Lamp posts should be fixed at the junction of roads.

1.12. FACTORY LIGHTING

In an industrial establishment an adequate amount of light produces the following *good effects :*

1. The productivity of labour is increased.
2. The quality of work is improved.
3. Number of work stoppages are reduced.
4. Accidents are reduced.

A factory-lighting installation, in common with indoor equipments, should provide the following :

(*i*) Adequate illumination on the working plane ;

(*ii*) Good distribution of light ;

(*iii*) Simple and easily cleaned fittings ;

(*iv*) Avoid glare (from the lamp itself as well as from any polished surface, which may be within the line of vision)

General, local and emergency lighting :

- In factories and workshops the usual scheme is to mount a number of lamps at a sufficient height so that uniform distribution of light over the working the plane is obtained. In large machine shops the height is governed by the necessity of keeping the lamps above the travelling crane.
- On some points fairly intense illumination is required. For this purpose local lighting can be provided by means of adjustable fittings attached to the machine or bench in question or mounted on portable floor standards. Such lamps should be mounted in deep reflectors to avoid the glare.
- It is very desirable to provide auxiliary lighting from the sources other than the main electric supply preferably from batteries or from small petrol driven generator set. If however, emergency light circuits are operated from main electric supply, these should be completely separated from main lighting circuit