Unit-2: Illumination System

Important Terms:

Light: It is defined as the radiation energy from a hot body that produces the visual sensation upon the human eye. It is usually denoted by Q, expressed in lumen-hours, andis analogous to watt-hour.

Luminous flux: it is defined as the total quantity of light energy emitted per second from a luminous body. It is represented by the symbol F and is measured in lumens. The concept of luminous flux helps us to specify the output and efficiency of a given light source.

Luminous intensity: luminous intensity in any given direction is the luminous flux emitted by the source per unit solid angle, measured in the direction in which the intensity is required. It is denoted by symbol I and is measured in candela(cd) or lumens/steradian.

If **F** is the luminous flux radiated out by the source within a solid angle of ω steradian in any particular direction then $I = F/\omega$ lumens/steradian or candela (cd).

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

Lumens = candle power X solid angle = cp X ω

The total lumens given out by the source of one candela are 4π lumens.

Candle power: Candle power is the light radiating capacity of a source in a given direction and is defined as the number of lumens given out by the source in a unit solid angle in a given direction. It is denoted by a symbol **C.P.**

C.P. = lumens/ω

Illumination: When the light falls upon any surface, the phenomenon is called the illumination. It is defined as the number of lumens, falling on the surface, per unit area. It is denoted by the symbol E and is measured in lumens per square meter or meter-candle or lux.

If a flux of **F** lumens falls on a surface of area **A**, then the illumination of that surface is

$$E = F/A \text{ lumens/m}^2 \text{ or lux}$$

Lux or meter candle: It is the unit of illumination and is defined as the luminous flux falling per square meter on the surface which is everywhere perpendicular to the rays of light from a source of one candle power and one meter away from it.

Foot candle: It is also the unit of illumination and is defined as the luminous flux falling per square foot on the surface which is everywhere perpendicular to the rays of light from a source of one candle power and one foot away from it.

$$1 \text{ foot-candle} = 1 \text{ lumen/ft}^2 = 10.76\text{-meter candle or lux}$$

Candle: It is the unit of luminous intensity. It is defined as $1/60^{th}$ of the luminous intensity per cm^2 of a black body radiator at the temperature of solidification of platinum (2,043^{0}K).

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

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

Mean hemispherical candle power: (M.H.S.C.P) It is defined as the mean of candle powers in all directions above or below the horizontal plane passing through the source of light.

Reduction factor: The reduction factor of a source of light is the ratio of its mean spherical candle power to its mean horizontal candle power.

$$\textbf{\textit{reduction factor}} = \frac{M.S.C.P.}{M.H.C.P.}$$

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

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

Brightness: When the eye receives a great deal of light from an object we say it is bright, and brightness is an important quantity in illumination. It is all the same whether the light is produced by the object or reflected from it.

Brightness is defined as the luminous intensity per unit projected area of either a surface source of light or a reflecting surface and is denoted by L.

If a surface area A has an effective luminous intensity of I candelas in a direction θ to thenormal, then the brightness (luminance) of that surface is

$$L = \frac{I}{a\ cos\theta}$$

The unit of brightness is candela/m^2 (nits), candela/cm^2 (stilb) or candela/ft^2

Glare:- The size of the opening of the pupil in the human eye is controlled by its iris. If the eye is exposed to a very bright source of light the iris automatically contacts in order to produce the amount of light admitted and prevent damaged to retina this reduces the sensitivity, so that other objects within the field of vision can be only imperfectly seen. In other words glare maybe defined as brightness with in the field of vision of such a character as the cause annoyance discomfort interference with vision.

Space height ratio:- it is defined as the ratio of distance between adjacent lamps and height of their mountains.

$$Space\ to\ \text{height}\ ratio = \frac{\text{h}orizontal\ distance\ between\ two\ adjacent\ lamps}{mounting\ \text{height}\ of\ lamps\ above\ working\ plane}$$

Utilization factor or co-efficient of utilization:- It is defined as the ratio of total lumens reaching the working plane to total lumens given out by the lamp.

$$Utilization\ Factor = \frac{total\ lumens\ reaching\ the\ working\ plane}{total\ lumens\ given\ out\ by\ the\ lamp}$$

Maintenance factor: Due to accumulation of dust, dirt and smoke on the lamps, they emit less light than that they emit when they are new ones and similarly the walls and ceilings e.t.c. after being covered with dust, dirt and smoke do not reflect the same output of light, which is reflected when they are new. Lumens

The ratio of illumination under normal working conditions to the illumination when the things are perfectly clean is known as maintenance factor.

$$Mintenance\ Factor = \frac{illumination\ under\ normal\ working\ conditions}{illumination\ when\ every\ thing\ is\ clean}$$

Depreciation factor: this is merely the reverse of the maintenance factor and is defined as the ratio of the initial meter candles to the ultimate maintained metre-candles on the working plane. Its value is more than unity.

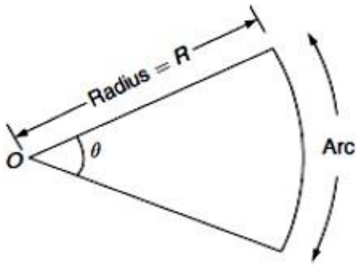
Waste light factor: Whenever a surface is illuminated by a number of sources of light, there is always a certain amount of waste of light on account of over-lapping and falling of light outside at the edges of the surface. The effect is taken into account by multiplying the theoretical value of lumens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

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 value varies from unity for clean atmosphere to 0.5 for foundries.

Beam factor: 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 the account the absorption of light by reflector and front glass of the projector lamp. Its value varies from 0.3 to 0.6.

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 the fallowing figure. 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's value always less than unity.

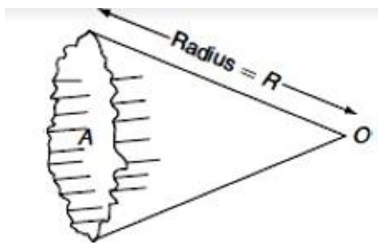
Plane angle: A plane angle is the angle subtended at a point in a plane by two converging lines. It is denoted by the Greek letter 'θ' (theta) and is usually measured in degrees or radians.



$$\theta = \frac{arc}{radious}\ radians$$

One radian is defined as the angle subtended by an arc of a circle whose length by an arc of a circle whose length is equals to the radius of the circle.

Solid angle: Solid angle is the angle subtended at a point in space by an area, i.e., the angle enclosed in the volume formed by numerous lines lying on the surface and meeting at the point. It is usually denoted by symbol 'ω' and is measured in steradian.



$$\omega = \frac{area}{(radious)^2} = \frac{A}{r^2}$$

The largest solid angle subtended at a point is that due to a sphere at its centre. If **r** is the radius of any sphere, its surface area is **4π²** and the distance of its surface area from the centre is r, therefore, solid angle subtended at its centre by its surface,

$$\omega = \frac{4\pi r^2}{\boldsymbol{r^2}} = 4\pi \textbf{ steradians}$$

Steradian: It is the unit of solid angle and is defined as the solid angle that subtends a surface on the sphere equivalent to the square of the radius.

Example 1: A 200-V lamp takes a current of 1.2 A, it produces a total flux of 2,860 lumens. Calculate:
1. the MSCP of the lamp and
2. the efficiency of the lamp.

Solution:
Given V = 200 V, I = 1.2 A, flux = 2,860 lumens.

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

Lamp efficiency = lumens flux/power input = 2860/(200*1.2) lumens/watt

Example 2: A room with an area of 6 × 9 m is illustrated by ten 80-W lamps. The luminous efficiency of the lamp is 80 lumens/W and the coefficient of utilization is 0.65. Find the average illumination.

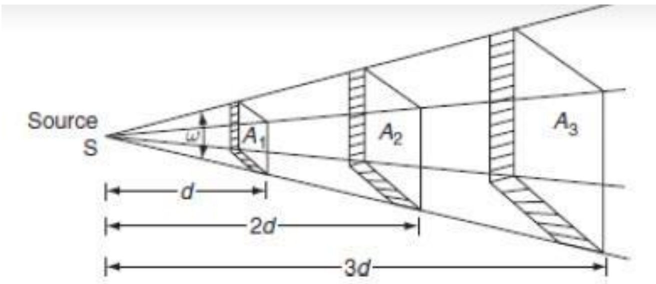
Solution:
Room area = 6 × 9 = 54 m .
Total wattage = 80 × 10 = 800 W.
Total flux emitted by ten lamps = 80 × 800 = 64,000 lumens.
Flux reaching the working plane = 64,000 × 0.65 = 41,600 lumens.

$$\textbf{Illumination}, \mathrm{E} = \frac{\phi}{A} = \frac{41{,}600}{54} = 770.37\ lux$$

Laws of Illumination

Mainly there are two laws of illumination.
1. Inverse square law.
2. Lambert's cosine law.

1. **Inverse square law:** This law states that 'the illumination of a surface is inversely proportional to the square of distance of the surface from the source of light.



Let, '*S*' be a point source of luminous intensity '*I*' candela, the luminous flux emitting from source crossing the three parallel plates having areas *A A* , and *A* square meters, which are separated by a distances of *d,* 2*d,* and 3*d* from the point source respectively as shown in Fig.

For are A_1, solid angle $\omega = A_1/d^2$
Luminous flux reaching the area A_1 = luminous intensity × solid angle

$$= I * \omega = I * A_1/d^2$$

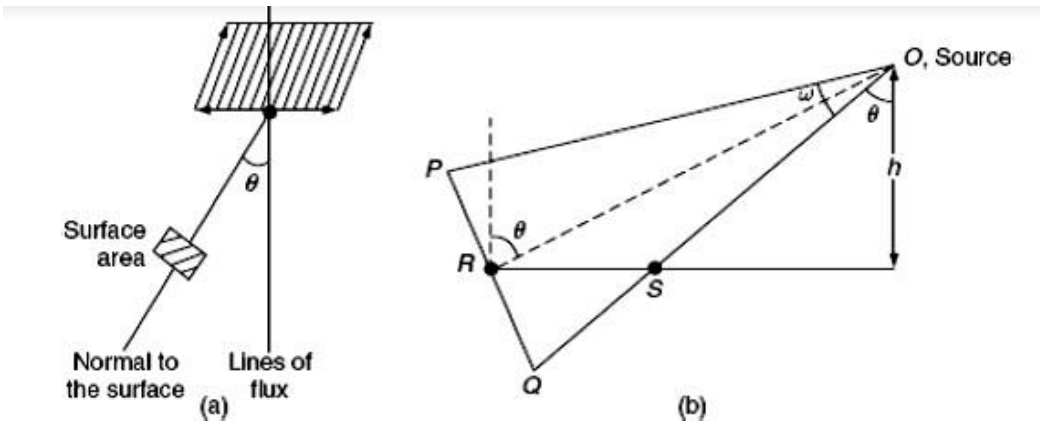
Illumination 'E_1' on the surface area 'A_1' is:
$E_1 = flux/area = I * A_1/d^2 * 1/A_1$
$\boldsymbol{E_1 = I/d^2\ lux}$
Similarly, illumination 'E_2' on the surface *area* A_2 is:
$\boldsymbol{E_2 = I/(2d)^2\ lux}$
Similarly, illumination 'E_3' on the surface *area* A_3 is:
$\boldsymbol{E_3 = I/(3d)^2\ lux}$

From above equations

$E_1 : E_2 : E_3 = \boldsymbol{I/d^2 : I/(2d)^2 : I/(3d)^2}$

Hence, from Equation, illumination on any surface is inversely proportional to the square of distance between the surface and the source.

2. **Lambert's cosine law:** This law states that illumination, E at any point on a surface is directly proportional to the cosine of the angle between the line of flux AND the normal at that point.



Let us assume that the surface is inclined at an angle 'θ' to the lines of flux as shown in Fig. (a)

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

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

$PQ = RS\cos\theta.$

$\therefore$ The illumination of the surface $PQ, E_{PQ} = \dfrac{\text{flux}}{\text{area of } PQ}$

$$= \frac{I \times \omega}{\text{area of } PQ} = \frac{I}{\text{area of } PQ} \times \frac{\text{area of } PQ}{d^2} \quad [\because \omega = \text{area}/(\text{radius})^2]$$

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

$\therefore$ The illumination of the surface $RS, E_{RS} = \dfrac{\text{flux}}{\text{area of } RS} = \dfrac{\text{flux}}{\text{area of } PQ/\cos\theta}$

$[\because PQ = RS\cos\theta]$

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

From Fig (b)

$$\cos\theta = h/d$$

or $$d = h/\cos\theta$$

Substitute value of *d* in above equation

$$\therefore E_{RS} = \frac{I}{(h/\cos\theta)^2} \times \cos\theta = \frac{I}{h^2}\cos^3\theta$$

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

where *d* is the distance between the source and the surface in m, *h* is the height of source from the surface in m, and *I* is the luminous intensity in candela.
Hence, above Equation is also known as 'cosine cube' law. This law states that the illumination at any point on a surface is dependent on the cube of cosine of the angle between line of flux and normal at that point.

Note - *From the above laws of illumination, it is to be noted that inverse square law is only applicable for the surfaces if the surface is normal to the line of flux. And Lambert's cosine law is applicable for the surfaces if the surface is inclined an angle 'θ' to the line of flux.*