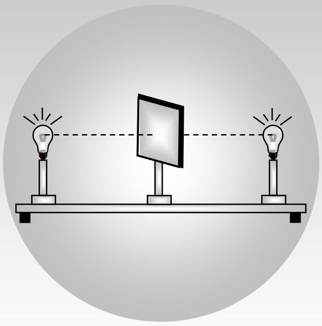


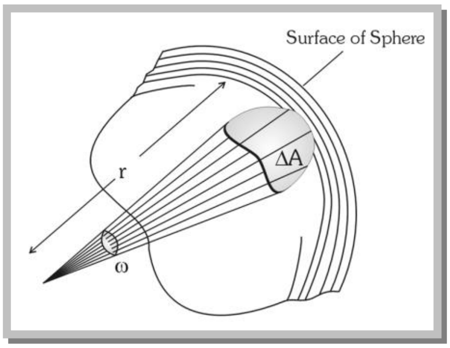
Photometry

The branch of optics that deals with the study and measurement of the light energy is called photometry.

Important Definitions

(1) **Solid angle**

The area of a spherical surface subtends an angle at the centre of the sphere. This angle is called solid (ω).



(i) $\omega = \dfrac{\text{Area of } \Delta A}{r^2}$

(ii) It's unit is steradian.

(iii) Solid angle subtended by the whole sphere at it's centre is 4π radians.

(2) **Radiant flux (R)**

The total energy radiated by a source per second is called radiant flux. It's S.I. unit is **Watt (W)**.

(3) **Luminous flux (ϕ)**

The total light energy emitted by a source per second is called luminous flux. It represents the total brightness producing capacity of the source. It's S.I. unit is **Lumen (lm)**.

Note : ❑ The luminous flux of a source of (1/685) watt emitting monochromatic light of wavelength 5500 Å is called 1 lumen.

(4) **Luminous efficiency (η)**

The Ratio of luminous flux and radiant flux is called luminous efficiency *i.e.* $\eta = \dfrac{\phi}{R}$.

Light source	Flux (lumen)	Efficiency (lumen/watt)
40 W tungsten bulb	465	12

60 W tungsten bulb	835	14
500 W tungsten bulb	9950	20
30 W fluorescent tube	1500	50

(5) **Luminous Intensity (L)**

In a given direction it is defined as luminous flux per unit solid angle *i.e.*

$$L = \frac{\phi}{\omega} \rightarrow \frac{\text{Light energy}}{\text{sec} \times \text{solid angle}} \xrightarrow{\text{S.I. unit}} \frac{\text{lumen}}{\text{steradian}} = \text{candela } (Cd)$$

Note : ❑ The luminous intensity of a point source is given by : $L = \frac{\phi}{4\pi} \Rightarrow \phi = 4\pi \times (L)$

(6) **Illuminance or intensity of illumination (I)**

The luminous flux incident per unit area of a surface is called illuminance. $I = \frac{\phi}{A}$

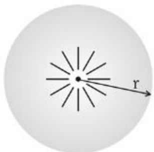
(i) **Unit :** S.I. unit – $\frac{\text{Lumen}}{m^2}$ or Lux (lx)

CGS unit – Phot

$1\,\text{Phot} = 10^4\,\text{Lux} = \frac{1\,\text{Lumen}}{cm^2}$

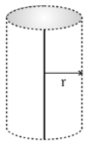
(ii) Intensity of illumination at a distance r from

→ Point source



$I = \frac{\phi}{4\pi r^2} \Rightarrow I \propto \frac{1}{r^2}$

→ Line



$I = \frac{\phi}{2\pi r l} \Rightarrow I \propto \frac{1}{r}$

Note : ❑ In case of a parallel beam of light $I \propto r$.

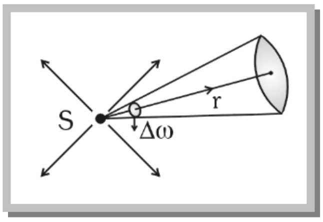
❑ If a luminous flux of 1 lumen is falling on an area of $1 m^2$ of a surface, then the illuminance of that surface will be 1 Lux.

(7) **Difference between illuminance (intensity of illumination) and luminance (Brightness) of a surface**

The illuminance represents the luminous flux incident on unit area of the surface, while luminance represents the luminous flux reflected from a unit area of the surface.

Relation Between Luminous Intensity (L) and Illuminance (I)

If S is a unidirectional point source of light of luminous intensity L and there is a surface at a distance r from source, on which light is falling normally.

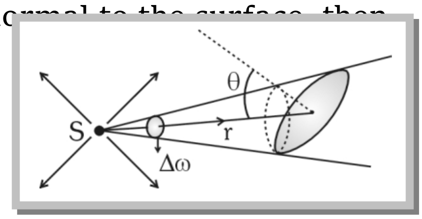


(1) Illuminance of surface is given by : $I = \frac{L}{r^2}$

(2) For a given source L = constant so $I \propto \frac{1}{r^2}$; This is called. Inverse square law of illuminance.

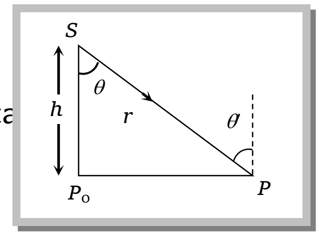
Lambert's Cosine Law of Illuminance

In the above discussion if surface is so oriented that light from the source falls, on it obliquely and the central ray of light makes an angle θ with the normal to the surface, then



(1) Illuminance of the surface $I = \frac{L\cos\theta}{r^2}$

(2) For a given light source and point of illumination (*i.e.* L and r = constant) $I \propto \cos\theta$ this is called Lambert's cosine law of illuminance. $\Rightarrow I_{max} = \frac{L}{r^2} = I_o (\text{at}\,\theta = 0^o)$



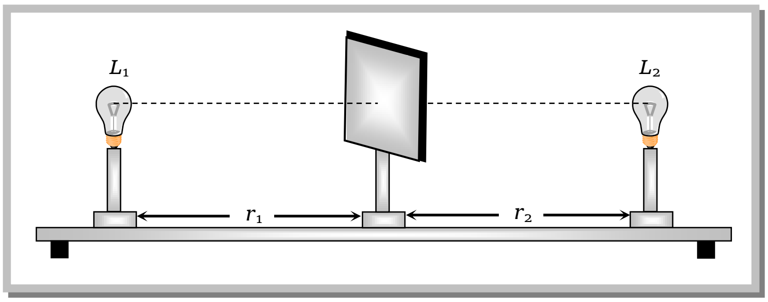
(3) For a given source and plane of illuminance (*i.e.* L and h = consta

$\cos\theta \frac{h}{r}$ so $I = \frac{L}{h^2}\cos^3\theta$ or $I = \frac{Lh}{r^3}$ *i.e.* $I \propto \cos^3\theta$ or $I \propto \frac{1}{r^3}$

Note : ❑ I varies with distance as $\frac{1}{r^2}$ for isotropic point source, as $\left(\frac{1}{r}\right)$ for line source and is independent of r in case of parallel beam.

Photometer and Principle of Photometry

A photometer is a device used to compare the illuminance of two sources.



Two sources of luminous intensity L_1, and L_2 are placed at distances r_1 and r_2 from the screen so that their flux are perpendicular to the screen. The distance r_1 and r_2 are adjusted till $I_1 = I_2$.

So $\frac{L_1}{r_1^2} = \frac{L_2}{r_2^2} \Rightarrow \frac{L_1}{L_2} = \left(\frac{r_1}{r_2}\right)^2$; This is called principle of photometry.

Note : ❑ $R \propto \phi \propto L$ so that $\frac{R_1}{R_2} = \frac{\phi_1}{\phi_2} = \frac{L_1}{L_2}$

❑ 40 *watt* fluorescent tube gives more light than a filament bulb of same wattage because filament bulb emits light along with ultraviolet and infrared radiation. In a fluorescent tube, gas discharge produces only light and ultraviolet radiation. Since ultraviolet radiations too are converted into visible light through the phenomenon of photoluminescence, the illuminance, luminous flux or luminous efficiency of a

40 *watt* fluorescent tube will be more than that of the filament bulb of same wattage.

Example

Example: 1 If luminous efficiency of a lamp is 2 lumen/watt and its luminous intensity is 42 candela, then power of the lamp is

(a) 62 *W* (b) 76 *W* (c) 138 *W* (d) 264 *W*

Solution: (d) Luminous flux $= 4\pi L = 4 \times 3.14 \times 42 = 528\ Lumen$

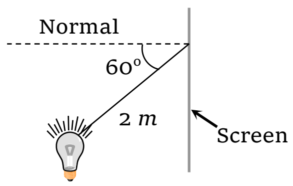
Power of lamp $= \dfrac{\text{Luminous flux}}{\text{Luminous efficiency}} = \dfrac{528}{2} = 264\ W$

Example: 2 An electric bulb illuminates a plane surface. The intensity of illumination on the surface at a point 2*m* away from the bulb is 5×10^{-4} phot (*lumen/cm*^{2}). The line joining the bulb to the point makes an angle of 60° with the normal to the surface. The intensity of the bulb in *candela* is **[IIT-JEE 1980; CPMT 1991]**

(a) $40\sqrt{3}$ (b) 40 (c) 20 (d) 40×10^{-4}

Solution: (b) $I = \dfrac{L\cos\theta}{r^2} \Rightarrow L = \dfrac{I \times r^2}{\cos\theta}$

$= \dfrac{5 \times 10^{-4} \times 10^{4} \times 2^2}{\cos 60^\circ} = 40\ Candela$



Example: 3 In a movie hall, the distance between the projector and the screen is increased by 1% illumination on the screen is

(a) Increased by 1% (b) Decreased by 1% (c) Increased by 2% (d) Decreased by 2%

Solution: (d) $I = \dfrac{L}{r^2} \Rightarrow \dfrac{dI}{I} = -\dfrac{2dr}{r}$ ($\because L$ = constant) $\Rightarrow \dfrac{dI}{I} \times 100 = -\dfrac{2 \times dr}{r} \times 100 = -2 \times 1 = -2\%$

Example: 4 Correct exposure for a photographic print is 10 *seconds* at a distance of one metre from a point source of 20 *candela*. For an equal fogging of the print placed at a distance of 2 *m* from a 16 *candela* source, the necessary time for exposure is

(a) 100 *sec* (b) 25 *sec* (c) 50 *sec* (d) 75 *sec*

Solution: (c) For equal fogging $I_2 \times t_2 = I_1 \times t_1 \Rightarrow \dfrac{L_2}{r_2^2} \times t_2 = \dfrac{L_1}{r_1^2} \times t_1 \Rightarrow \dfrac{16}{4} \times t_2 = \dfrac{20}{1} \times 10 \Rightarrow t_2 = 50\,Sec.$

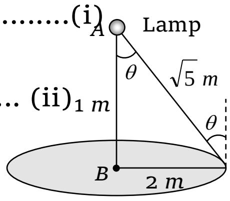
Example: 5 A bulb of 100 *watt* is hanging at a height of one meter above the centre of a circular table of diameter 4 *m*. If the intensity at a point on its rim is I_0, then the intensity at the centre of the table will be **[CPMT 1996]**

(a) I_0 (b) $2\sqrt{5}I_0$ (c) $2I_0$ (d) $5\sqrt{5}I_0$

Solution: (d) The illuminance at *B* $I_B = \dfrac{L}{1^2}$ ....(i)

and illuminance at point *C* $I_C = \dfrac{L\cos\theta}{(\sqrt{5})^2} = \dfrac{L}{(\sqrt{5})^2} \times \dfrac{1}{\sqrt{5}} \Rightarrow I_0 = \dfrac{L}{5\sqrt{5}}$ .... (ii)

From equation (i) and (ii) $I_B = 5\sqrt{5}\ I_0$



Example: 6 A movie projector forms an image $3.5m$ long of an object $35\ mm$. Supposing there is negligible absorption of light by aperture then illuminance on slide and screen will be in the ratio of **[CPMT 1982]**

(a) 100 : 1 (b) $10^4 : 1$ (c) 1 : 100 (d) $1 : 10^4$

Solution: (b) $I \propto \frac{1}{r^2}$ So, $\frac{\text{Illuminance on slide}}{\text{Illuminance on screen}} = \frac{(\text{Length of image on screen})^2}{(\text{Length of object on slide})^2} = \left(\frac{3.5\ m}{35\ mm}\right)^2 = 10^4 : 1$

Example: 7 A 60 *watt* bulb is hung over the center of a table $4' \times 4'$ at a height of 3'. The ratio of the intensities of illumination at a point on the centre of the edge and on the corner of the table is **[CPMT 1976, 84]**

(a) $(17/13)^{3/2}$ (b) 2 / 1 (c) 17 / 13 (d) 5 / 4

Solution: (a) The illuminance at A is $I_A = \frac{L}{(\sqrt{13})^2} \times \cos\theta_1 = \frac{L}{13} \times \frac{3}{\sqrt{13}} = \frac{3L}{(13)^{3/2}}$

The illuminance at B is $I_B = \frac{L}{(\sqrt{17})^2} \times \cos\theta_2 = \frac{L}{17} \times \frac{3}{\sqrt{17}} = \frac{3L}{(17)^{3/2}}$

$\therefore \frac{I_A}{I_B} = \left(\frac{17}{13}\right)^{3/2}$