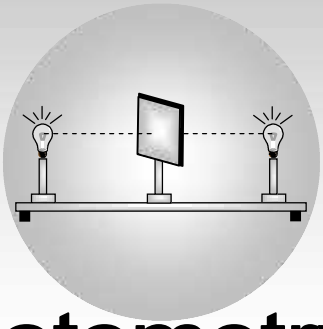


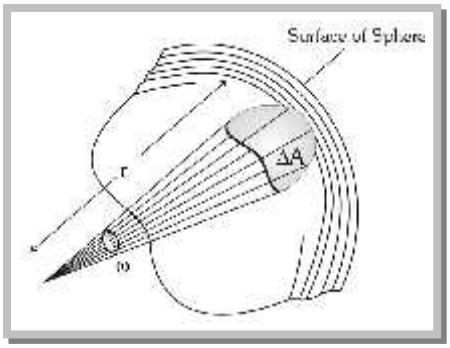
Photometry

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 (μ).



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

(ii) It's unit is steradian.

(iii) Solid angle subtended by the whole sphere at it's centre is 4® 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 (¤)**

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 (¦)**

The Ratio of luminous flux and radiant flux is called luminous efficiency *i.e.* $¦ = \frac{¤}{R}$.

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.*

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

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

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

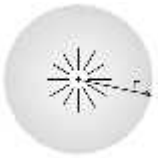
The luminous flux incident per unit area of a surface is called illuminance. $I = \frac{¤}{A}$

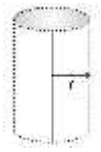
(i) **Unit :** S.I. unit – $\frac{\text{Lumen}}{m^2}$ or Lux (lx)

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  $I = \frac{¤}{4®r^2} \Rightarrow I \propto \frac{1}{r^2}$

→ Line source  $I = \frac{¤}{2®rl} \Rightarrow I \propto \frac{1}{r}$

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

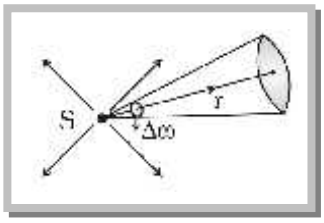
❑ If a luminous flux of 1 lumen is falling on an area of $1m^2$ of a surface, then the illuminance of that surface will be 1 Lux.

(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.

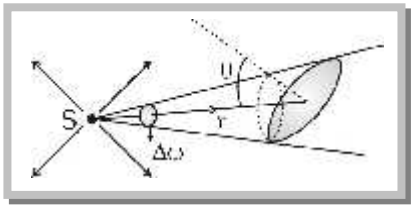


(1) Illuminance of surface is given by : $I = \frac{L}{r^2}$

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

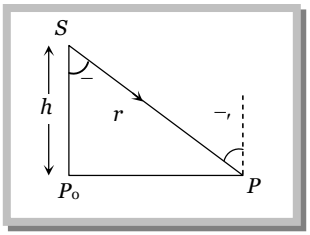
Lambert's Cosine Law of Illuminance

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 $^-$ with the normal to the surface, then



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

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



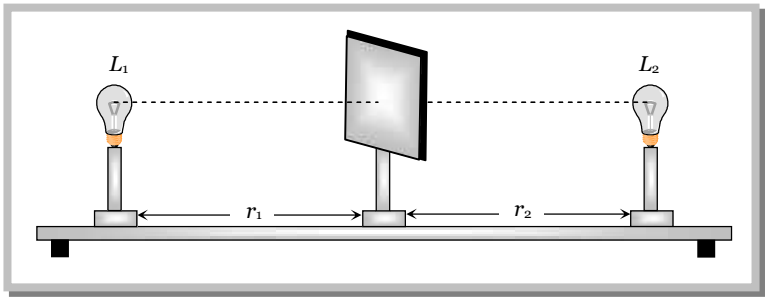
(3) For a given source and plane of illuminance (*i.e.* L and h = constant)

$\cos^{-} \frac{h}{r}$ so $I = \frac{L}{h^2}\cos^{3}-$ or $I = \frac{Lh}{r^3}$ *i.e.* $I \propto \cos^{3}-$ 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 : ❑ $R \propto ¤ \propto L$ so that $\frac{R_1}{R_2} = \frac{¤_1}{¤_2} = \frac{L_1}{L_2}$

❑ 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 $= 4® L = 4 \times 3.14 \times 42 = 528$ *Lumen*

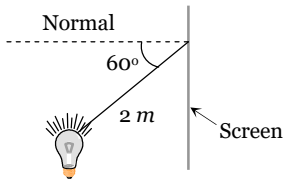
$$\text{Power of lamp} = \frac{\text{Luminous flux}}{\text{Luminous efficiency}} = \frac{528}{2} = 264 \ W$$

***Example*: 2** An electric bulb illuminates a plane surface. The intensity of illumination on the surface at a point $2m$ 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^o with the normal to the surface. The intensity of the bulb in *candela* is

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

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

$= \frac{5 \times 10^{-4} \times 10^4 \times 2^2}{\cos 60^\circ} = 40$ *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) $I = \frac{L}{r^2} \Rightarrow \frac{dI}{I} = -\frac{2dr}{r}$ ($\because$ L = constant) $\Rightarrow \frac{dI}{I} \times 100 = -\frac{2 \times dr}{r} \times 100 = -2 \times 1 = -2\%$

***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 $I_2 \times t_2 = I_1 \times t_1 \Rightarrow \frac{L_2}{r_2^2} \times t_2 = \frac{L_1}{r_1^2} \times t_1 \Rightarrow \frac{16}{4} \times t_2 = \frac{20}{1} \times 10 \Rightarrow t_2 = 50\,Sec$.

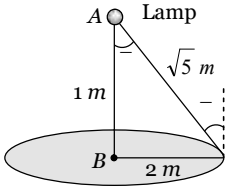
***Example*: 5** A bulb of 100 *watt* is hanging at a height of one meter above the centre of a circular table of diameter 4 *m*. If the intensity at a point on its rim is I_0, then the intensity at the centre of the table will be

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

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

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

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

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

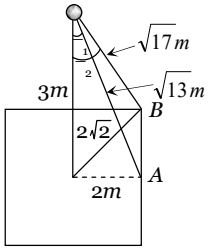
***Example*: 7** A 60 *watt* bulb is hung over the center of a table $4' \times 4'$ at a height of 3'. The ratio of the intensities of illumination at a point on the centre of the edge and on the corner of the table is

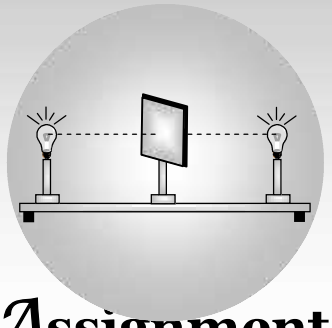
(a) $(17/13)^{3/2}$ (b) 2 / 1 (c) 17 / 13 (d) 5 / 4

Solution: (a) The illuminance at A is $I_A = \frac{L}{(\sqrt{13})^2} \times \cos^{-}_1 = \frac{L}{13} \times \frac{3}{\sqrt{13}} = \frac{3L}{(13)^{3/2}}$

The illuminance at B is $I_B = \frac{L}{(\sqrt{17})^2} \times \cos^{-}_2 = \frac{L}{17} \times \frac{3}{\sqrt{17}} = \frac{3L}{(17)^{3/2}}$

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





Assignment

Photometry

Basic Level

1. "Lux" is a unit of
(a) Luminous intensity of a source (b) Illuminance on a surface
(c) Transmission coefficient of a surface (d) Luminous efficiency of source of light

2. Total flux produced by a source of 1 *cd* is
(a) $\frac{1}{4®}$ (b) $8®$ (c) $4®$ (d) $\frac{1}{8®}$

3. If the luminous intensity of a 100 *W* unidirectional bulb is 100 candela, then total luminous flux emitted from the bulb is
(a) 861 *lumen* (b) 986 *lumen* (c) 1256 *lumen* (d) 1561 *lumen*

4. The maximum illumination on a screen at a distance of 2 *m* from a lamp is 25 *lux*. The value of total luminous flux emitted by the lamp is
(a) 1256 *lumen* (b) 1600 *lumen* (c) 100 *candela* (d) 400 *lumen*

5. A small lamp is hung at a height of 8 feet above the centre of a round table of diameter 16 *feet*. The ratio of intensities of illumination at the centre and at points on the circumference of the table will be
(a) 1 : 1 (b) 2 : 1 (c) $2\sqrt{2}:1$ (d) 3 : 2

6. Lux is equal to
(a) 1 *lumen/m*^{2} (b) 1 *lumen/cm*^{2} (c) 1 *candela/m*^{2} (d) 1 *candela/cm*^{2}

7. Five *lumen/watt* is the luminous efficiency of a lamp and its luminous intensity is 35 *candela*. The power of the lamp is
(a) 80 *W* (b) 176 *W* (c) 88 *W* (d) 36 *W*

8. A lamp rated at 100 *cd* hangs over the middle of a round table with diameter 3 *m* at a height of 2 *m*. It is replaced by a lamp of 25 *cd* and the distance to the table is changed so that the illumination at the centre of the table remains as before. The illumination at edge of the table becomes *X* times the original. Then *X* is
(a) $\frac{1}{3}$ (b) $\frac{16}{27}$ (c) $\frac{1}{4}$ (d) $\frac{1}{9}$

9. The distance between a point source of light and a screen which is 60 *cm* is increased to 180 *cm*. The intensity on the screen as compared with the original intensity will be
(a) (1 / 9) times (b) (1 / 3) times (c) 3 times (d) 9 times

10. A source of light emits a continuous stream of light energy which falls on a given area. Luminous intensity is defined as
(a) Luminous energy emitted by the source per second (b) Luminous flux emitted by source per unit solid angle
(c) Luminous flux falling per unit area of a given surface (d) Luminous flux coming per unit area of an illuminated surface

11. Venus looks brighter than other stars because
(a) It has higher density than other stars (b) It is closer to the earth than other stars
(c) It has no atmosphere (d) Atomic fission takes place on its surface

12. To prepare a print the time taken is 5 sec due to lamp of 60 watt at 0.25 *m* distance. If the distance is increased to 40 *cm* then what is the time taken to prepare the similar print
(a) 3.1 *sec* (b) 1 *sec* (c) 12.8 *sec* (d) 16 *sec*

13. A lamp is hanging 1 *m* above the centre of a circular table of diameter 1*m*. The ratio of illuminaces at the centre and the edge is
(a) $\frac{1}{2}$ (b) $\left(\frac{5}{4}\right)^{\frac{3}{2}}$ (c) $\frac{4}{3}$ (d) $\frac{4}{5}$

6 Photometry

14. Two stars situated at distances of 1 and 10 light years respectively from the earth appear to possess the same brightness. The ratio of their real brightnesses is

(a) 1 : 10 (b) 10 : 1 (c) 1 : 100 (d) 100 : 1

15. The intensity of direct sunlight on a surface normal to the rays is I_0. What is the intensity of direct sunlight on a surface, whose normal makes an angle of 60^o with the rays of the sun

(a) I_0 (b) $I_0\left(\frac{\sqrt{3}}{2}\right)$ (c) $\frac{I_0}{2}$ (d) $2I_0$

16. Inverse square law for illuminance is valid for

(a) Isotropic point source (b) Cylindrical source (c) Search light (d) All types of sources

17. 1% of light of a source with luminous intensity 50 *candela* is incident on a circular surface of radius 10 *cm*. The average illuminance of surface is

(a) 100 *lux* (b) 200 *lux* (c) 300 *lux* (d) 400 *lux*

18. Two light sources with equal luminous intensity are lying at a distance of 1.2 *m* from each other. Where should a screen be placed between them such that illuminance on one of its faces is four times that on another face

(a) 0.2 *m* (b) 0.4 *m* (c) 0.8 *m* (d) 1.6 *m*

19. Two lamps of luminous intensity of 8 *Cd* and 32 *Cd* respectively are lying at a distance of 1.2 *m* from each other. Where should a screen be placed between two lamps such that its two faces are equally illuminated due to two sources

(a) 10 *cm* from 8 *Cd* lamp (b) 10 *cm* from 32*Cd* lamp (c) 40 *cm* from 8 *Cd* lamp (d) 40 *cm* from 32 *Cd* lamp

20. A lamp is hanging along the axis of a circular table of radius *r*. At what height should the lamp be placed above the table, so that the illuminance at the edge of the table is $\frac{1}{8}$ of that at its center

(a) $\frac{r}{2}$ (b) $\frac{r}{\sqrt{2}}$ (c) $\frac{r}{3}$ (d) $\frac{r}{\sqrt{3}}$

21. A point source of 100 *candela* is held 5*m* above a sheet of blotting paper which reflects 75% of light incident upon it. The illuminance of blotting paper is

(a) 4 *phot* (b) 4 *lux* (c) 3 *phot* (d) 3 *lux*

22. A lamp is hanging at a height 40 *cm* from the centre of a table. If its height is increased by 10 *cm* the illuminance on the table will decrease by

(a) 10 % (b) 20% (c) 27% (d) 36%

23. Which has more luminous efficiency

(a) A 40 *watt* bulb (b) A 40 *watt* fluorescent tube (c) Both have same (d) Cannot say

24. A small of light is to be suspended directly above the centre of a circular table of radius *R*. What should be the height of the light source above the table so that the intensity of light is maximum at the edges of the table compared to any other height of the source

(a) $\frac{R}{2}$ (b) $\frac{R}{\sqrt{2}}$ (c) R (d) $\sqrt{2}R$

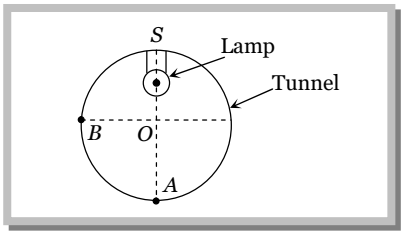
25. An electric lamp is fixed at the ceiling of a circular tunnel as shown is figure. What is the ratio the intensities of light at base *A* and a point *B* on the wall

(a) 1 : 2

(b) $2:\sqrt{3}$

(c) $\sqrt{3}:1$

(d) $1:\sqrt{2}$



26. When sunlight falls normally on earth, a luminous flux of 1.57×10^5 *lumen* $/m^2$ is produced on earth. The distance of earth from sun is 1.5×10^8 *Km*. The luminous intensity of sun in candela will be

(a) 3.53×10^{27} (b) 3.53×10^{25} (c) 3.53×10^{29} (d) 3.53×10^{21}

27. In the above problem, the luminous flux emitted by sun will be

(a) 4.43×10^{25} *lm* (b) 4.43×10^{26} *lm* (c) 4.43×10^{27} *lm* (d) 4.43×10^{28} *lm*

28. A screen receives 3 *watt* of radiant flux of wavelength 6000 *Å*. One lumen is equivalent to 1.5×10^{-3} *watt* of monochromatic light of wavelength 5550 *Å*. If relative liminosity for 6000 *Å* is 0.685 while that for 5550 Å is 1.00, then the luminous flux of the source is

(a) 4×10^3 *lm* (b) 3×10^3 *lm* (c) 2×10^3 *lm* (d) 1.37×10^3 *lm*

29. In a grease spot photometer light from a lamp with dirty chimney is exactly balanced by a point source distance 10 *cm* from the grease spot. On clearing the chimney, the point source is moved 2 *cm* to obtain balance again. The percentage of light absorbed by dirty chimney is nearly

(a) 56% (b) 44% (c) 36% (d) 64%

30. A point source of 3000 *lumen* is located at the centre of a cube of side length 2*m*. The flux through one side is

(a) 500 *lumen* (b) 600 *lumen* (c) 750 *lumen* (d) 1500 *lumen*

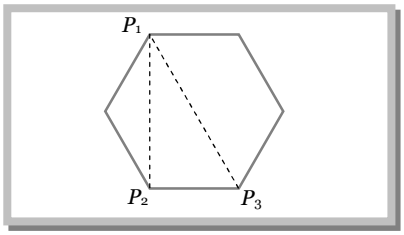
31. A light source is located at P_1 as shown in the figure. All sides of the polygon are equal. The intensity of illumination at P_2 is I_0. What will be the intensity of illumination at P_3

(a) $\frac{3\sqrt{3}}{8}I_0$

(b) $\frac{I_0}{8}$

(c) $\frac{3}{8}I_0$

(d) $\frac{\sqrt{3}}{8}I_0$



32. Light from a point source falls on a small area placed perpendicular to the incident light. If the area is rotated about the incident light by an angle of 60°, by what fraction will the illuminance change

(a) It will be doubled (b) It will be halved (c) It will not change (d) It will become one-fourth

33. A point source of light moves in a straight line parallel to a plane table. Consider a small portion of the table directly below the line of movement of the source. The illuminance at this portion varies with its distance *r* from the source as

(a) $E \propto \frac{1}{r}$ (b) $E \propto \frac{1}{r^2}$ (c) $E \propto \frac{1}{r^3}$ (d) $E \propto \frac{1}{r^4}$

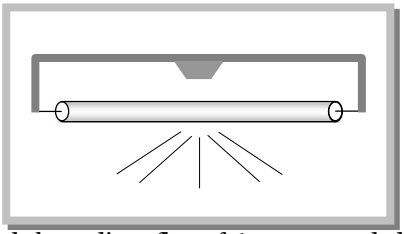
34. Figure shows a glowing mercury tube. The illuminances at point *A, B* and *C* are related as

(a) $B > C > A$

(b) $A > C > B$

(c) $B = C > A$

(d) $B = C < A$



35. The relative luminosity of wavelength 600 *nm* is 0.6. Find the radiant flux of 600 *nm* needed to produce the same brightness sensation as produced by 120 *W* of radiant flux at 555 *nm*

(a) 50*W* (b) 72*W* (c) $120 \times (0.6)^2 W$ (d) 200*W*

36. The separation between the screen and a plane mirror is 2*r*. An isotropic point source of light is placed exactly midway between the mirror and the screen. Assume that mirror reflects 100% of incident light. Then the ratio of illuminances on the screen with and without the mirror is

(a) 10 : 1 (b) 2 : 1 (c) 10 : 9 (d) 9 : 1

37. The separation between the screen and a concave mirror is 2*r*. An isotropic point source of light is placed exactly midway between the mirror and the point source. Mirror has a radius of curvature *r* and reflects 100% of the incident light. Then the ratio of illuminances on the screen with and without the mirror is

(a) 10 : 1 (b) 2 : 1 (c) 10 : 9 (d) 9 : 1

38. Find the luminous intensity of the sun if it produces the same illuminance on the earth as produced by a bulb of 10000 *candela* at a distance 0.3 *m*. The distance between the sun and the earth is $1.5 \times 10^{11} m$

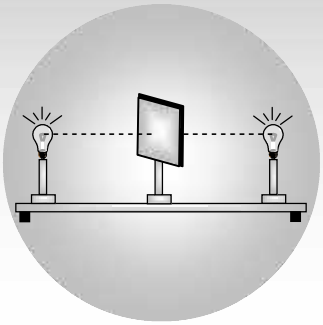
(a) $25 \times 10^{22} cd$ (b) $25 \times 10^{18} cd$ (c) $25 \times 10^{26} cd$ (d) $25 \times 10^{36} cd$

39. A point light source is to be suspended above the centre of a circular table of radius *R*. In order to produce maximum illuminance at the edges of the table, the height of the light source must be

(a) *R* (b) 2*R* (c) $\frac{R}{\sqrt{2}}$ (d) $\sqrt{2} \times R$

40. A lamp is hanging at a height of 4*m* above a table. The lamp is lowered by 1*m*. The percentage increase in illuminace will be

(a) 40 % (b) 64% (c) 78% (d) 92%



Answer Sheet

Assignments

1	2	3	4	5	6	7	8	9	10
b	c	c	a	c	a	c	a	a	b
11	12	13	14	15	16	17	18	19	20
b	c	b	c	c	a	b	c	c	d
21	22	23	24	25	26	27	28	29	30
b	d	b	b	d	a	d	d	c	a
31	32	33	34	35	36	37	38	39	40
c	c	c	d	d	c	b	c	c	c