Module 1

Illumination Engineering Basics

Lesson
5
Laws of Illumination

Instructional Objectives

1. Define Standard of Illumination?
2. What is a Candela?
3. Understand MSLI
4. State Freschner's Law
5. State Inverse Square law of Illumination.

Laws of Illumination

The original standard of light was Wax Candle, which is highly unreliable. It was replaced by a Vaporized Pentane Lamp. This is equal to10 original Candles. In the year 1909, Incandescent Lamp was taken as standard by comparison with a Pentane Lamp. Thing to be kept in mind is Primary Standard should be reproducible. It was in1948, Luminous Intensity; based on Luminance (objective brightness) of a small aperture due to Light from a Radiator maintained at 1773°c i.e. Solidification temperature of platinum was adopted as Standard. It consists of:

1. Radiator – Fused Thoria – Thorium Oxide. 45mm long internal dia of 2.5mm. Packed with Fused Thoria Powder at the bottom.
2. Supported Vertically Pure Platinum in a Fused thoria crucible with a small aperture of 1.5mm in a large refractory container.
3. Platinum melted by a High Frequency Eddy current.Luminance = 589000 Candles /m2 ≈ 600 000 units

The standard is shown in Fig.1.

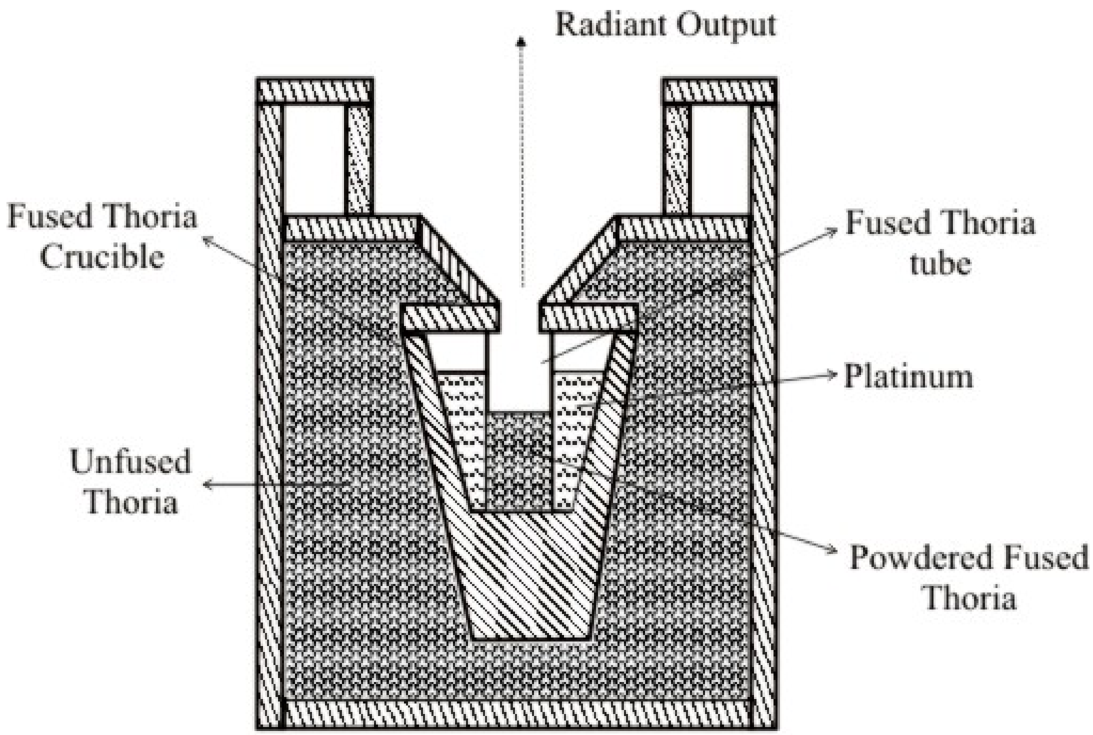


Fig 1. Primary Standard Of Light

Transparent

Common unit of light intensity is candela. It is Luminous intensity in the Perpendicular direction of a surface, 1 / 600,000 of a black body at temperature of solidification or Freezing of Platinum under Standard Atmospheric pressure. It is abbreviated as Cd. It is indicative of Light Radiating Capacity of a source of Lamp.

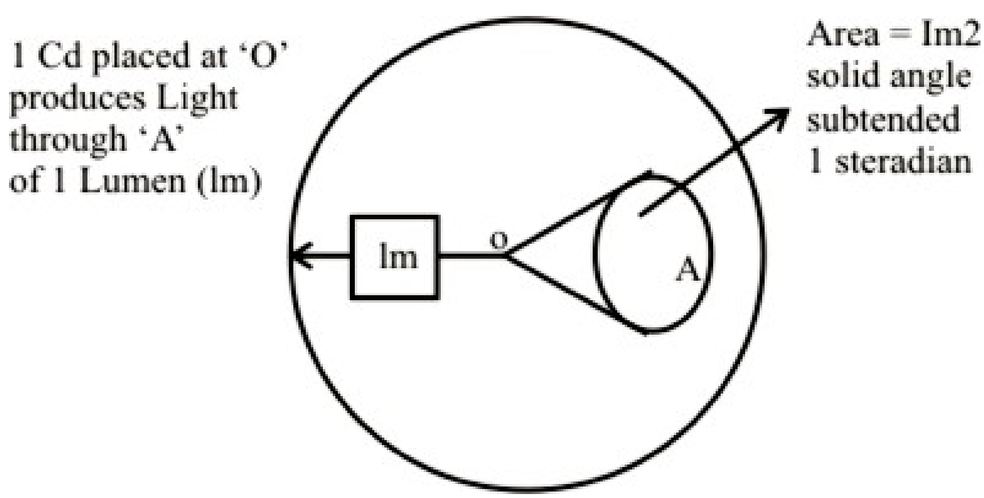


Fig. 2 Light flux

Consider a transparent sphere of radius 1m shown in Fig.2. If we place a 1 Cd source at the centre then light flux coming out through an area of $1m^2$ over 1 steradian solid angle will be 1 lumen.

Thus Luminous Intensity over 1 Str. by 1, Cd, we call it 1 lumen ≈ 1 lm. Basic unit of Light Flux. ∴ Total Flux = 4 π lumens, out of the sphere in Fig 2.
If the Solid Angle be dω and Luminous Intensity I Cd at the center then Luminous flux in dω = dϕ = I dω lm.

$$\therefore\ I = \frac{d\varphi}{d\omega} Cd$$

Yet another important unit is MSLI. It means Mean Spherical Luminous Intensity. Average value of Luminous Intensity in all directions. Therefore for the case in Fig 2.

$$\phi = I\ 4\pi \text{ lumens}$$

Now we define Luminous intensity on a surface. It is known as Illuminance. It is Luminous Flux per unit area or lumens per sq m. = lumen / m^2 = lm / m^2 = lux (lx).

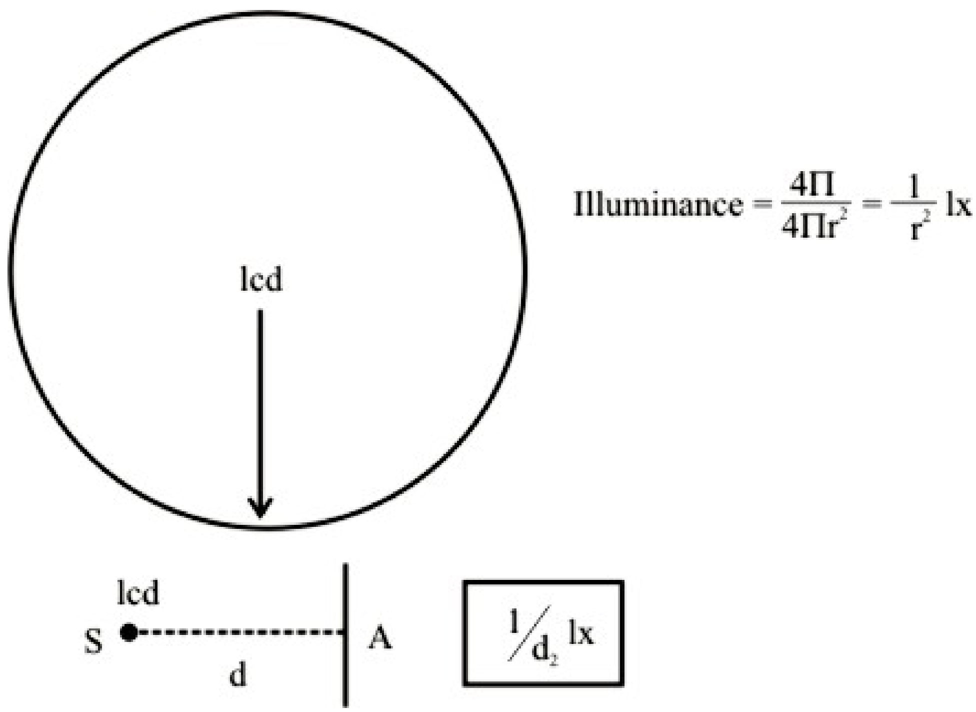


Fig. 3 Definition of Illuminance.

Frechner's law

Weber in 1830 found that I – Stimulus (Intensity) produces dI – Least perceptible increment affecting sense organs. Then the ratio

$\frac{dI}{I} = \text{Constant} \cdots$ Under fixed – 1) Fatigue

2) Attention and
3) Expectation.

Thus we have sensitivity given by the equation

$$S = C \log \frac{I}{I_o} \cdots\cdots\cdots\cdots(2)$$

Here I_0 is the threshold intensity. This is known as Frechner's Law. The same percentage change in stimulus Calculated from the least amount perceptible. Gives same change in sensation. Sensation produced by optic nerves have logarithmic dependence or relationship to Light Radiation producing the sensation.

Inverse Square Law

Intensity of Illumination produced by a point source varies inversely as square of the distance from the source. It is given by the equation and as shown in Fig. 3

$$E = \frac{I}{D^2} \cdots\cdots\cdots\cdots(3)$$

Where I is

Lambert's Cosine Law of Incidence

$$E = \frac{I \cos \propto}{D^2} \cdots\cdots\cdots(4)$$

This – tells us the variation of Illuminance on arbitrary surface inclined at an angle of α. As shown in Fig 4.

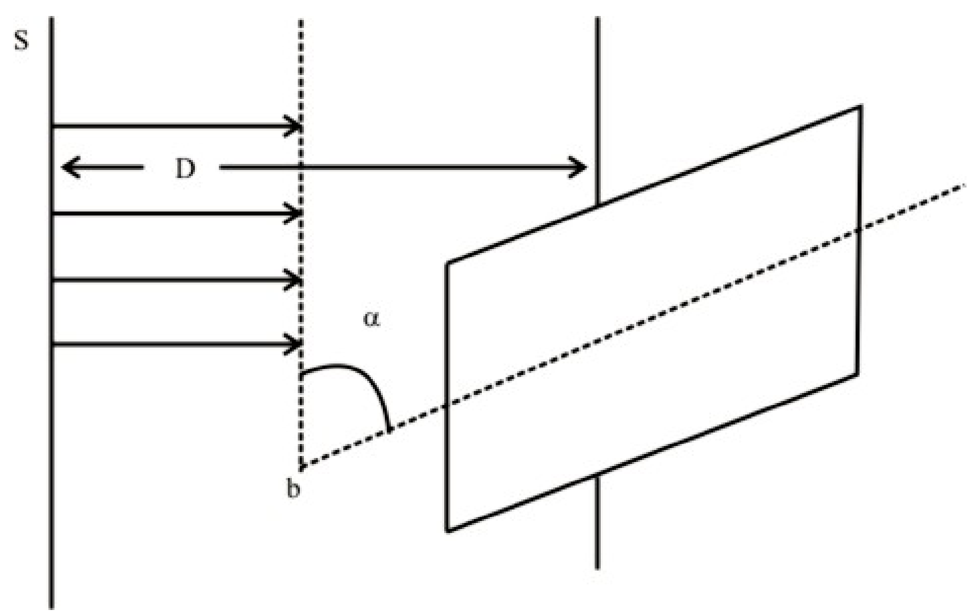


Fig. 4 Lambert's Cosine Law of Emission

$$I \propto = I \cos \propto \cdots\cdots\cdots\cdots(5)$$

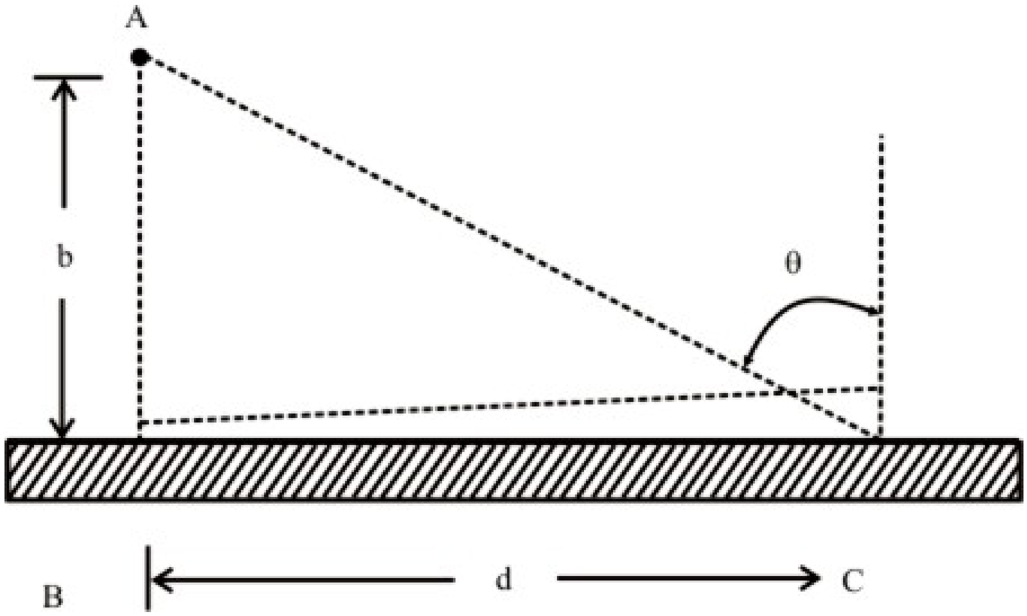


Fig. 5 Typical Lighting Scheme

Fig. 5 shows a lamp placed at A, $b\overline{m}$ above the floor. For this scheme Fig 6. shows the variation of Illuminance on the floor. It is well known that Illuminance is maximum under the lamp at 'B'.

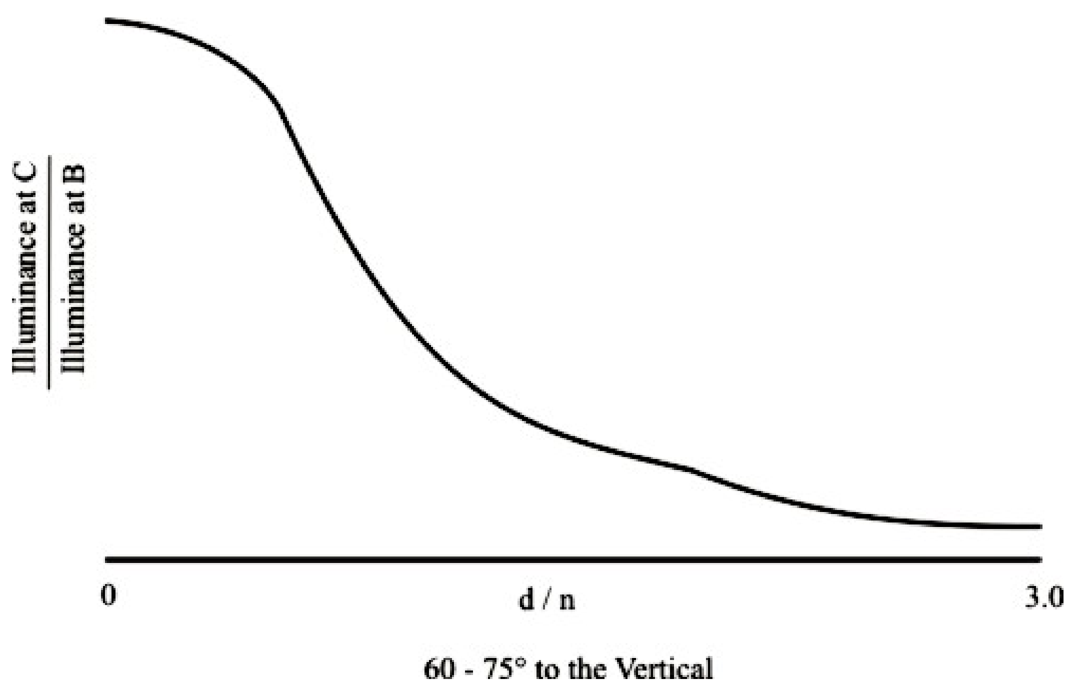


Fig. 6 Variation of Illuminance

$$\text{Illuminance at B} = \frac{\text{LI in direction AB}}{b^2}$$

$$\text{Illuminance at C} = \frac{\text{LI in direction AC}}{AC^2}$$

$$= \frac{\text{LI in direction AB} \times \text{Cos}\theta}{(b^2 + d^2)}$$

$$= \frac{\text{LI in direction AB} \times b}{(b^2 + d^2)^{3/2}}$$

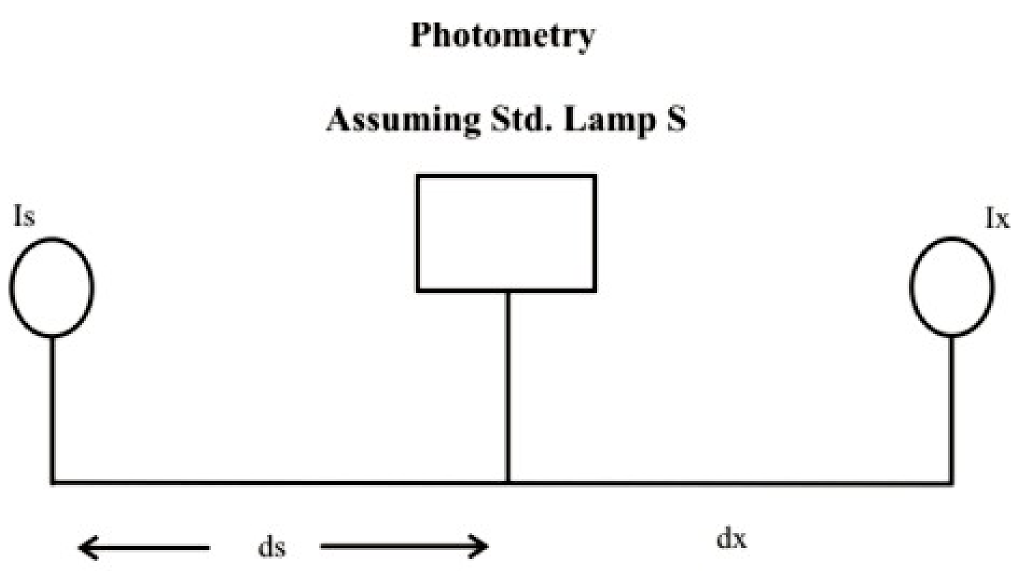
$$\text{Cos}\theta = \frac{b}{\sqrt{b^2 + d^2}}$$

$\therefore$ Illuminance at C = Illuminance at Bx Cos3θ

$$= \frac{\text{Illuminance at B}}{[1 + (d/b)^2]^{3/2}}$$

Next is to measure the candle power of the lamp. Typical measurement can be done using a photometric bench shown in Fig. 7 where I_S represents standard lamp. I_X represents test lamp. There is a screen at the centre called photometer head, adjusted for equal brightness on either side. Applying inverse law one can arrive at the value of I_X.

This lesson introduced the primary standard and other terminology related to measurement of light flux.



$$\frac{I_s}{ds^2} = \frac{Ix}{dx^2} \Rightarrow I_x = I_s\left(\frac{ds}{dx}\right)^2$$

Fig. 7 Photometric Bench

Lecture Summary

- Unit of luminous intensity is Candela (Cd), it is the luminous intensity of a surface which is1/600,000 of a blackbody, at the solidification temp. of Platinum (1773 °C) under standard atmospheric pressure.
- Luminous intensity over 1 steradian solid angle by a source of 1 Cd is called as 1 lumen flux (lm)
- MSLI = average intensity x solid angle (mean spherical Luminous intensity).
- Luminous Flux = luminous intensity × solid angle
- Illuminance is luminous flux per unit area
- **Frechner's Law** – the same percentage change in stimulus calculated from the least amount perceptible gives the same change in sensation.
- **Inverse Square Law** – The intensity of illumination produced by a point source varies inversely as square of the distance from the source.
- **Lambert's Cosine Law of Incidence –** $E = \frac{I \times \cos\alpha}{D^2}$
- **Lambert's Cosine law of Emission –** $I_m = I \times \cos\alpha$

Tutorial Questions

- What is the standard unit of luminous intensity?

  Candela (Cd)
- What is MSLI?

  Mean Spherical Luminous Intensity. This unit is used as the light flux is radialy outwards from a source which may be assumed to be a point.
- What is the standard procedure to measure luminosity?
- Luminosity can be measured by the standard procedure of photometry

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