SSC-JE 2025

Staff Selection Commission

Junior Engineer Examination

Electrical Engineering

Estimation & Costing and Utilization of Electrical Energy

Well Illustrated **Theory** *with*

Solved Examples and **Practice Questions**

MADE EASY PUBLICATIONS

Estimation & Costing
and
Utilization of Electrical Energy

Contents

Chapter 1

Illumination

1.1 Introduction

The basic idea of study of illumination engineering is to thoroughly understand the principle of illumination for interior light design which include domestic light and factory lighting. Further applications are highway lighting, sports ground lighting, flood lighting and airport lighting. Artificial lighting produced electrically due to cleanliness, ease of control as well as low cost and is playing an important role in modern every day life. To summaries the essential features of lighting system,

1. It must possess sufficient illumination of suitable colour on the working surface.
2. To avoid the glare.
3. To avoid the unnecessary shadow.
4. Good maintenance.

1.2 Nature of Light

- Lighting is one of the major uses of electrical energy. Sun is the biggest source of natural light. Artificial lighting may be electrical or non-electrical. Where there is no natural light, use of artificial light is made.
- Artificial lighting produced electrically has advantages like cleanliness, ease of control, reliability, steady output and low cost.
- When light falls on a surface, the surface is illuminated and the process is called *illumination* i.e. light is the cause and illumination is the result of that light on surfaces on which it falls.
- Light is a form of vibrant radiant energy which falls on a body and it becomes visible to the eye.

NOTE

The waves of light travel with a velocity of 3×10^8 metres/second,

$$v = f \times \lambda$$

where v is the velocity of light in m/sec, f is the frequency in Hertz (Hz) and λ is the wavelength in metres.

When the light falls upon any surface, the phenomenon is known as illumination.

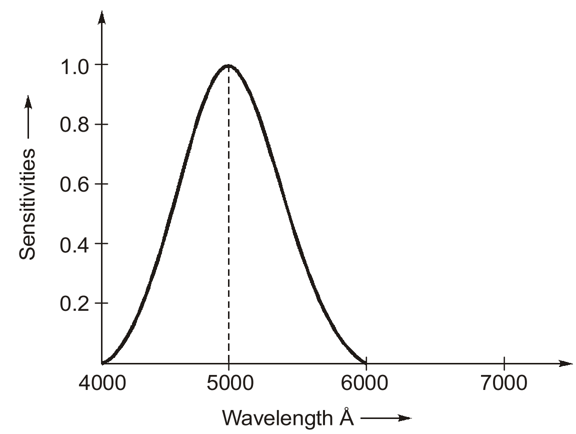
Light Spectrum

- The colour of light depends upon the wavelength of radiation. It has been found that the spectrum of light consists of SEVEN different colours. These are: Red, Orange, Yellow, Green, Blue, Indigo and Violet. The wavelength of Red light is 75×10^{-8} m and of violet is 40×10^{-8} m. Thus the spectrum has wavelength varying from 40×10^{-8} m to 75×10^{-8} m.

- However prior to red light, there are infrared or heat waves with a wavelength of about 3×10^{-5} m to 75×10^{-8} m and beyond violet there are ultraviolet rays with wavelength between 3×10^{-8} to 40×10^{-8} m i.e. after 7500 A.U. the radiations are known as infrared and below 4000 A.U. they are called ultra violet.

Angstrom Unit (Å)

- A metre or even a centimeter is a very large unit for measuring the wavelengths. So a smaller unit, known as Angstrom unit (Å) is generally used.
  1 Å = 10^{-8} cm = 10^{-10} m and 1 micron (μ) = 10^{-6} m etc.
- A list of colour with their wavelength is given below:
  So in terms of these units:
  Wavelength of red light = 7500 Å
  Wavelength of violet light = 4000 Å
  Wavelength of blue light = 5000 Å
  Wavelength of yellow light = 6500 Å
- Visible light can have a wavelength between 4000 Å and 7500 Å. The wavelength of infrared rays varies from 3×10^{5} Å to 7500 Å and of ultraviolet rays from 300 Å to 4000 Å.
- The human eye is most sensitive to light having wavelength of 5500 Å. This light has greenish yellow colour and is unsuitable for most of the practical purposes.

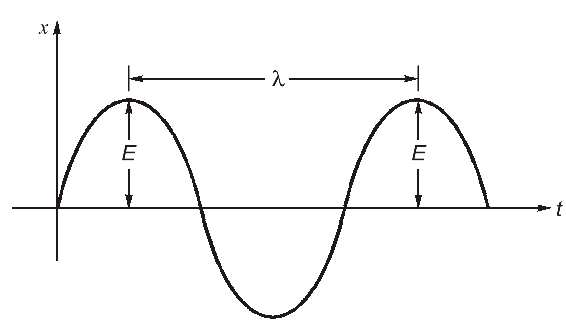


Eye sensitivity curve

- The sensitivity of the eye to light of different wavelength varies from person to person. This also depend upon the age of the person. The graph between relative sensitivity of eye and wavelength is shown in figure.

Wavelength of Light

The distance between two successive crests or two successive troughs is called wavelengths or the distance between two successive particles of medium which are in phase is called wavelength and it is denoted by λ. Angstrom unity (AU) is the unit of wavelength of light and equal to 10^{-10} m.



Some Important Definitions used in Illumination

For devising the modern lighting schemes, the selection of fittings and the types of lamps required, a knowledge of the following terms is essential.

1. **Light:** It is defined as the radiant energy from a hot body which produces the visual sensation upon the human eye. The velocity of light,

$$v = f\lambda$$

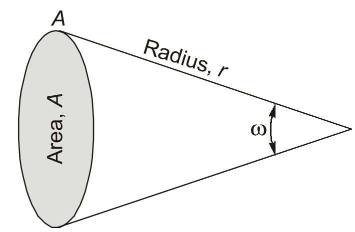
2. **Luminous Flux:** It is the total quantity of light energy radiated per second from a luminous body in the form of light waves. It is measured in lumens. It is represented by symbol F or ϕ.

3. **Lumen:** One lumen is the luminous flux emitted by a point source of one candle power per unit solid angle.

i.e.,
$$\text{Lumens} = \text{Candle power} \times \text{Solid angle}$$
$$= \text{C.P.} \times \omega$$

4. **Solid Angle:** The solid angle is measured in steradians (ω). Solid angle is the angle generated by the surface passing through the point space and periphery of the area. It is denoted by ω.

Solid angle is given by the ratio of the area of the surface of the square of the distance between the area and the point.



Solid angle

i.e.
$$\omega = \frac{A}{r^2}$$

Since the surface of a sphere has an area equal to $4\pi r^2$.

∴ Total angle,
$$\omega = \frac{4\pi r^2}{r^2} = 4\pi \text{ steradians}$$

5. **Luminous Intensity (I):** It is the amount of luminous flux emitted by a source per unit solid angle. It is measured in candela or lumens per steradian.

i.e.,
$$I = \frac{\phi}{\omega}$$
$$1 \text{ Candela} = 1 \text{ Lumen/steradian}$$

6. **Illumination or Intensity of Illumination (E):** It is the luminous flux received by a surface per unit area of surface. Its units depends upon the units in which area is measured. It is measured in lumens per square meter or lux or meter candle.

7. **Candle Power (C.P.):** The candle power of a source of light in any direction is the number of lumens per unit solid angle in that direction.

Total flux emitted by a source of 1 candle power in all directions = 4π Lumens

8. **Phot or cm. Candle:** It is the illumination produced by a uniform source of 1 candle power (C.P.) on the inner surface of a sphere of 1 cm. radius. It gives lumens/cm^2.

9. **Plane Angle:** It is subtended at a point in a plane by two converging lines and its magnitude is given by $\theta = \dfrac{\text{arc}}{\text{radius}}$ radians. The largest angle subtended at a point is 2π radians.

10. **Lux or Metre Candle:** It is defined as the illumination produced by a uniform source of 1 C.P. on the inner surface of a sphere of 1 metre radius,

$$1 \text{ Phot} = 10^4 \text{ Lux or lumens per square meter}$$

11. **Foot Candle or Lumens/Square Foot:** This the illumination produced by a source of 1 C.P. on the inner surface of a sphere of 1 foot radius,

$$1 \text{ foot candle} = 10.7608 \text{ lux}$$
$$1 \text{ Lux} = 0.09293 \text{ ft. candle}$$

12. **Brightness of Luminance (B):** The brightness of a surface is the number of reflected or emitted lumens per unit area. It is measured in stilb or lambert,

$$1 \text{ Stilb} = 1 \text{ Candle/cm}^2$$

$$1 \text{ Lambert} = 1 \text{ Lumen/cm}^2$$

13. **Luminous Efficiency or Radiant Efficiency:** The rays emitted by a hot body depend upon its temperature. The rays consists of not only of light but also of heat and other electromagnetic radiation such as infrared and ultraviolet rays.

$$\text{Luminous or Radiant efficiency} = \frac{\text{Energy radiated as light}}{\text{Total energy radiated}}$$

It is measured in lumens/watt.

The efficiency of a source in lumens/watt is given by

$$\eta = 4\pi \times \frac{\text{Mean spherical candle power}}{\text{Watts}}$$

14. **Mean Spherical Candle Power (MSCP):** It is the average of the candle power in all directions,

$$\text{MSCP} = \frac{\text{Total flux in lumens}}{4\pi}$$

15. **Mean Hemi Spherical Candle Power (MHSCP):** It is the mean of all the candle power taken over a hemisphere,

$$\text{MHSCP} = \frac{\text{Total flux in lumens}}{2\pi}$$

16. **Mean Horizontal Candle Power:** It is the average of the candle powers in all directions in the horizontal phase containing the surface.
17. **Reduction factor:** Reduction factor at spherical reduction,

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

18. **Lamp Efficiency:** It is defined as the ratio of the luminous flux to the power input. It is expressed in lumens/watt.
19. **Depreciation Factor or Maintenance Factor:** The efficiency of a projector lamp is seriously affected by the dust and dirt which accumulate on the projector lamp during its course of use. So these must be cleaned at regular intervals. In lighting calculations, this is taken into account by applying a factor of 1.3 to 1.4.

$$\text{Depreciation factor} = \frac{\text{Illumination with clean new lamp and fittings}}{\text{Illumination under working conditions}}$$

20. **Coefficient of Utilization (U):** This is given by the ratio,

$$U = \frac{\text{Light falling on a given surface}}{\text{Light emitted by source}}$$

The value of coefficient of utilization depends upon (i) Direct or Indirect lighting scheme design (ii) Type of fitting, its height and (iii) Colour of walls etc. Its value varies between 0.4 to 0.6.

21. **Space to Height Ratio:** This is equal to $= \dfrac{\text{Horizontal spacing between two lamps}}{\text{Height of lamps above working plane}}$

In general this ratio should not exceed 1.5.

22. **Coefficient of Reflection or Reflection Factor:** When the light falls on a highly polished surface such as a mirror, it is reflected such that the angle of incidence is equal to angle of reflection. The ratio of reflected light to the incident light is known as the reflection factor.

$$\text{Reflection factor} = \frac{\text{Reflected light}}{\text{Incident light}}$$

It is always less than unity.

23. **Specular Reflector:** This is a special case of reflection when the surface is highly reflective such as in case of a mirror. There is almost not diffusion then and glare is produced.

24. **Efficiency of a Lamp or its Specific Output:** It is the ratio of total luminous flux emitted by the lamp to power intake or it is defined as the lumens per watt or watts per candle power.

    It is measured in lumens/watt.

$$\text{Lumen/watt} = \frac{4\pi \times \text{M.S.C.P.}}{\text{Watts}}$$

Sodium vapour lamp produces 100 lumen/watts

Mercury lamp produces 40-50 lumens/watts

Incandescent lamp produces 12-20 lumens/watts

25. **Specific Consumption:** It is the ratio of power input to the source of light to its candle power and is measured in watts/C.P.

26. **Glare:** The opening of the pupil eye is controlled by the iris. If a bright defect comes into view of the eye, a 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 amount of light received on the retina from every object in the field of view and it makes difficult to see the object desired. At the same time portion of retina which received image of bright object remain fatigued. This phenomenon is called as glare and a good lighting design must avoid glare at any cost. For this purpose, very bright sources of light should be avoided.

27. **Shadow:** Shadows also cause fatigue of eyes and can be avoided by using high mounting heights of lamps not less than 2.5 m, by using large number of lamps and employing wide surface sources of light by using globes. Shadows are undesirable in drawing offices where we are to see flat surface. But places where one has to perceive three dimensional form, shadows are desirable. A certain amount of shadow is desirable in artificial lighting as it helps to give shape to the solid objects and make them easily recognized.

Example - 1.1 Colour of light depends upon

(a) frequency. (b) wavelength.

(c) speed of light. (d) both frequency and wavelength.

***Solution:* (d)**

Example - 1.2 The wavelength of 5,500 Å will give light of

(a) green colour (b) red colour

(c) orange colour (d) yellow-green colour

***Solution:* (d)**

Example - 1.3 Unit of illumination is

(a) lumen. (b) lambert.
(c) lux. (d) steradians

Solution: (c)

1.3 Laws of Illumination

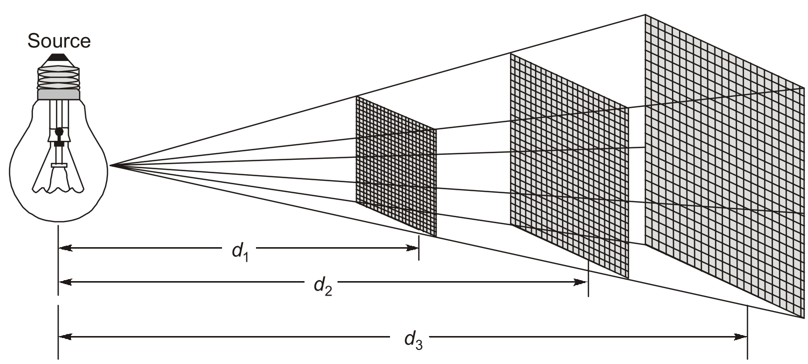
1. Inverse Square Law

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

$$E = \frac{I}{d^2} \quad ...(1.1)$$

Where, E = Illumination, I = Luminous intensity of the source in candle power
and D = distance between surface and source

This is known as **inverse square law**.



Inverse square law

2. Lambert's Cosine Law

- According to this law illumination varies directly as the cosine of the angle between the normal to the surface and the direction of incident light.

$$E \propto \cos\theta \quad ...(1.2)$$

- Combining equation (1.1) and (1.2),

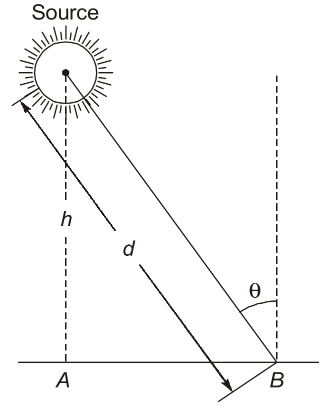
$$E \propto \frac{I}{d^2}\cos\theta \quad ...(1.3)$$

This is known as cosine law of illumination.

- From figure, $\cos\theta = \frac{h}{d}$ or $d = \frac{h}{\cos\theta}$

$$E = \frac{I}{h^2}\cos^3\theta \quad ...(1.4)$$

This is known as cosine cube law and is useful for evaluating illumination in street lighting etc.



Lambert's cosine law

Example - 1.4 The illumination at a surface due to a source of light placed at a distance '*d*' from the surface varies as

(a) $1/d^2$ (b) $1/d$
(c) d (d) d^2

***Solution:* (a)**

1.4 Sources of Light

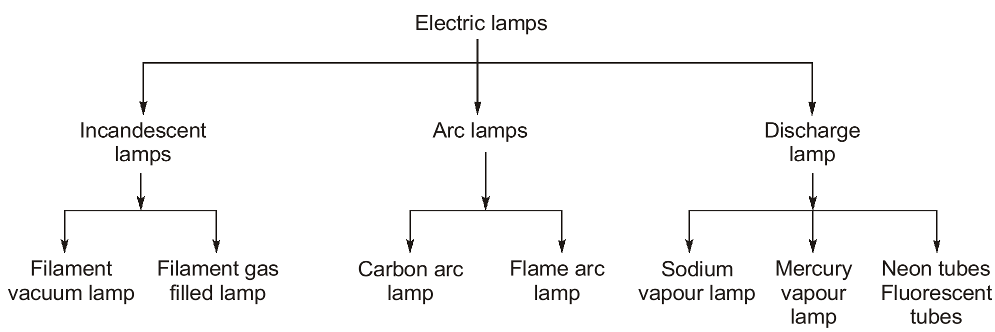
The following are the different methods to produce light electrically:

(i) By passing electric current through filament (wire) raising its temperature to emit light.

(ii) By establishing an arc between two electrodes producing light. This principle is utilized in arc lamps.

(iii) To maintain electric discharge through gas or vapour such as in vapour lamps, fluorescent tubes etc.

The following chart shows the list of various lamps.



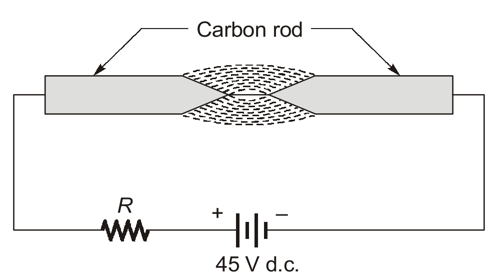
1.5 Different Types of Lamps

Arc Lamps

In an arc lamp electric current is made to flow through two electrodes. When two rods touch it produces hot arc resulting in light due to vapourization of some of carbon. There are various types of arc lamps such as carbon arc lamp and flame arc lamp.

Carbon Arc Lamp

- Carbon arc lamps are still used in cinema projector, search light and flash cameras.
- When two carbon rods are placed end to end and connected to dc supply of 45 V, the current flows through them. If they are slightly pulled, an arc will be formed between two carbon rods and white light will be produced. The arc is maintained by transfer of carbon particles from one rod to another rod.



Carbon arc lamp

- The rate of burning of positive rod is twice of that of negative rod, that is why the X-section of the positive rod is twice of that of the negative one. A resistance R is used for stabilizing the arc.

- The whole assembly is put into a sealed tube with addition of some gas. Different gases produce different colours. Neon gives reddish light, argon gives bluish-white light and helium gives pinkish light. The efficiency is 12 lumens/watt.

Incandescent-Lamps or Filament Lamp

- When any material whose melting point is very high is heated to very high temperature, it starts radiating electromagnetic waves, which are having heat and light energy. This phenomenon is called *incandescence* if heating temperature is in the range of 4000 to 6000°C absolute and light emission is mostly in red light. It is also called filament lamp.
- Advantages of incandescent lamps are given below:
  1. It has low initial cost.
  2. Brightness is easily controlled.
  3. High quality of colour.
  4. Ambient temperature do not effect their working.

Carbon Filament Lamps

- The carbon filament lamps were used in earlier days and consists of a fine filament of carbon suitably mounted in an evacuated bulb. The vacuum is necessary in order to expel any oxygen which will necessarily reduce the life of the filament. A temperature of about 1700°C is possible before the carbon starts vapourising at an excessive rate. Since it is the maximum temperature which increases efficiency. So carbon filament lamps are less efficient.
- Disadvantages of Carbon filament lamps.
  1. Carbon filament lamps cannot be operated at higher temperature, so their efficiency is low.
  2. It starts vapouring at about 1800° C, this not only reduces life of the filament and vapourised Carbon would settle down on the inside of bulb and blackening it.
  3. The filament of Carbon is brittle and would break easily. So a search was made for another materials and later on Tungsten filament lamps were developed.

Tungsten Filament Lamps

- In this case the lamp filament is made of tungsten metal. Again there are two types, the vacuum lamp and the gas filled lamp. In case of vacuum lamp of filament temperature of about 2000°C is possibly (compared to 1700°C of carbon) so a higher efficiency is obtained. The glass lamp is evacuated to prevent oxidation of the filament and also to prevent the temperature being lowered by radiation.
- The material used for filament must have the following properties:
  1. It must have high melting point, low vapour pressure, high resistivity and low temperature coefficient.
  2. It must be ductile and very strong mechanically to withstand vibrations during normal use.

Gaseous Discharge Lamps

- A tungsten filament gas filled lamp suffer from two disadvantages; low efficiency (12 lumens per watt in case of a 100 W lamp) and coloured light (yellowish-white). The gas discharge lamps have been developed to overcome these shortcomings.
- Discharge lamp works on the phenomenon of electric discharge through vapour or gas. The colour of the light obtained depends upon the nature of the gas or vapour used.