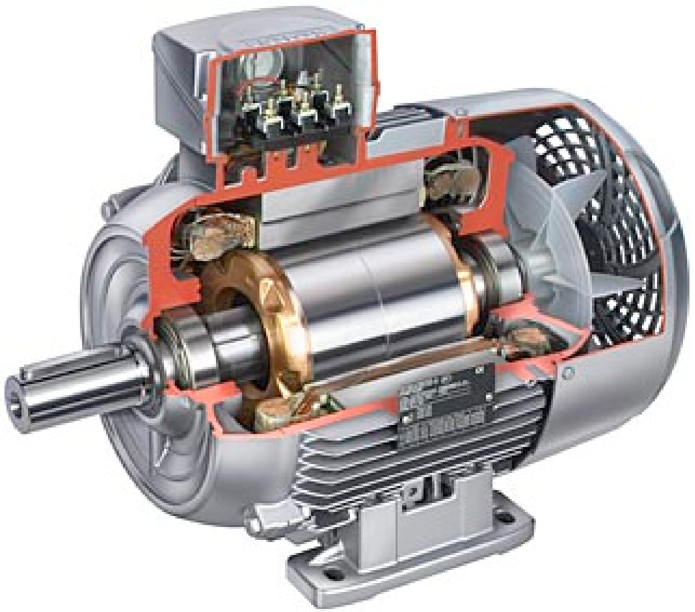
# EEE 3352

## Electromechanics & Electrical Machines



## Lecture 9: Illumination

Dr A Zulu 

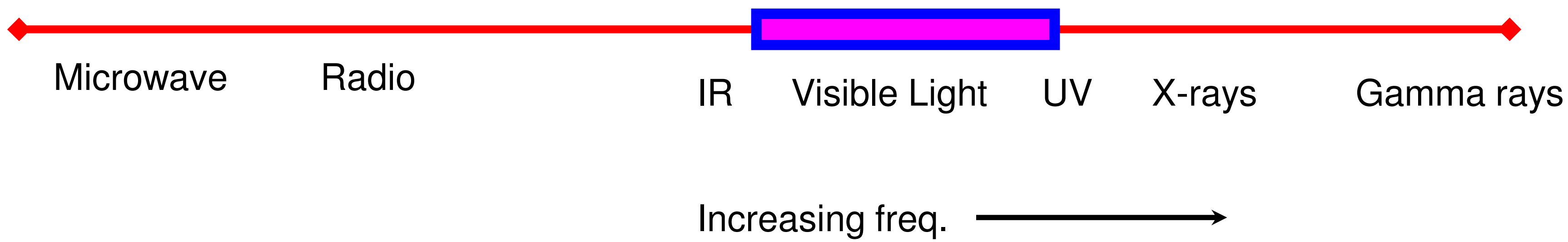
# 9. Illumination

1. Electromagnetic spectrum
2. Sources of artificial lighting
3. Definitions
4. Cosine law of illumination
5. Illuminance on a surface
6. Illumination factors
7. Requirements of lighting
8. Electric lighting

# Objectives:

- at the end of the lecture, students should be able to
  - identify the position of visible light on the EM spectrum
  - classify sources of artificial lighting
  - define quantities of illumination
  - apply  the laws illumination in lighting design
  - apply factors of illumination in lighting design
  - describe the types electric lighting

# 9.1 Electromagnetic spectrum




Range of visible spectrum:

From **Red**: 4 x $10^{14}$ Hz [750 nm] to **Violet**: 7 x $10^{14}$ Hz [400nm]

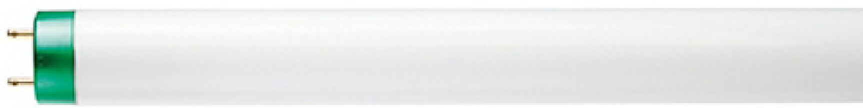
Propagation speed = $c$ = 3 x $10^{8}$ m/s

# 9.2 Sources of artificial lighting

- incandescent
  - continuous spectrum
  - intensity of different colours depend on temperature of source

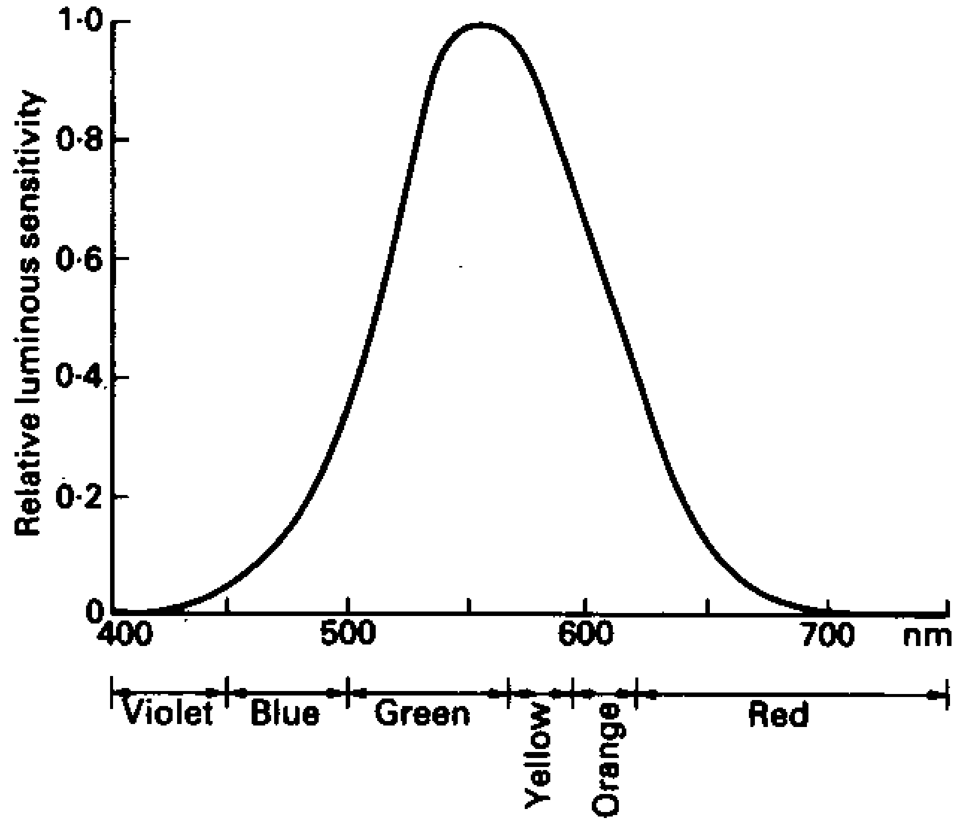
- gaseous discharge
  - discontinuous spectrum
  - e.g. sodium lamp produces 2 yellow lines at 589.0 and 598.6 nm, so close it appears monochromatic

- fluorescent
  - based on electric discharge of ionized gas (plasma), with UV
  - internal coating of lamp with fluorescent material, for visible light

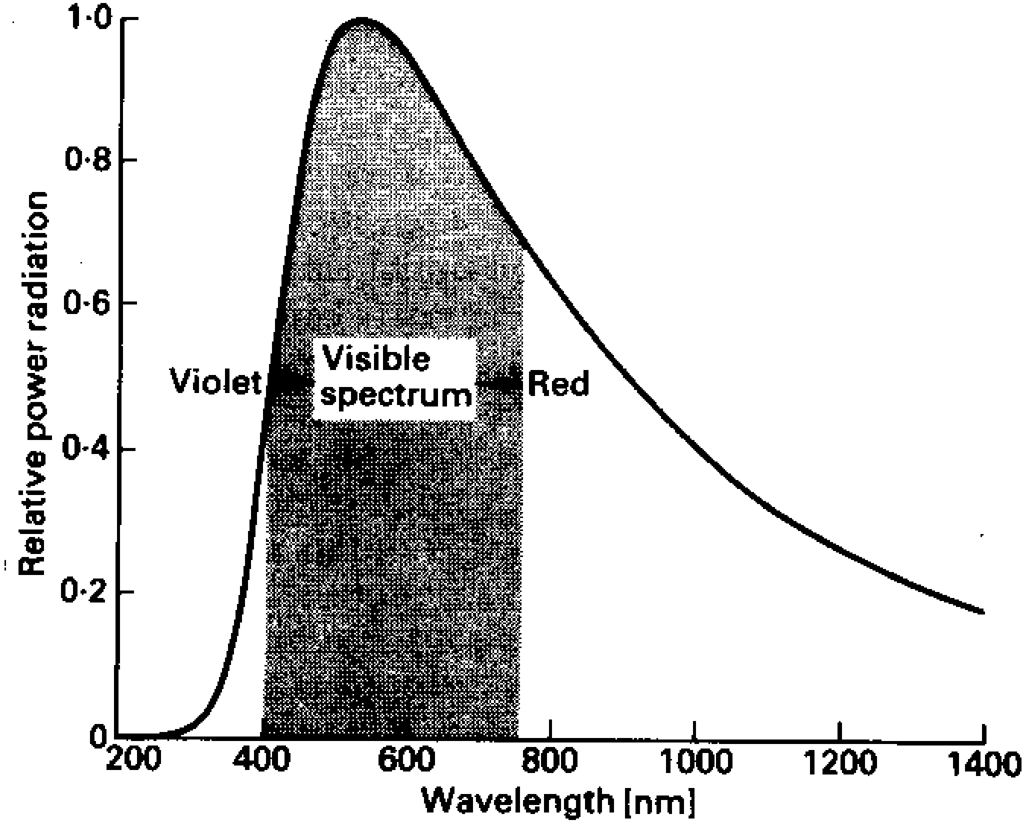


- light emitting diode
  - mechanism  of electroluminescence in  semiconductor materials
  - visible light, no UV ; low power activation

## Human eye

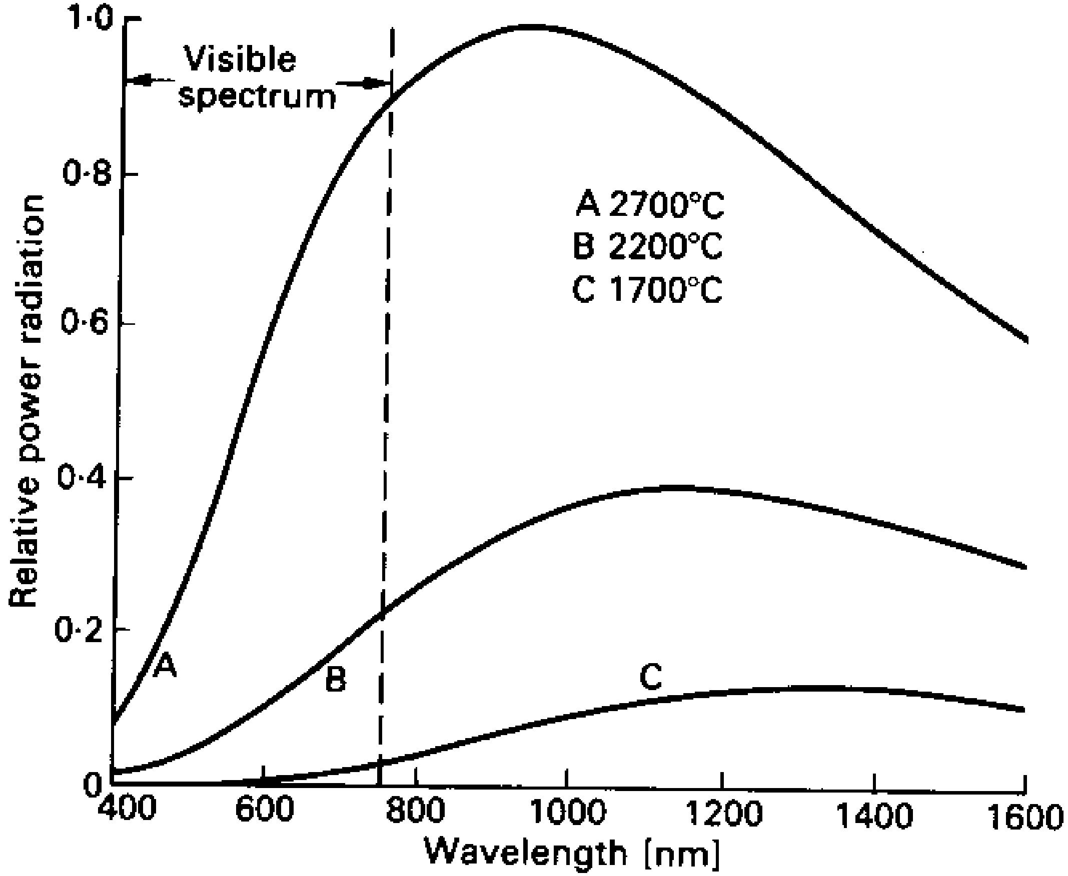



## Sun




- peak sensitivity of eye is at 555 nm
- maximum power radiation from the sun is at 500 nm

# Incandescent light



# 9.3 Definitions

1) luminous flux ($\phi$)

   a. radiation ability to produce visual sensation

   b. radiant energy weighted according to its ability to cause the sensation of light

      - a matter of the wavelength of energy and the sensitivity of the eye to it

   c. the total quantity of light emitted per second by a light source

   d. unit is lumen [lm]

2) luminous intensity ($I$)

a. the light radiating capacity of a source

b. the luminous flux emitted per unit of solid angle in a given direction

c. unit is candela [cd]

- define 1 cd (see 1st lecture)

3) point source

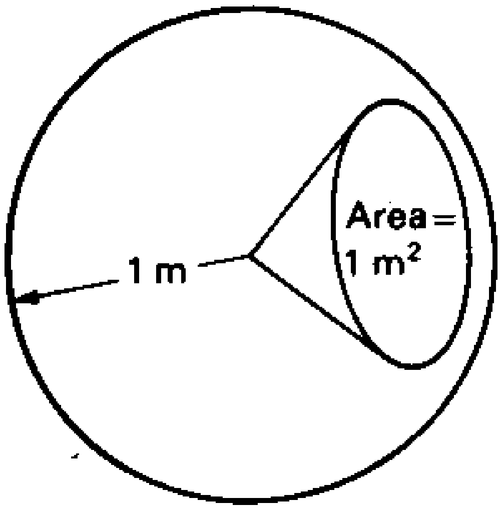
- a source that can be considered to be concentrated at a point

4) uniform point source

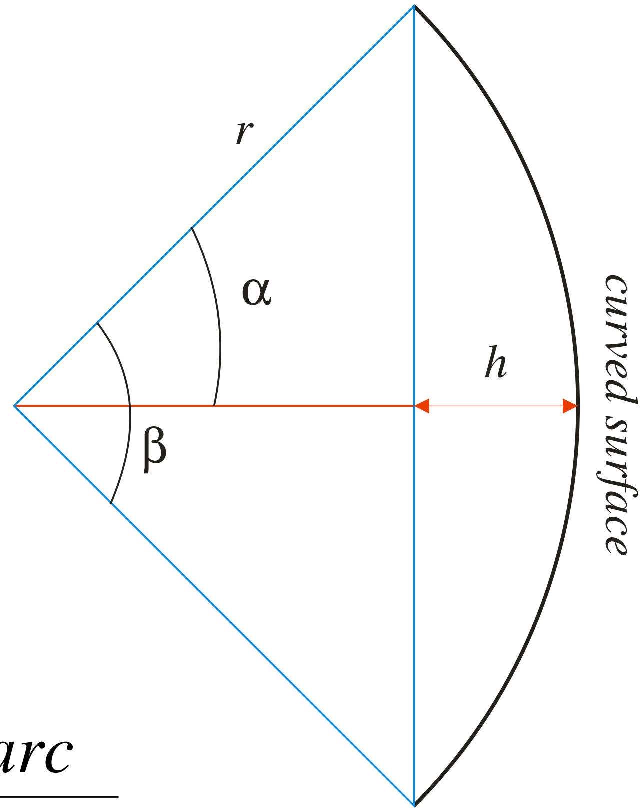
- a point source emitting light evenly in all directions

5) steradian (unit solid angle) ($\omega$)

- solid angle subtended at the center of a sphere 1 m radius by 1 $m^2$ of area on the surface of the sphere



# Relationship between solid angle $\omega$ and plane angle $\beta$




$$\beta = 2\alpha$$

- arc [radian] $\beta = \dfrac{arc}{radius}$

- solid angle [steradian] $\omega = \dfrac{surface\ area}{(radius)^2}$

- surface area *A* covered by spherical segment of height *h*

$$A = 2\pi r h$$

$$h = r - r\cos\alpha = r(1-\cos\alpha)$$

$$A = 2\pi r\left[r(1-\cos\alpha)\right] = 2\pi r^2(1-\cos\alpha)$$

$$\omega = \frac{A}{r^2} = \frac{2\pi r^2(1-\cos\alpha)}{r^2} = 2\pi(1-\cos\alpha)$$

$$\omega = 2\pi(1-\cos\frac{\beta}{2})$$

## 6) lumen

- the luminous flux emitted in a unit solid angle by a uniform point source having a luminous intensity of 1 cd
- Consider a point source of 1 cd, at centre (oo) of transparent sphere of radius $r = 1$ m
  - luminous flux through each 1 $m^2$ is 1 lm

$$S_A = 4\pi r^2 = 4\pi$$

$$\therefore \varphi_{\text{total}} = 4\pi \ \ [\text{lm}]$$

  - for a point source of $I$ cd , $d\phi$ in $d\omega$ steradians is

$$d\phi = I \cdot d\omega \rightarrow I = \frac{d\phi}{d\omega}$$

7) mean spherical luminous intensity ($I_{mean}$)

- average value of luminous intensity in all directions

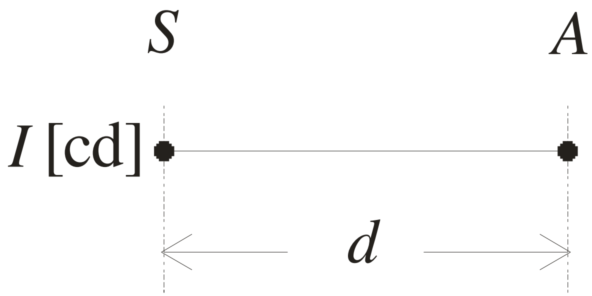
8) illuminance ($E$)

- luminous flux per unit area
- units [$lm/m^2$] or lux [lx]

- consider a sphere $r$ = 1 m, point source of 1 cd at oo

$$\frac{E_{(\text{at}\ r)}}{E_{(\text{at}\ r=1\ \text{m})}} = \frac{\phi/4\pi r^2}{\phi/4\pi} = \frac{4\pi}{4\pi r^2} = \frac{1}{r^2}$$

- inverse square law of illumination



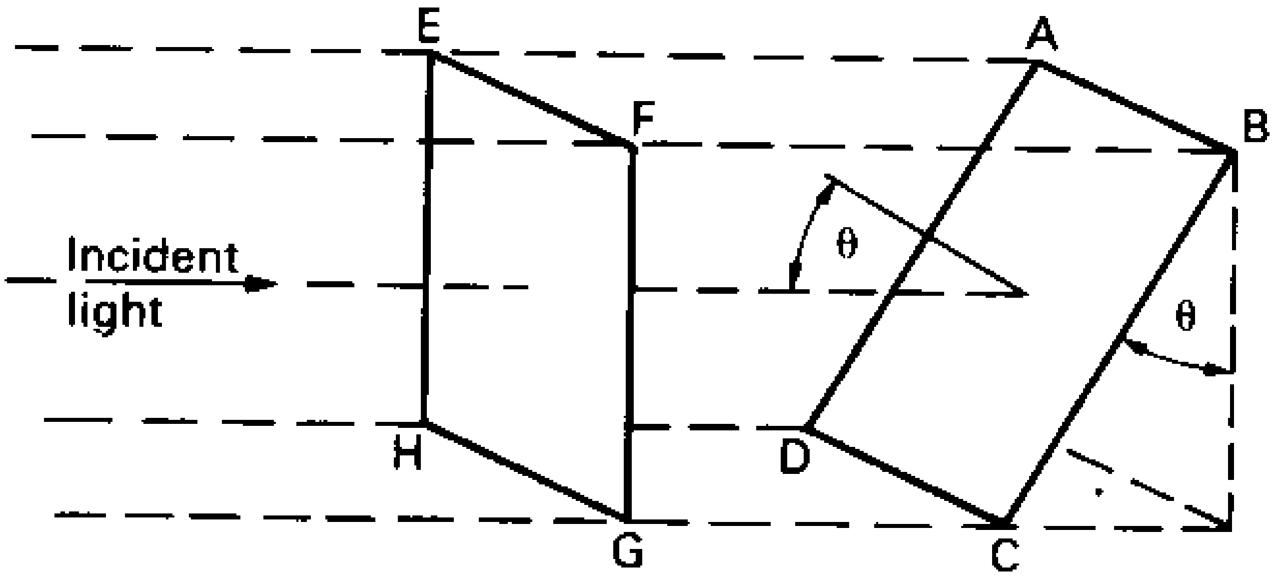

$$E_A = \frac{I}{d^2}$$

## 9) Luminance (*L*)

- of a source in a given direction
- is the luminous intensity in that direction per unit of projected area
- unit [cd/$m^2$]
- e.g.

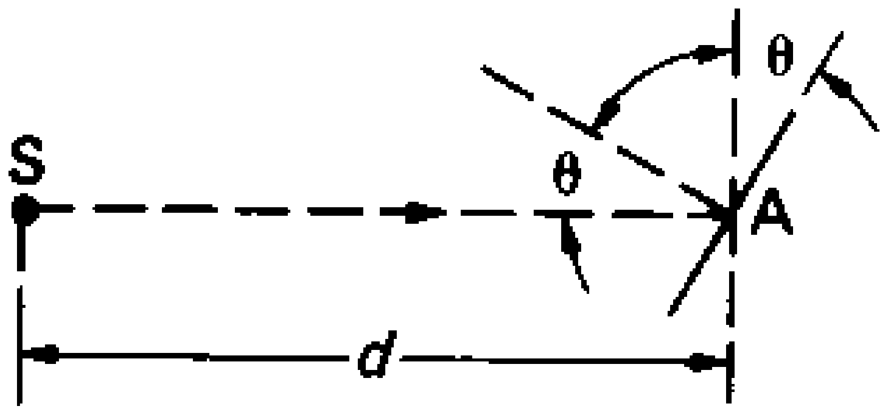
| Source | *L* [cd/$m^2$] |
|---|---|
| Zenith sun | $6 \times 10^8$ |
| Tungsten bulb, gas-filled, clear (100 W) | $6.5 \times 10^6$ |
| Mercury low-pressure, fluorescent (80 W) | $0.9 \times 10^4$ |
| Clear blue sky | $0.4 \times 10^4$ |

# 9.4 Cosine law of illuminance




$$\frac{E_{\mathrm{ABCD}}}{E_{\mathrm{EFGH}}}=\frac{\phi/S_{ABCD}}{\phi/S_{EFGH}}=\frac{S_{EFGH}}{S_{ABCD}}=\cos\theta$$

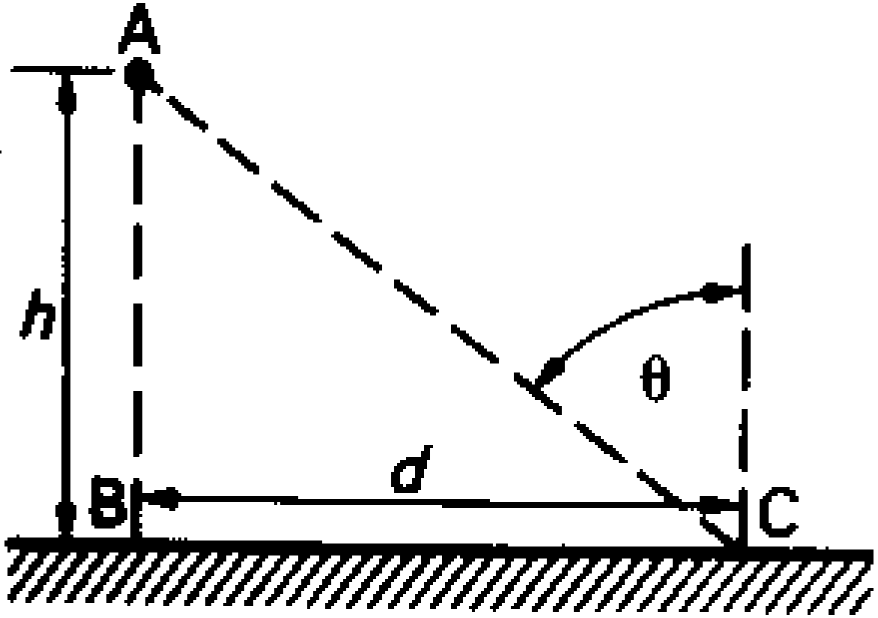
- if the surface at *A*, illuminated from a point source *S*
  - is tilted so that the angle of incidence of light is $\theta$




- the illuminance $E_A$ is

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

# 9.5 Illuminance on a surface




$$AC = \left(h^2 + d^2\right)^{\frac{1}{2}}$$

$$\cos\theta = \frac{h}{\left(h^2 + d^2\right)^{\frac{1}{2}}}$$

Inverse square law + cosine law of *E*

$$E_B = \frac{I_{AB}}{h^2}$$

$$E_C = \frac{I_{AC}\cos\theta}{AC^2} = I_{AC} \cdot \frac{h}{\left(h^2 + d^2\right)^{\frac{3}{2}}}$$

- Assume the luminous intensity is uniform in the lower hemisphere

$$I_{AB} = I_{AC} = I$$

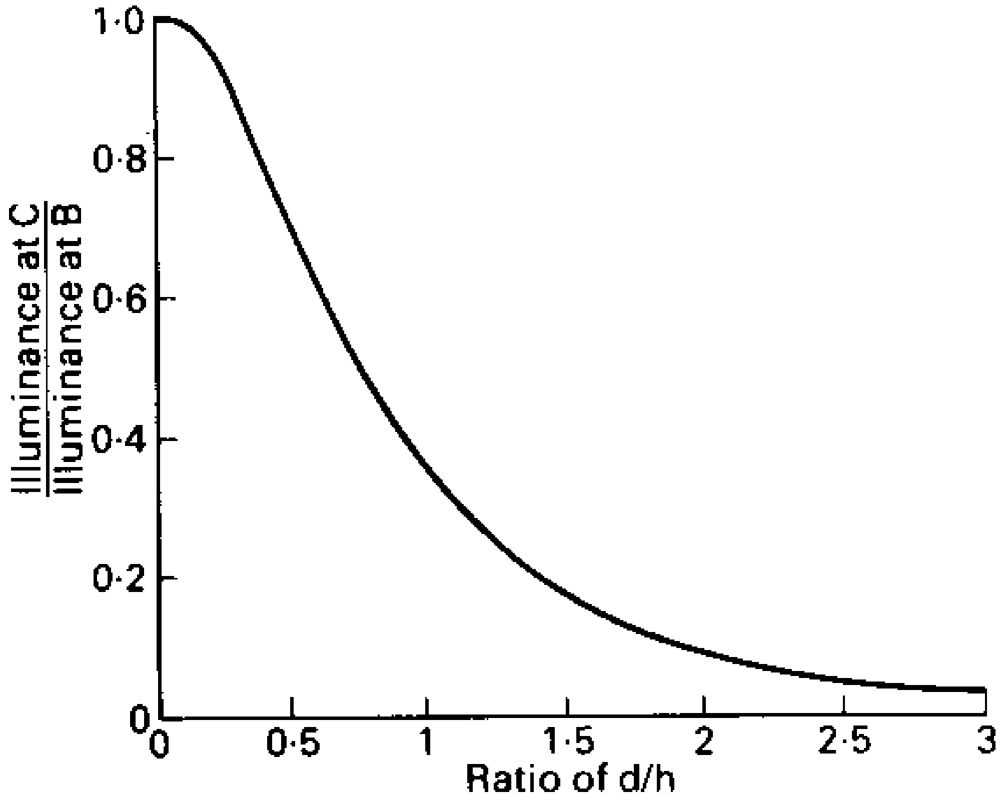
$$I = E_B \cdot h^2$$

$$I = E_C \cdot \frac{\left(h^2 + d^2\right)^{\frac{3}{2}}}{h}$$

$$E_C = E_B \cdot \frac{h^3}{\left(h^2 + d^2\right)^{\frac{3}{2}}} = E_B \left[\frac{h}{\left(h^2 + d^2\right)^{\frac{1}{2}}}\right]^3 = E_B \cos^3 \theta$$

$$E_C = E_B \cos^3 \theta$$

$$E_C = E_B \cdot \frac{h^3}{\left(h^2\left[1+\left\{\frac{d}{h}\right\}^2\right]\right)^{\frac{3}{2}}} = \frac{E_B}{\left[1+\left\{\frac{d}{h}\right\}^2\right]^{\frac{3}{2}}}$$




- *E* falls dramatically away from points directly over the source
- improvement:
    - distribute light at angle of 60-75° to vertical using a luminaire

# 9.6 Factors of illumination

## Utilisation factor (U.F.)

- Let
  - $A$ = area of surface to be illuminated
  - $E$ = average illuminance on surface

- $\therefore$ useful luminous flux = $EA$

$$U.F. = \frac{\text{useful lumens}}{\text{total lumens emitted by lamps}}$$

$$U.F = \frac{EA}{\text{total lumens from lamps}}$$

- influence on U.F.
    - reflection factor ($r_{ceilng}$, $r_{wall}$ )
    - room index
- tables of U.F.s for various
    - {shapes, luminaires, spacing/height ratio, ceiling colour}
        - are available, e.g.
            - open reflectors, U.F. = 0.4 -  0.8
            - pendant fittings, U.F. ≈ 0.1

## Maintenance factor (M.F.)

$$M.F. = \frac{\text{Illuminance at given time}}{\text{Illuminance with lamps NEW and fittings CLEAN}}$$

- takes account of depreciation in useful luminous flux resulting from
  - accumulation of dust on bulbs and luminaires
  - fall in output of lamp with time

$$total \quad lumens \quad from \quad lamps \quad when \quad new = \frac{EA}{U.F. \times M.F.}$$

# 9.7 Requirements of lighting

## Minimum illuminance at working plane

- $E_{min}$ at any working plane ≥ 70% $E_{max}$
- guidance for spacing of luminaires
  - 1 - 1.5 times their height above working plane, e.g.
    - factory $E_{min}$ ≥ 400 lx
    - fine working assembly $E_{min}$ = 1 – 2 klx

## Provision of shadow (or shading)

- to give objects their 3-dimensional characteristics
- to make shapes recognisable

## Task / Background / Surrounding ratio

- principal object: brightest
- background : less bright
- surrounding: least bright

- recommended illumination ratio:
  - 10 : 3 : 1

# 9.8 Electric lighting

- luminous efficacy
  - the amount of luminous flux produced per unit input power to the lighting apparatus

$$= \frac{\text{total luminous flux produced}}{\text{input power}} \quad [\text{lm/W}]$$

  - e.g.
    - 100-W gas-filled incandescent lamp: 12-20 lm/W
    - 400-W mercury lamp with yttrium coating: 50 lm/W
    - 1-kW mercury iodide lamp: 85 lm/W
    - 400-W sodium lamp: 100 lm/W
    - warm white fluorescent lamp; 60 lm/W

# Types of electric lighting

- Incandescent lamps
    - vacuum
    - gas-filled
- Discharge lamps
    - high-pressure mercury–vapour
    - low-pressure and high-pressure sodium vapour
    - low-pressure fluorescent mercury vapour
- LED lamps

# Examples

1) A 500-cd lamp emits light uniformly in all directions and is suspended 5 m above the centre of a working plane which is 7 m square. Find the illuminance below the lamp and also at each corner of the square.

2) A lamp having a luminous intensity of 500 lumens per steradian is hung 4 m above a circular area of 6 m diameter. Calculate the illuminance at
   a. centre of area
   b. periphery of the area
   c. average illuminance on the area

3) A drawing hall 30 m x 15 m with a ceiling height of 5 m is provided with general illumination of 120 lx. Taking U.F. = 0.5, M.F. = 0.71, determine the number of fluorescent tubes required, their spacing, mounting height and total wattage. The luminous efficacy of a fluorescent tube is 40 lm/W for an 80-W tube.

- End of Lecture 9 -