Summary of Previous lecture

→ Basics of Thermal Radiation

→ emission characteristics of surface

1) emissive Power (E_b)

2) emissivity (ε)

3) monochromatic emissive Power ($E_{b\lambda}$)

4) monochromatic emissivity (ε_λ)

$$E_b = \int_{\lambda=0}^{\lambda=\infty} E_{b\lambda}\, d\lambda$$

$$= 2\pi C_1 \int_{\lambda=0}^{\lambda=\infty} \frac{1\, d\lambda}{\lambda^5\left(\exp(C_2/\lambda T)-1\right)}$$

$$= 2\pi C_1 \frac{\sigma T^4}{C_2^4}\left(\frac{\pi^4}{90}\right)$$

→ Various law

1) Planck's law
2) Wien's law
3) Kirchoff's law

$\left.\right\}$ black body

4) Stefan boltzman law

$$E_b = \sigma T^4$$

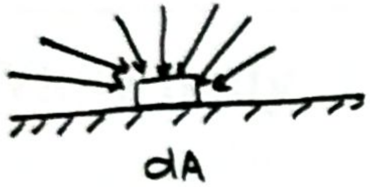
$$\sigma = 5.67 \times 10^{-8}\ W/m^2K^4$$

→ Surface Property like

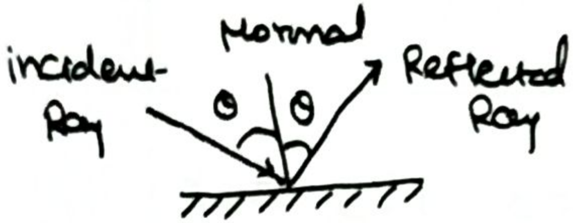
Absorptivity, Reflectivity, Transmissivity

Radiation incident on surface

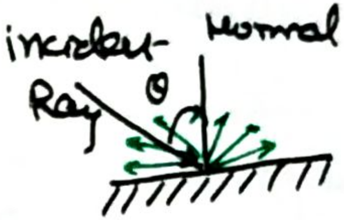
- **Irradiation (G)**
  It is defined as the total incident radiation on surface from all direction per unit area, per unit time and is expressed in term of W/m^2



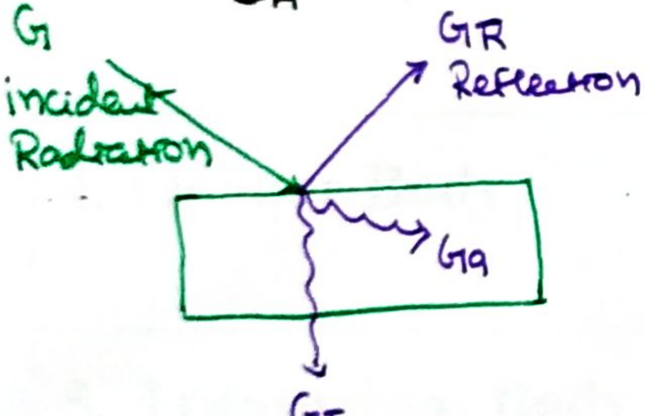
$$G = \frac{dq}{dA}$$



Specular Reflection



Diffuse Reflection (intensity is same in All Direction)



$$G = G_a + G_R + G_T$$

$$\frac{G}{G} = \frac{G_a}{G} + \frac{G_R}{G} + \frac{G_T}{G}$$

$$1 = \frac{G_a}{G} + \frac{G_R}{G} + \frac{G_T}{G}$$

$$1 = \alpha + \rho + \tau$$

$$\alpha = \frac{G_a}{G} = \text{Absorptivity}$$

$$\rho = \frac{G_R}{G}$$

$$\tau = G_T/G$$

* monochromatic Irradiation (G_λ)

$$G_\lambda = \frac{G}{d\lambda} \qquad E_{b\lambda} = \frac{E_b}{d\lambda}$$

$$G = \int_{\lambda=0}^{\lambda=\infty} G_\lambda \, d\lambda$$

α_λ

ρ_λ

τ_λ

Concept of various type of surface (bodies)

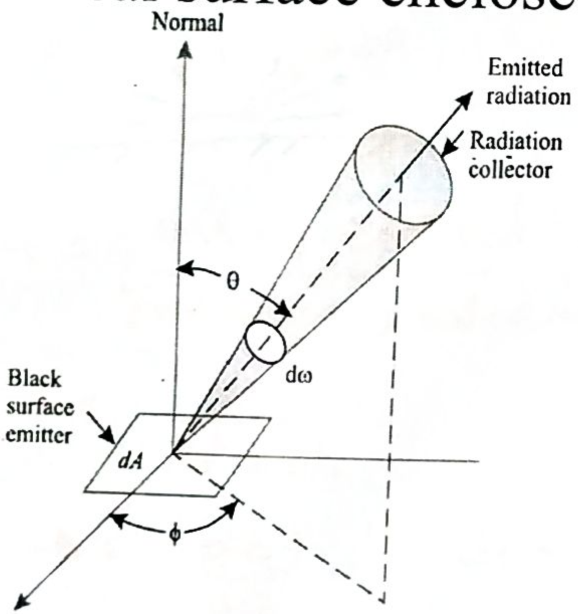
Types of Surface	Value of α, ρ , τ	Characteristics
1. Black Body	$\alpha=1 \quad \tau=0 \quad \rho=0$	Absorbs All the Radiant energy
2. White Body	$\alpha=0 \quad \rho=1 \quad \tau=0$	All the energy Reflected back
3. Gray Body	$\alpha=\alpha_\lambda$	Absorptivity of surface Doesnot vary with variation of λ wave length
4. Opaque Body	$\tau=0 \quad \alpha+\rho=1$	No irradiation Transmitted through
5. Transparent Body	$\alpha=0 \quad \rho=0 \quad \tau=1$	All the irradiation Transmitted through Surface

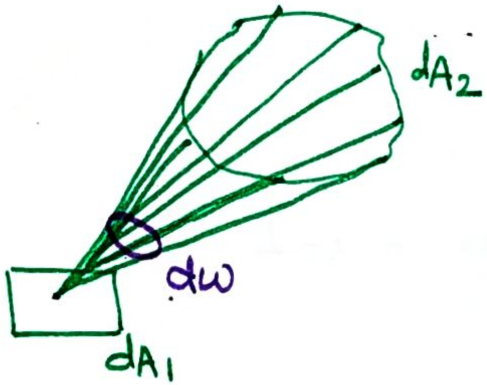
Terms Related to Directional Nature of Radiation

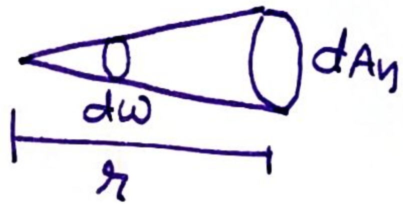
Solid Angle

A unit solid angle is defined as the angle covered by unit area on a surface of sphere of unit radius when joined with the centre of the sphere and it is measured in steradians

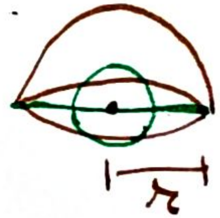
Solid angle is defined as a portion of the sphere enclosed by a conical surface with vertex of the cone at the centre of sphere. It is measured by the ratio of the spherical surface enclosed by the cone to the square of the radius of sphere







$$d\omega = \frac{dA_n}{r^2}$$



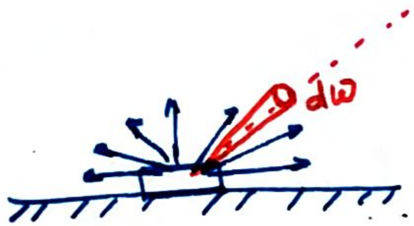
$$\frac{2\pi r^2}{r^2} = 2\pi$$

- **Intensity of radiation**

Intensity of radiation is defined as rate of energy leaving a surface in a given direction per unit solid angle per unit area of the emitting surface normal to mean direction in space

- **Monochromatic Intensity of radiation**

It is defined as the radiant energy emitted by a black body at temperature T, streaming through a unit area normal to the direction of propagation per unit wavelength per unit solid angle about the propagation of beam



$$I_b = \frac{\text{energy emitted}}{\text{Projected area} \times \text{Solid Angle}}$$

$$= \frac{W}{m^2 \times sr}$$

$$I_b = \frac{de}{d\omega} \Rightarrow de = I\, d\omega$$

$$\int de = \int I\, d\omega$$

$$I_{b\lambda} = \frac{\text{energy emitted}}{\text{Projected area} \times \text{wave length} \times \text{Solid Angle}}$$

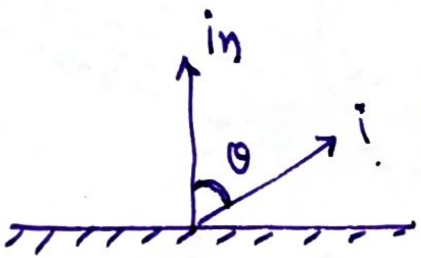
$$= \frac{W}{m^2 \times \mu m \times sr}$$

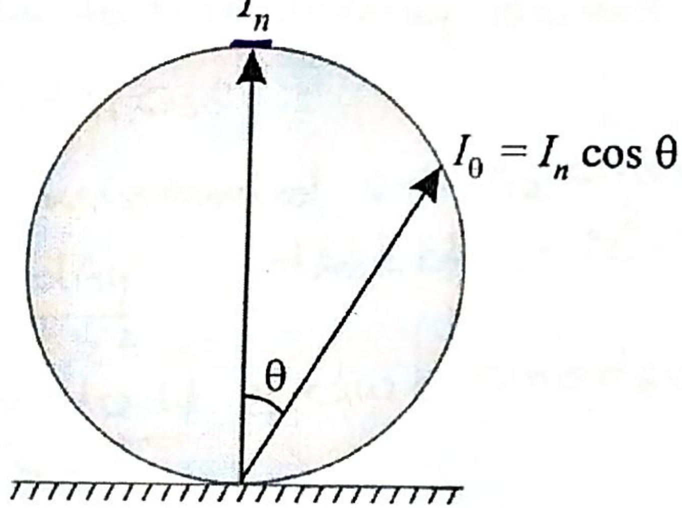
$$I_{b\lambda} = \frac{de}{d\lambda\, d\omega}$$

$$I_b = \int_{\lambda=0}^{\lambda=\infty} I_{b\lambda}\, d\lambda \quad W/m^2 sr$$

Lambert cosine law

Law states that the total emissive power from a surface in any direction is directly proportional to the cosine of the angle of emission



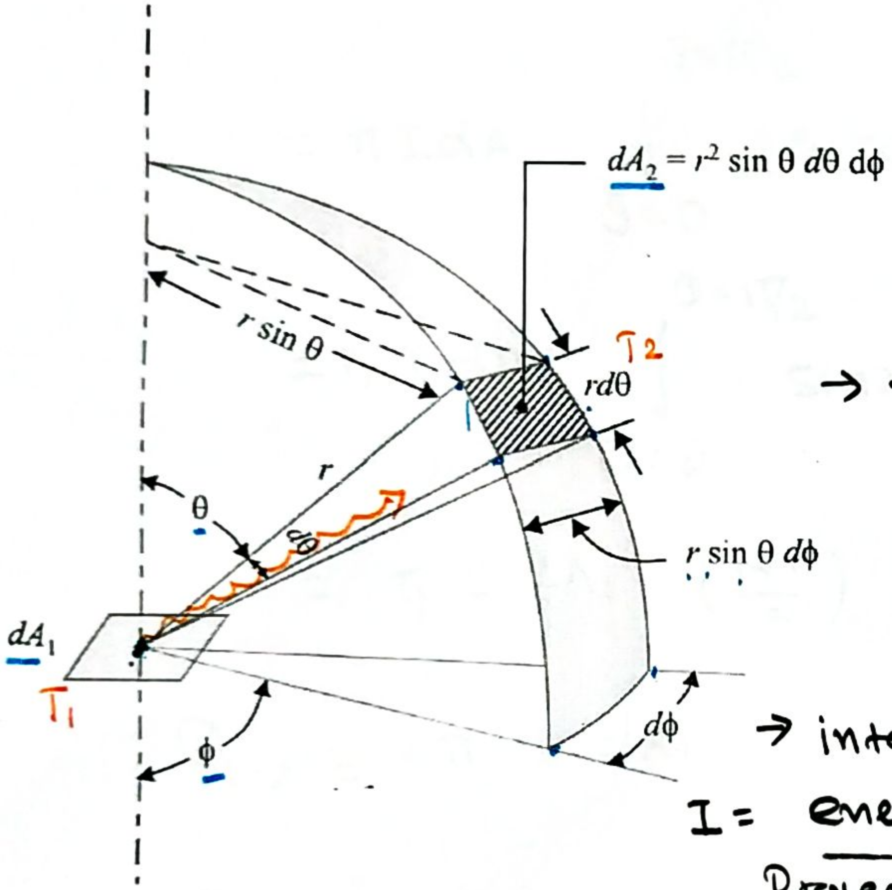


$i_\theta = $ ____ ?

$$\boxed{i_\theta = I_n \cos\theta}$$

Relation between intensity of radiation and emissive power

→ cylindrical



→ heat Transfer from dA_1 to elementary area dA_2

→ Projected area of dA_1 on a plane Perpendicular to line joining dA_1 and dA_2

$= dA_1 \cos\theta$

→ Solid Angle subtended by dA_2 on dA_1

$$d\omega = \frac{dA_n}{r^2} \qquad dA_n = dA_2 = r^2 \sin\theta \, d\theta \, d\phi$$

$$d\omega = \frac{\cancel{r^2} \sin\theta \, d\theta \, d\phi}{\cancel{r^2}} \Rightarrow d\omega = \sin\theta \, d\theta \, d\phi$$

→ intensity of Radiation

$$I = \frac{\text{energy emitted}}{\text{Projected area} \times \text{Solid Angle}} = \frac{d\Phi_{1-2}}{dA_1 \cos\theta \times \sin\theta \, d\theta \, d\phi}$$

$$d\Phi_{1-2} = I \, dA_1 \cos\theta \, \sin\theta \, d\theta \, d\phi$$

Total heat Transfer

$$\int d\Phi_{1-2} = I \, dA_1 \int_{\theta=0}^{\theta=\pi/2} \int_{\phi=0}^{\phi=2\pi} \sin\theta \cos\theta \, d\theta \, d\phi = I \, dA_1 \int_{\theta=0}^{\theta=\pi/2} \sin\theta \cos\theta \, d\theta \, [2\pi - 0]$$

$$\varphi_{1-2} = I dA_1 \int_{\theta=0}^{\theta=\pi/2} \sin\theta \cos\theta \, d\theta \, (2\pi - 0)$$

$$= \pi I dA_1 \int_{\theta=0}^{\theta=\pi/2} 2 \sin\theta \cos\theta \, d\theta$$

$$= \pi I dA_1 \int_{\theta=0}^{\theta=\pi/2} \sin 2\theta \, d\theta$$

$$= \pi I dA_1 \left(\frac{1+1}{2} \right)$$

$$\varphi_{1-2} = \pi I dA_1$$

$$E = \frac{\varphi}{dA_1}$$

$$\boxed{\varphi = E dA_1}$$

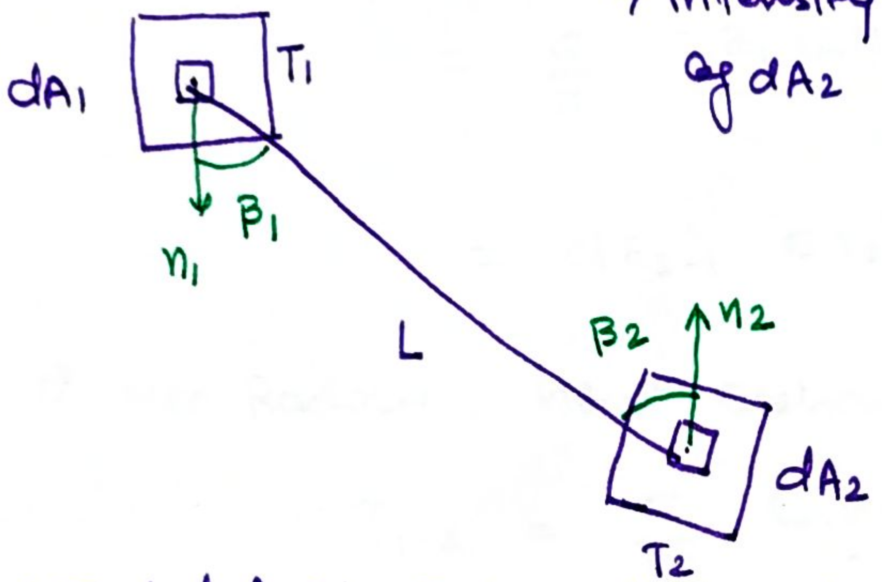
$$E d\cancel{A_1} = \pi I d\cancel{A_1}$$

$$E = \pi I$$

$$\boxed{E_b = \pi I_b}$$

$$E_{b\lambda} = \pi I_{b\lambda}$$

Radiation Heat Exchange between two black surface



→ intensity of Radiation i emitted by dA_1 in the Direction of dA_2

$$E_b = \pi I_b \qquad E_b = \sigma T_1^4$$

$$I_b = \frac{E_b}{\pi}$$

$$I_b = \frac{\sigma T_1^4}{\pi}$$

$$I_b = \frac{\sigma T_1^4}{\pi} \cos\beta_1$$

→ Solid Angle subtended by dA_2 at dA_1 $\left(\frac{dA_y}{r^2}\right)$

$$= \frac{dA_2 \cos\beta_2}{L^2}$$

→ Rate at which Radiation emitted by dA_1 flows toward dA_2

$$i = \frac{d\phi}{A \times d\omega} \Rightarrow d\phi = i \times A \times d\omega$$

$$d\phi_{1-2} = \frac{\sigma T_1^4}{\pi} \cos\beta_1 \times dA_1 \times \frac{dA_2 \cos\beta_2}{L^2}$$

$$d\phi_{1-2} = \frac{\cos\beta_1 \cos\beta_2 \, dA_2}{\pi L^2} \sigma T_1^4 dA_1$$

$$= dF_{1-2} \; \sigma T_1^4 dA_1$$

$$dF_{1-2} = \frac{\cos\beta_1 \cos\beta_2 \, dA_2}{\pi L^2}$$

dF_{1-2} = Shape factor

= view factor

= Configuration factor

→ Similarly Rate at which Radiation emitted by dA_2 flows toward dA_1 and is absorbed by dA_1

$$= \frac{\sigma}{\pi} \frac{\cos\beta_1 \cos\beta_2 \, dA_1 dA_2}{L^2} T_2^4$$

$$= dF_{2-1} \, \sigma T_2^4 \cdot dA_2$$

→ Net Radiative heat exchange Rate

$$d\Phi_{1-2} = \frac{\sigma}{\pi} \frac{\cos\beta_1 \cos\beta_2 \, dA_1 dA_2}{L^2} (T_1^4 - T_2^4)$$

$$= dF_{1-2} \, \sigma (T_1^4 - T_2^4) \, dA_1$$

$$= dF_{2-1} \, \sigma (T_1^4 - T_2^4) \, dA_2$$

from above eqn

$$dF_{1-2} \, dA_1 = dF_{2-1} \, dA_2$$

Reciprocity Theorem