# Radiation Assignment Solution

1. Radiant energy with an intensity of 800 W/m$^2$ strikes a flat plate normally. The absorptivity is twice the transmissivity and thrice the reflectivity. Determine the rate of absorption, transmission and reflection of energy.

Ans:) transmissivity of opaque solid = 0.

Let, $\alpha$ = absorptivity
$\rho$ = reflectivity
$\tau$ = transmissivity.

From energy balance,

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

or, $\alpha + \frac{\alpha}{2} + \frac{\alpha}{3} = 1$

$\Rightarrow \alpha = 0.5455$

$\therefore$ Absorption $Q_a = \alpha Q_0 = 0.5455 \times 800$
$= 436.4 \text{ W/m}^2$

Transmission $Q_t = \tau Q_0 = \frac{0.5455}{3} \times 800$
$= 145.47 \text{ W/m}^2$.

Reflection $Q_r = \rho Q_0 = \frac{0.5455}{2} \times 800 = 218.2 \text{ W/m}^2$.

from earth

2. Consider a tungsten filament light bulb whose filament is at temperature of 2860K. If the filament is considered to be gray, what fraction of total energy emitted by the bulb is in the visible wavelength spectrum from 0.35 μm to 0.7 μm. If the filament is a rectangle of size 5mm×2mm and consumes 60W, determine the efficiency of the bulb.

Ans:) $\lambda_1 T = 0.35 \times 2860 = 1001$ μm-K.

$\lambda_2 T = 0.7 \times 2800 = 2002$ μm-K.

$F_{0-\lambda_1} = 0.00032$

$F_{0-\lambda_2} = 0.0667$

$\therefore F_{\lambda_1-\lambda_2} = F_{0-\lambda_2} - F_{0-\lambda_1}$

$= 0.0667 - 0.00032 = 0.06638.$

Only 6.638% of energy is emitted in the visible wavelength range.

The remaining 93.362% goes to heat the room,

Obviously, tungsten filament bulbs are highly inefficient as sources of light.

Area of the bulb filament from two sides

$= 2 \times (0.005 \times 0.002) = 20 \times 10^{-6}\ m^2$

Energy in the visible region

$= 0.06638 \times 5.67 \times 10^{-8} \times 20 \times 10^{-6} \times (2860)^4$

$= 5.036$ W

$\therefore$ Efficiency $= \frac{5.036}{60} = 0.0839$ or $8.39\%$.

3. A small black body has a total emissive power of $4.5 kW/m^2$. Determine its surface temperature and the wavelength of maximum emission. In which range of spectrum does this emission fall?

Sol: $E = \sigma_b T^4$

$4.5 \times 1000 = 5.67 \times 10^{-8} T^4$

$\Rightarrow T = 530.77$ K

The wavelength of emission maximum is given by Wein's law. That is

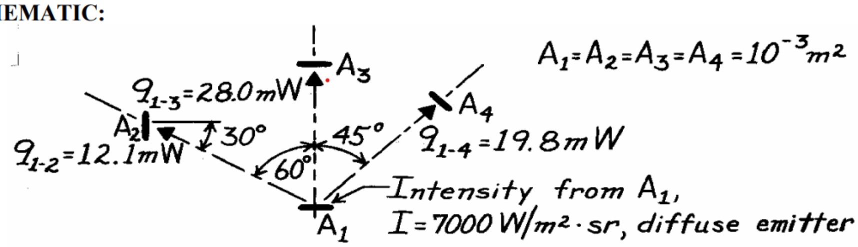
$$\lambda_{max} T = 2.8908 \times 10^{-3}$$

$$\lambda_{max} = \frac{2.898 \times 10^{-3}}{530.77}$$

$$= 5.46 \times 10^{-6}\, m = 5.46\ \mu m.$$

4. The rate at which radiation is intercepted by each of the three surfaces is known as shown in the figure. Evaluate the irradiation at each of the three surfaces.

**SCHEMATIC:**




The irradiation at surface j due to emission from surface 1 is,

$$G_j = \frac{q_{1-j}}{A_j}$$

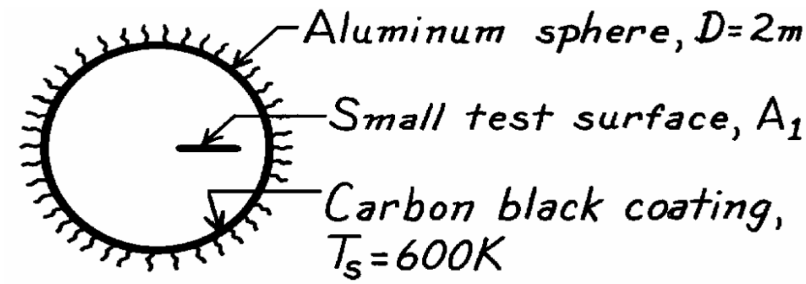
$$\therefore A_1 = A_2 = A_3 = A_4 = 10^{-3}\ m^2.$$

$$\therefore G_2 = \frac{12.1 \times 10^{-3}}{10^{-3}} = 12.1\ W/m^2$$

$$G_3 = \frac{28 \times 10^{-3}}{10^{-3}} = 28\ W/m^2$$

$$G_4 = \frac{19.8 \times 10^{-3}}{10^{-3}} = 19.8\ W/m^2.$$

5. Estimate the irradiation on a small test object placed inside an evacuated aluminum (D = 2m, serving as a radiation test chamber) sphere when its inner surface is lined with carbon black and at 500K. What effect will surface coating have?




Assumptions :- (i) Sphere walls are isothermal
(ii) Test surface area is small compared to enclosed surface

This isothermal sphere in an enclosure behaves like a black body.
∴ The irradiation on a small surface within the enclosure is equal to the blackbody emissive power at the temp. of enclosure.

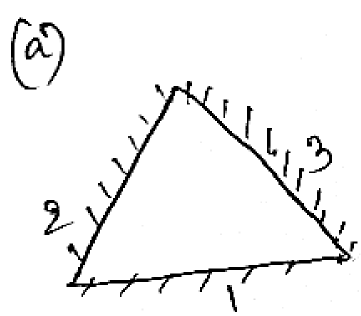
$\therefore G_1 = E_b T_s = \sigma T_s^4 = 7348 \ W/m^2$.

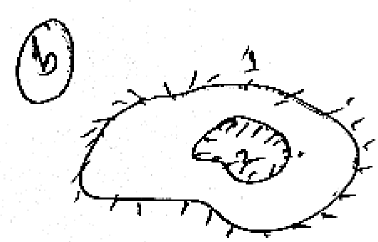
The irradiation is independent of the nature of the enclosure surface coating properties.

6. Calculate the shape factors for the configurations shown in the figures given below:

(a) long tube with cross-section of equilateral triangle.

(b) black body inside a black enclosure.



Ans:)

(a) For surface 1:

$$F_{11} + F_{12} + F_{13} = 1$$

The flat surface 1 cannot see itself and so $F_{11} = 0$. That gives

$$F_{12} + F_{13} = 1$$

Due to symmetry,

$$F_{12} = F_{13} = 0.5$$

Similarly, for surface 2,

$$F_{21} + F_{23} = 1$$

$$\Rightarrow F_{23} = 1 - F_{21}$$

Again, $F_{21} = \frac{A_1}{A_2} F_{12} = F_{12}$ $[\because A_1 = A_2]$

$$\Rightarrow F_{23} = 1 - F_{12} = 1 - 0.5 = 0.5.$$

(b) $F_{11} + F_{12} = 1$

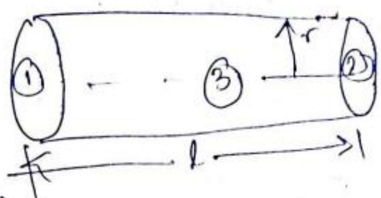
$$F_{11} = 1 - \frac{A_2}{A_1} F_{21}$$

Further, $F_{21} = 1$ so,

$$F_{11} = 1 - \frac{A_2}{A_1}$$

7. Consider a thin hollow cylinder of 8cm diameter and 10cm length. If the radiant shape factor of the circular surface of this cylinder is 0.172, estimate the shape factor of curved surface of the cylinder with respect to itself.

Ans:)




for surfaces 1 and 2,

$$A_1 F_{12} = A_2 F_{21}$$

Since, $A_1 = A_2$, we get.

$$F_{12} = F_{21} = 0.172.$$

Also, $F_{11} = F_{22} = 0$.

$F_{31} = F_{32}$ [symmetry].

Now, $F_{11} + F_{12} + F_{13} = 1$

$\Rightarrow F_{12} + F_{13} = 1 \quad [\because F_{11} = 0]$

$\Rightarrow F_{13} = 1 - F_{12} = 1 - 0.172 = 0.828$

Also, $F_{31} + F_{32} + F_{33} = 1$

$\Rightarrow F_{31} + F_{31} + F_{33} = 1 \quad [\because F_{31} = F_{32}]$

$\Rightarrow F_{33} = [1 - 2F_{31}]$

Again, $A_1 F_{13} = A_3 F_{31}$

$\Rightarrow F_{31} = \frac{A_1}{A_3} F_{13} = \frac{\pi r^2}{2\pi r l} F_{13}$

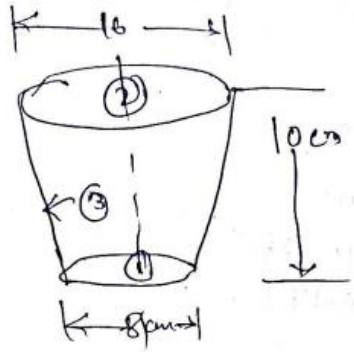
$= \frac{r}{2l} F_{13}$

$= 0.1656$

$\therefore F_{33} = 1 - 2 \times 0.1656 = 0.6688.$

8. A truncated cone of height 10cm has top and bottom diameters of 8cm and 16cm respectively. The bottom surface is stated to intercept 15% of radiation leaving top surface. Determine the shape factor between the (i) top and the conical side surfaces, and (ii) the side surface and itself.

Ans:)




$r_1 = 4cm$
$r_2 = 8cm.$
$h = 10 cm.$

Area of the curved surfaces,

$$A = \pi(r_1 + r_2)\sqrt{(r_2 - r_1)^2 + h^2}$$

$$= 405.83 \ cm^2,$$

(i) we have, $F_{21} = 0.15$.

Now, $A_1 F_{12} = A_2 F_{21}$

$$\Rightarrow F_{12} = \frac{A_2}{A_1} F_{21} = \frac{\pi \times 8^2}{\pi \times 4^2} \times 0.15 = 0.6$$

Further, $F_{11} + F_{12} + F_{13} = 1$

$F_{12} + F_{13} = 1$ $[\because F_{11} = 0]$

or, $F_{13} = 1 - F_{12} = 1 - 0.6 = 0.4$

Again, $F_{21} + F_{22} + F_{23} = 1$

$\Rightarrow F_{21} + F_{23} = 1$ $\quad [\because F_{22} = 0]$

$\Rightarrow F_{23} = 1 - F_{21}$

$= 1 - 0.15 = 0.85.$

(ii) $F_{32} = \frac{A_2}{A_3} F_{23} = \frac{\pi \times 8^2}{405.83} \times 0.85 = 0.421$

$F_{31} = \frac{A_1}{A_3} F_{13} = \frac{\pi \times 4^2}{405.83} \times 0.4 = 0.0798$

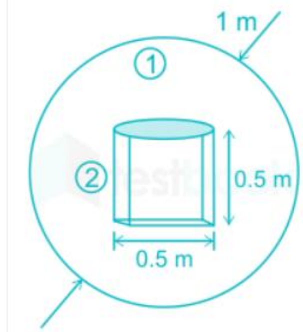
From the identity,

$$F_{31} + F_{32} + F_{33} = 1$$

$$\Rightarrow F_{33} = 1 - F_{31} - F_{32}$$

$$= 1 - 0.0495 - 0.421 = 0.5295.$$

9. A solid cylinder (surface 2) is located at the center of a hollow sphere (surface 1). The diameter of the sphere is 1m while the cylinder has a diameter and length of 0.5m each. Calculate $F_{11}$.




surface Area of sphere $(A_1) = \pi D^2 = \pi (1)^2 = \pi m^2$.

Total surface area of cylinder $(A_2) = \pi dh + 0.5 \pi d^2$

$$= \pi (0.5)(0.5) + 0.5\pi (0.5)^2$$

$$= 0.375 \pi \ m^2.$$

Since the surface area of the cylinder is either concave or flat, $\therefore F_{21} = 1$

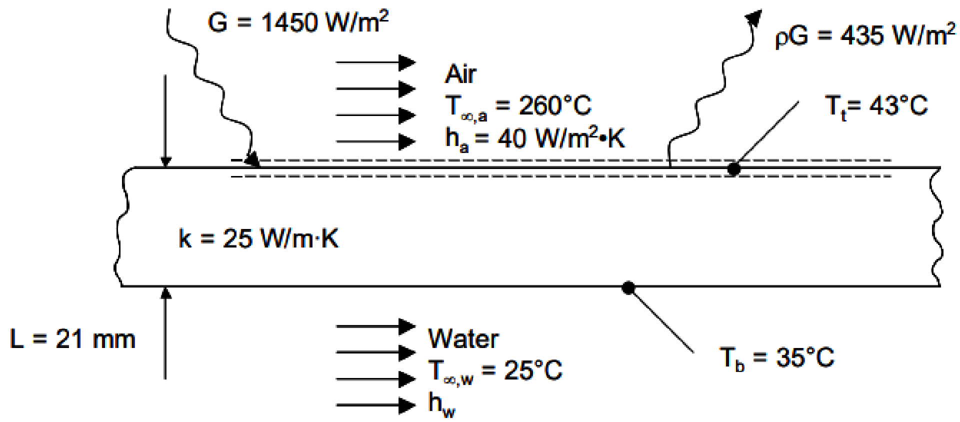
$$\because A_1 F_{12} = A_2 F_{21}$$

$$F_{12} = \frac{A_2 F_{21}}{A_1}$$

$$= \frac{0.375 \cancel{\pi} \times 1}{\cancel{\pi}} = 0.375.$$

Also, $F_{11} + F_{12} = 1 \quad \therefore F_{11} = 1 - 0.375 = 0.625.$

10. For a given system, calculate the transmissivity, reflectivity, absorptivity, and emissivity of the plate, along with the convection coefficient associated with the water flow, assuming an opaque and diffuse surface. Also assume water is opaque to thermal radiation.

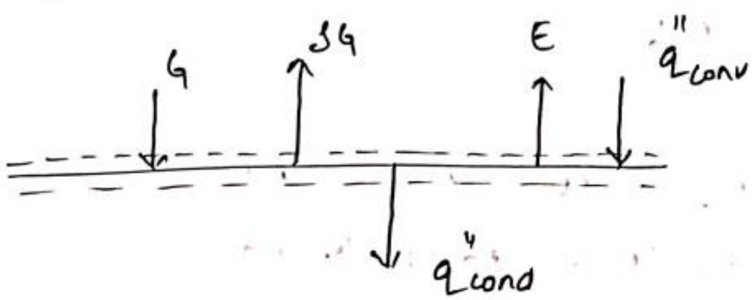



The plate is opaque $\therefore$ $\tau = 0$.

The reflectivity is, $\rho = \rho G / G = \dfrac{435}{1450} = 0.3$

Absorptivity $\alpha = 1 - \tau - \rho = 1 - 0 - 0.3 = 0.7$

Considering an energy balance on top surface,




$\therefore$ $q''_{cond} = G + q''_{conv} - \rho G - E$ $\quad \{ E = \varepsilon \sigma T_s^4 \}$.

$\therefore$ $\varepsilon = \dfrac{G + q''_{conv} - \rho G - q''_{cond}}{\sigma T_t^4} = 0.303$

Radiosity, $J = E + \rho G = 0.303 \times 5.67 \times 10^{-8} \times (273 + 43)^4 + 435$

$= 606 \ W/m^2$.

Again considering energy ~~to~~ balance on bottom surface, $q''_{cond} = q''_{conv}$

$$\therefore \ h_w = \frac{K(T_t - T_b)}{L(T_b - T_{\infty,w})}$$

$$= \frac{25 \times (43 - 35)}{0.021\ (35 - 25)} = 952 \ W/m^2K.$$