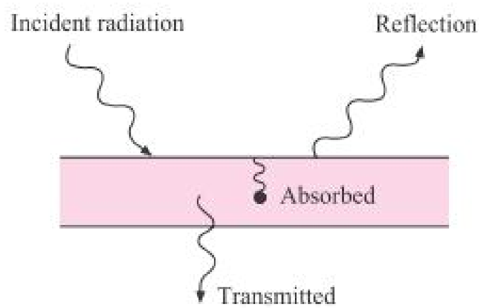
Radiation Heat Transfer

Thermal radiation is that electromagnetic radiation emitted by a body as a result of its temperature.

Radiation Properties

When radiant energy strikes a material surface, part of the radiation is reflected, part is absorbed, and part is transmitted.



If
ρ = the fraction reflected = Reflectivity
α = the fraction absorbed = absorptivity
τ = the fraction transmitted = transmissivity

This mean

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

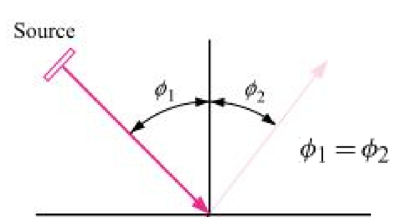
For most solid, $\tau = 0$

$$\therefore \ \rho + \alpha = 1$$

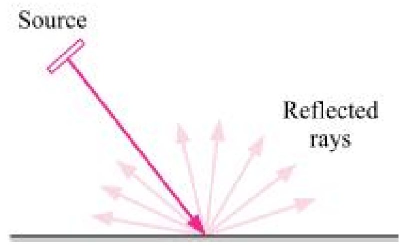
For black body $\rho = 0$

Reflection is of Two Types

1- Specular reflection, when the angle of incidence is equal to the angle of reflection.



2- Diffuse reflection, when an incident beam is distributed uniformly in all directions after reflection.



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The emissive power of a body E is defined as the energy emitted by the body per unit area and per unit time.

Black body is a body which absorbs all the incident radiation falling upon it. Thus, **Eb** is the emissive power of a black body.

$$\therefore \epsilon = \frac{E}{Eb}$$

For black body, $\epsilon = 1$

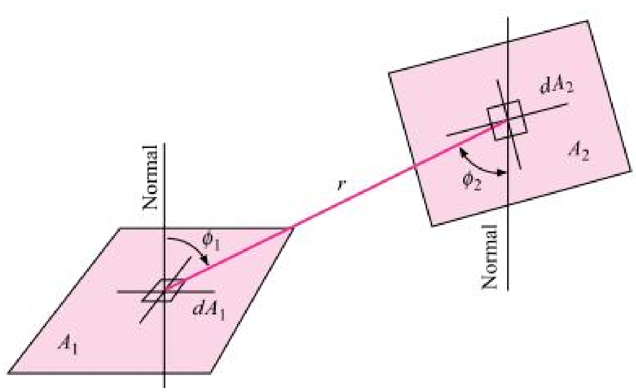
and $$Eb \propto T^4$$

Where T is the absolute temperature of a body (K).

The constant proportion (σ) is called Stefan-Boltzmann constant = 5.669×10^{-8} W/m^2.K^4

$$q_{net} = A \cdot \sigma (T_1^4 - T_2^4)$$

Radiation Shape Factor



Consider two black surfaces A1 and A2, as shown in Figure. The radiation shape factors are defined as:

F_{1-2} = fraction of energy leaving surface 1 that reaches surface 2
F_{2-1} = fraction of energy leaving surface 2 that reaches surface 1
F_{i-j} = fraction of energy leaving surface i that reaches surface j

The calculations of shape factors for a few geometries are given in figures 8.12 to 8.16 (also table 8.2).

The energy leaving surface 1 and arriving at surface $E_{b1}A_1F_{12}$
The energy leaving surface 2 and arriving at surface $E_{b2}A_2F_{21}$

Since the surfaces are black, all the incident radiation will be absorbed, and the net energy exchange is

$$E_{b1}A_1F_{12} - E_{b2}A_2F_{21} = Q_{1-2}$$

If both surfaces are at the same temperature, there can be no heat exchange, that is, $Q_{1-2} = 0$. Also, for $T_1 = T_2$

$$E_{b1} = E_{b2}$$

so that

$$A_1F_{12} = A_2F_{21} \qquad \textbf{[8-18]}$$

The net heat exchange is therefore

$$Q_{1-2} = A_1F_{12}(E_{b1} - E_{b2}) = A_2F_{21}(E_{b1} - E_{b2}) \qquad \textbf{[8-19]}$$

Equation (8-18) is known as a reciprocity relation, and it applies in a general way for any two surfaces i and j:

$$A_iF_{ij} = A_jF_{ji} \qquad \textbf{[8-18}\boldsymbol{a}\textbf{]}$$

Although the relation is derived for black surfaces, it holds for other surfaces also as long as diffuse radiation is involved.

Heat Transfer Between Black Surfaces — EXAMPLE 8-2

Two parallel black plates 0.5 by 1.0 m are spaced 0.5 m apart. One plate is maintained at 1000°C and the other at 500°C. What is the net radiant heat exchange between the two plates?

■ Solution

The ratios for use with Figure 8-12 are

$$\frac{Y}{D} = \frac{0.5}{0.5} = 1.0 \qquad \frac{X}{D} = \frac{1.0}{0.5} = 2.0$$

so that $F_{12} = 0.285$. The heat transfer is calculated from

$$\begin{aligned} q &= A_1F_{12}(E_{b1} - E_{b2}) = \sigma A_1F_{12}(T_1^4 - T_2^4) \\ &= (5.669 \times 10^{-8})(0.5)(0.285)(1273^4 - 773^4) \\ &= 18.33\ \text{kW} \quad [62{,}540\ \text{Btu/h}] \end{aligned}$$