Transmission of Heat

Heat Transmission

Heat can be transferred from one part of system to another. It is called heat transmission.

There are three methods of heat transmission :

(i) **Conduction** In solids, heat is transmitted from higher temperature to lower temperature without actual movements of the particles. This mode of transmission of heat is called conduction.

(ii) **Convection** The process of heat transmission in which the particles of the fluid (liquid or gas) move is called convection.

Land breeze, see-breeze and trade wind are formed due to convection.

(iii) **Radiation** The process of heat transmission in the form of electromagnetic waves, is called radiation.

Radiation do not require any medium for propagation.

It propagates without heating the intervening medium.

The heat energy transferred by radiation is called radiant energy.

Heat from the sun reaches the earth by radiation.

Conduction of Heat in a Conducting Rod

Steady State

The state of a conducting rod in which no part of the rod absorbs heat is called the steady state.

Isothermal Surface

A surface of a material whose all points are at the same temperature is called an isothermal surface.

Temperature Gradient

The rate of change of temperature with distance between any two isothermal surfaces is called temperature gradient.

$$\text{Temperature gradient} = \frac{\text{Change in temperature}}{\text{Perpendicular distance}} = \frac{\Delta\theta}{\Delta x}$$

Its SI unit is °C per metre and dimensional formula is $[L^{-1}\theta]$.

Thermal Conductivity

It measures the ability of a material to conduct heat.

The amount of heat flow in a conducting rod,

$$Q = \frac{KA\,\Delta\theta t}{l}$$

where, K = coefficient of thermal conductivity,

A = area of cross-section,

l = length of rod,

$\Delta\theta$ = temperature difference between the ends of the rod

and t = time.

The SI unit of K is $Wm^{-1}\,K^{-1}$ and its dimensional formula is $[MLT^{-3}\theta^{-1}]$.

The value of K is large for good conductors and very small for insulators.

Thermal Current and Thermal Resistance

The rate of flow of heat is known as thermal or heat current. It is denoted by H.

$$H = \frac{KA\delta\theta}{l}$$

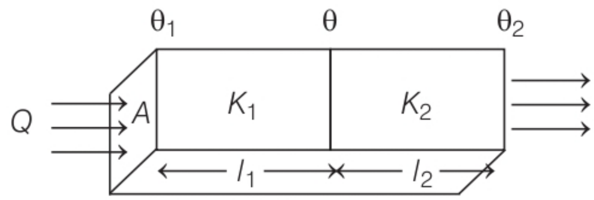
Thermal resistance is given by

$$R = \frac{\Delta\theta}{H} = \frac{l}{KA}$$

where, $\Delta\theta$ is temperature difference at the ends of the rod and H is rate of flow of heat.

Its SI unit is K/W and its dimensional formula is $[M^{-1}L^{-2}T^{3}\theta^{-1}]$.

When Two Conducting Rods are Connected in Series



Rate of heat flow, $H = \dfrac{Q}{t} = \dfrac{K_1 A(\theta_1 - \theta)}{l_1} = \dfrac{K_2 A(\theta - \theta_2)}{l_2}$

Temperature of contact surface, $\theta = \dfrac{\dfrac{K_1\theta_1}{l_1} + \dfrac{K_2\theta_2}{l_2}}{\dfrac{K_1}{l_1} + \dfrac{K_2}{l_2}} = \dfrac{K_1\theta_1 l_2 + K_2\theta_2 l_1}{K_1 l_2 + K_2 l_1}$

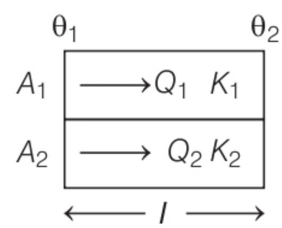
Equivalent thermal conductivity, $H = \dfrac{l_1 + l_2}{\dfrac{l_1}{K_1} + \dfrac{l_2}{K_2}}$

Equivalent thermal resistance, $R = R_1 + R_2$

When two Conducting Rods are Connected in Parallel

Rate of heat flow,

$$H = \frac{Q}{t} = \left(\frac{K_1 A_1}{l} + \frac{K_2 A_2}{l}\right)(\theta_1 - \theta_2)$$



Temperature gradient $= \dfrac{\theta_1 - \theta_2}{l}$

Equivalent thermal conductivity, $K = \dfrac{K_1 A_1 + K_2 A_2}{A_1 + A_2}$

Equivalent thermal resistance, $\dfrac{1}{R} = \dfrac{1}{R_1} + \dfrac{1}{R_2}$

Ingen-Hausz Experiment

The thermal conductivities of different materials are proportional to the square of the lengths of the melted wax on the rods of these materials in the steady state.

If $l_1, l_2, l_3, \ldots$ are the lengths of the melted wax on the rods of different materials having coefficient of thermal conductivities $K_1, K_2, K_3, \ldots$, then

$$K_1 : K_2 : K_3 : \ldots = l_1^2 : l_2^2 : l_3^2 : \ldots \text{ or } \frac{K_1}{K_2} = \frac{l_1^2}{l_2^2}$$

Formation of Ice on Lakes

Time taken to from x thickness of ice on lake,

$$t = \frac{\rho L}{2K\theta} x^2$$

where, ρ = density of ice, L = latent heat of freezing of ice,

K = coefficient of thermal conductivity of ice

and θ = temperature above lake.

Time taken to increase the thickness of ice from x_1 to x_2,

$$t = \frac{\rho L}{2K\theta} (x_2^2 - x_1^2)$$

Reflectance or Reflecting Power

The ratio of the amount of thermal radiations reflected by a body in a given time to the total amount of thermal radiations incident on the body in that time is called reflectance or reflecting power of the body.

It is denoted by r.

Absorptance or Absorbing Power

The ratio of the amount of thermal radiations absorbed by a body in a given time to the total amount of thermal radiations incident on the body in that time is called absorptance or absorbing power of the body.

It is denoted by a.

Transmittance or Transmitting Power

The ratio of the amount of thermal radiations transmitted by the body in a given time to the total amount of thermal radiations incident on the body in that time is called transmittance or transmitting power of the body. It is denoted by t.

Relation among reflecting power, absorbing power and transmitting power

$$r + a + t = 1$$

If body does not transmit any heat radiations, then $t = 0$

$$\therefore \quad r + a = 1$$

(i) r, a and t all are the pure ratio, so they have no unit and dimensions.

(ii) For perfect reflector, $r = 1$, $a = 0$ and $t = 0$.

(iii) For perfect absorber, $a = 1$, $r = 0$ and $t = 0$ (perfect black body).

(iv) For perfect transmitter, $t = 1$, $a = 0$ and $r = 0$.

Emissive Power

Emissive power of a body at a particular temperature is the total amount of thermal energy emitted per unit time per unit area of the body for all possible wavelengths.

It is denoted by e_λ.

$$e_\lambda = \frac{1}{A} \cdot \frac{d\theta}{dt}$$

Its SI unit is $Js^{-1}m^{-2}$ or Wm^{-2} and its dimensional formula is $[MT^{-3}]$.

Emissivity

Emissivity of a body at a given temperature is equal to the ratio of the total emissive power of the body (e_λ) to the total emissive power of a perfectly black body (E_λ) at that temperature.

Emissivity, $$\varepsilon = \frac{e_\lambda}{E_\lambda}$$

Perfectly Black Body

A body which absorbs completely the radiations of all wavelengths incident on it, is called a perfectly black body.

For a perfectly black body, emissive power $(E_\lambda) = 1$.

An ideal black body need not be black in colour.

The radiation from a black body depend upon its temperature only. These heat radiations do not depend on density mass, size or the nature of the body.

Lamp black is 96% black and platinum black is about 98% black.

A perfectly black body cannot be realised in practice. The nearest example of an ideal black body is the Ferry's black body.

Kirchhoff's Law

The ratio of emissive power (e_λ) to the absorptive power (a_λ) corresponding to a particular wavelength and at any given temperature is always a constant for all bodies and it is equal to the emissive power (E_λ) of a perfectly black body at the same temperature and corresponding to the same wavelength.

Mathematically, $$\left(\frac{e_\lambda}{a_\lambda}\right)_{\text{for any body}} = \text{constant } (E_\lambda)$$

Stefan's Law

Heat energy emitted per second per unit area of a perfectly black body

$$E \propto T^4 \quad \Rightarrow \quad E = \sigma T^4$$

where, σ is Stefan's constant and its value is $5.735 \times 10^{-8}\ \mathrm{Wm^{-2}\ K^{-4}}$.

If T_0 is the temperature of the surroundings, then $E = \sigma (T^4 - T_0^4)$

If ε is the emissivity of the body, then $E = \varepsilon \sigma T^4$

Energy radiated by whole body in t time, $E = \sigma A t T^4$

Newton's Law of Cooling

The rate of loss of heat of a liquid is directly proportional to the difference in temperature of the liquid and its surroundings, *i.e.*

$$-\frac{dT}{dt} \propto (T - T_0)$$

where, T and T_0 are the temperatures of the liquid and its surroundings.

Wien's Displacement Law

Wavelength corresponding to maximum emission decreases with increasing temperature.

$$\lambda_m T = \text{constant } (b)$$

where, λ_m = Wavelength corresponding to which maximum energy is radiated,

T = Absolute temperature

and b = Wien's constant $= 2.898 \times 10^{-3} \approx 3 \times 10^{-3}$ mK

When temperature of a black body increases, colour changes towards higher frequency, *i.e.* from red $\rightarrow$ orange $\rightarrow$ yellow $\rightarrow$ green $\rightarrow$ blue $\rightarrow$ violet.

Solar Constant

The amount of heat received from the sun by one square centimetre area of a surface placed normally to the sun rays at mean distance of the earth from the sun is known as solar constant. It is denoted by S.

$$S = \left(\frac{r}{R}\right)^2 \sigma T^4$$

where, r is the radius of sun and R is the mean distance of earth from the centre of sun. Value of solar constant is 1.937 cal $\mathrm{cm^{-2}\ min^{-1}}$.

Temperature of violet star is maximum while temperature of red star is minimum.