Thermal Properties of Matter

1. **Heat**
Heat is the form of energy which flows from hotter body to colder body by virtue of temperature difference. The amount of heat is measured in joule (SI unit). Another widely used unit for the heat is calorie, where 1 joule equals 4.2 calorie (cal).

2. **Temperature**
Temperature is the measure of degree of hotness or coldness of a body.
Consider, there are two bodies with temperatures T_1 and T_2 where $T_1 > T_2$, then the body with T_1 is called hotter body with respect to another one which is known as colder body.

3. **Measurement of Temperature**
The measurement of temperature is done by some specified scales. These scales are commonly called thermometers. It measures the temperature of the body in the unit as kelvin (K), degree centigrade (°C), degree fahrenheit (°F), etc, among which kelvin (K) is taken as the SI unit of temperature.

Different Scales to Measure the Temperature

Scale	Unit	Freezing or ice point (Lower fixed point)	Boiling or steam point (Upper fixed point)
Celsius scale	Degree centigrade (°C)	0°C	100°C
Fahrenheit scale	Degree Fahrenheit (°F)	32°F	212°F
Reaumur scale	Degree Reaumur (°R)	0° R	80°R
Kelvin scale	Kelvin (K)	273 K	373 K

Relation among the Temperatures Measured by Different Scales is given as

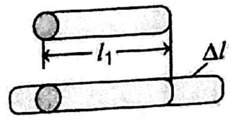
$$\frac{C-0}{100}=\frac{F-32}{180}=\frac{R-0}{80}=\frac{K-273}{100}=\frac{Ra-460}{212}$$

Here, C, F, R, K and Ra are the readings of celsius, fahrenheit, reaumur, kelvin and rankine scales.

4. **Thermal Expansion**
The phenomenon of change in dimensions of an object due to heat supplied is known as thermal expansion.
There are three types of thermal expansion.
(*i*) **Linear Expansion** The expansion in length of a body due to increase in its temperature is called the linear expansion.

$$\alpha_l=\frac{\Delta l}{l\Delta T}=\frac{\text{Increase in length}}{\text{Original length} \times \text{Rise in temperature}}$$

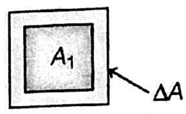
The quantity, α_l is known as coefficient of linear expansion.



Linear expansion

Hence, the coefficient of linear expansion of a material of a solid rod is defined as increase in length per unit original length per degree rise in temperature. Its unit is °C^{-1} or K^{-1}.

(*ii*) **Areal Expansion** The expansion in the area of a surface due to increase in its temperature is called areal expansion.



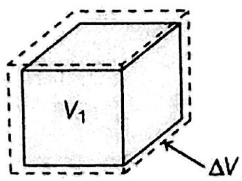
Areal expansion

$$\alpha_A=\frac{\Delta A}{A\Delta T}$$

$$=\frac{\text{Increase in surface area}}{\text{Original surface area} \times \text{Rise in temperature}}$$

where, α_A is known as coefficient of areal expansion. It depends on nature of the material of the plate.
Hence, coefficient of areal expansion of metal sheet is defined as the increase in its surface area per unit original surface area per degree rise in its temperature. Its unit is °C^{-1} or K^{-1}.

(*iii*) **Volume Expansion** The expansion in the volume of an object due to increase in its temperature is known as volume expansion.



Volume expansion

$$\alpha_V=\frac{\Delta V}{V_1\Delta T}$$

where, α_V is known as coefficient of volume expansion. Hence, the coefficient of volume expansion of a substance is defined as the increase in volume per unit original volume per degree rise in its temperature. Its unit is °C^{-1} or K^{-1}.

(*iv*) **Relation among the Coefficients of Expansion**

$$\alpha_l:\alpha_A:\alpha_V=1:2:3$$

i.e. $\alpha_A=2\alpha_l$ and $\alpha_V=3\alpha_l$

5. **Thermal Stress and Strain**
If a rod of length l is heated by a temperature ΔT, then increase in length of rod should have been $\Delta l = l\alpha\Delta T$.

But due to being fixed at ends, rod does not expand and a compressive thermal strain is developed in it whose value is

$$\text{Thermal (compressive strain)} = \frac{\Delta l}{l} = \alpha \cdot \Delta T$$

Here, α = linear expansion coefficient of the material of rod.

Thermal stress = $Y \times$ Thermal strain = $Y\alpha\,\Delta T$

Here, Y = Young's modulus of the material of given rod. If A be the cross-section area of the rod, then force exerted by the rod on the supports will be $F = Y\alpha\,\Delta T\,A$.

6. **Heat Capacity**

The heat capacity is defined as amount of heat needed to change the temperature by unity, i.e. 1°C, it is denoted by S and have SI unit $J\text{-}K^{-1}$.

$$\text{Heat capacity, } S = \frac{\Delta Q}{\Delta T}$$

where, ΔQ = heat absorbed or rejected by body and ΔT = change in temperature.

Dimensional formula of heat capacity = $[ML^2T^{-2}K^{-1}]$

(i) **Specific Heat Capacity** The amount of heat needed to raise the temperature of unit mass of a substance by unity is known as the specific heat capacity or specific heat. It is denoted by s and its SI unit is $J\text{-}kg^{-1}K^{-1}$.

$$s = \frac{S}{m} = \frac{\Delta Q}{m\Delta T}$$

$$\Rightarrow \text{Specific heat capacity, } s = \frac{1}{m}\frac{\Delta Q}{\Delta T}$$

where, m = mass of given substance.

(ii) **Molar Specific Heat Capacity** The amount of heat needed to raise the temperature of one mole of a substance (gas) by unity is known as the molar heat capacity of that substance. It is denoted by C. Its SI unit is $J\text{-}mol^{-1}K^{-1}$.

$$\text{Molar specific heat capacity, } C = \frac{s}{\mu} = \frac{\Delta Q}{\mu\Delta T}$$

where, μ = number of moles of substance.

7. **Calorimetry**

The principle of calorimetry states that total heat given by a hotter body equals to the total heat received by colder body, i.e. heat lost by hotter body = heat gained by colder body.

If there are two bodies of masses m_1 and m_2 and have values of specific heats s_1 and s_2 respectively, then for temperature difference ΔT, heat lost by hotter body = heat gained by colder body

$$\Rightarrow \quad m_1s_1\,\Delta T = m_2s_2\,\Delta T$$

Calorimeter It is a device used for measuring the quantities of heat.

8. **Change of State**

The process of converting one state of a substance into another state is known as change of state of a substance or matter.

Matter generally exists in three states

(*i*) Solid (*ii*) Liquid (*iii*) Gas

These states can be changed into one another by absorbing heat or ejecting heat.

There are some points which used in change of state

(*i*) **Melting and Melting Point** The process of change of state from solid to liquid is called melting. The temperature at which solid starts to liquefy is known as the melting point of that solid.

(*ii*) **Fusion and Freezing Point** The process of change of state from liquid to solid is called fusion. The temperature at which liquid starts to freeze is known as the freezing point of the liquid.

(*iii*) **Vaporisation and Boiling Point** The process of change of state from liquid to vapour (or gas) is called vaporisation. The temperature at which the liquid starts to evaporate is called the boiling point of the liquid.

(*iv*) **Sublimation** The process of change of state directly from solid to vapour (or gas) is known as sublimation. The reverse process of sublimation is not possible, e.g. Camphor, nepthalene balls, etc.

9. **Triple Point**

The temperature and pressure at which three curves (sublimation curve, fusion curve and vaporisation curve) co-exist simultaneously is known as the triple point of the substance. e.g. The triple point for water is represented by temperature 273.16 K and pressure 6.11×10^{-3} Pa.

The graph between temperature and pressure of substance can be plotted known as phase diagram (p-T diagram).

10. **Latent Heat**

The amount of heat transferred per unit mass during the change of phase of a substance without any change in its temperature is called latent heat of the substance for particular change. Latent heat is denoted by L and have SI unit $J\text{-}kg^{-1}$. If a mass m of a substance undergoes a change from one state to the other, then the quantity of heat required is given by

$$Q = mL.$$

i.e. Latent heat, $L = Q/m$

Hence, during the phase change, the heat required by the substance depends on the mass m of the substance and heat of transformation Q.

There are two types of latent heat of materials

(i) **Latent Heat of Fusion or Melting** It is latent heat for solid-liquid state change. It is denoted by L_f and is given by $L_f = \frac{Q}{m}$

Its SI unit is $J\text{-}kg^{-1}$.

(ii) **Latent Heat of Vaporisation** It is latent heat for liquid-gas state change. It is denoted by L_V and often referred to as heat of vaporisation. It is given by

Latent heat of vaporisation, $L_V = \frac{Q}{m}$ and its SI unit is $J\text{-}kg^{-1}$.

11. Heat Transfer

Heat is the form of energy which can flow from one body to another in the form of radiations, molecular vibrations, molecular displacement, etc. These processes of heat flow are collectively known as heat transfer.

There are three modes of heat transfer namely

(i) **Heat Transfer by Conduction** The transfer of heat taking place due to molecular vibrations (i.e. molecular collisions) is known as heat conduction. Generally in solids, heat is transferred by the process of conduction.

- The ability of material to conduct the heat through it is known as thermal conductivity. Thus, heat conduction is defined as the time rate of heat flow in a material for a given temperature difference.

  ∴ Heat transferred, $Q = KA\frac{\Delta T}{L}\cdot t$

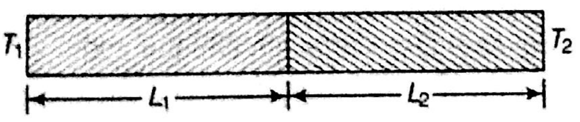
  where, A = area of cross-section of the material

  L = length of the material

  Here, K is known as coefficient of thermal conductivity of material of rod. The SI unit of K is $J\text{-}s^{-1}m^{-1}K^{-1}$ or $Wm^{-1}K^{-1}$. The term $\frac{\Delta T}{L}$ is known as temperature gradient.

- **Connection of Rods with Different Thermal Conductivities.** If two or more rods or conductors are connected with one another, the equivalent thermal conductivity as a whole may be altered.

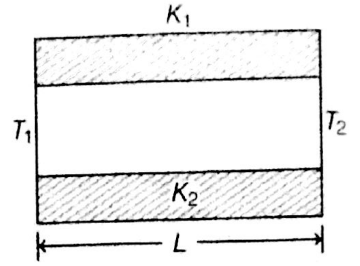
(a) **Series connection of two thermal conductors**



Equivalent thermal conductivity, $K_{eq} = \frac{2K_1K_2}{K_1 + K_2}$

Here, K_{eq} is the equivalent thermal conductivity of the collection of rods (as thermal conductor).

(b) **Parallel combination of two thermal conductors**



Equivalent thermal conductivity, $K_{eq} = \frac{K_1 + K_2}{2}$.

(ii) **Heat Transfer by Convection** Convection is the process in which heat is transferred from one point to another by the actual motion of matter from a region of high temperature to a region of lower temperature. This process of heat transfer takes place only in liquids.

(iii) **Heat Transfer by Radiation** It is a mode of heat transfer from one place to another without heating the intervening medium. The heat is transferred by the means of thermal radiations, radiant energy or simply radiation.

- **Thermal Radiation** The electromagnetic radiation emitted by a body by virtue of its temperature like the radiation by a red hot iron or light from filament lamp is called thermal radiation.
- **Black Body Radiation** A body that absorbs all the radiations falling on it is known as a black body. It emits the radiations at the fastest rate.

  The radiations emitted by a black body is known as black body radiation. The black body is also called the ideal radiator.

12. Absorptive and Emissive Powers and Emissivity

The ratio of the amount of thermal radiation absorbed by a body in a given time to the total amount of thermal radiations incident on the body in the same time is known as absorptance (a) or absorbing power of the body.

The emissive power of a body at a given temperature and for a given wavelength λ is defined as the amount of radiant energy per unit time per unit surface area of the body within a unit wavelength range around the wavelength λ.

The ratio of emissive power (e) of a body to the emissive power (E) of a perfect black body at the same temperature is called emissivity. It is denoted by ε.

Thus, **Emissivity,** $\varepsilon = \frac{e}{E}$

13. Kirchhoff's Law

It states that at a given temperature, the ratio of the emissive power (e_λ) to the absorptive power

(a_λ) corresponding to a certain wavelength is constant for all bodies and this constant is equal to the amusive power of the perfect black body (E_λ) at the same temperature and corresponding to the same wavelength.

That is $\frac{e_\lambda}{a_\lambda} = E_\lambda$ (constant)

Thus, a good absorber is also a good emitter.

14. Stefan-Boltzmann Law

Stefan-Boltzmann law states that the total energy emitted per second by a unit area of a body is proportional to the fourth power of its absolute temperature.

i.e. total energy, $E \propto T^4$

i.e. $$E = \sigma T^4$$

where, σ is a universal constant called Stefan Boltzmann constant.

$$\sigma = 5.735 \times 10^{-8}\ \text{Wm}^{-2}\ \text{K}^{-4}$$

If the body is not a perfect black body and has emissivity ε, then above relations get modified as

$$E = \varepsilon \sigma T^4$$

15. Wien's Displacement Law

Wien's displacement law states that the wavelength (λ_m) corresponding to which the energy emitted by a black body is maximum and is inversely proportional to its absolute temperature (T).

Thus, $$\lambda_m \propto \frac{1}{T} \quad \text{or} \quad \lambda_m T = b$$

where, $b =$ Wien's constant $= 2.9 \times 10^{-3}$ m K

16. Newton's Law of Cooling

Newton's law of cooling states that the rate of cooling of a body is directly proportional to the temperature difference between the body and its surroundings, provided the temperature difference is small.

i.e. Rate of loss of heat $\propto$ Temperature difference between the body and its surroundings

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

Rate of loss of heat, $-\frac{dQ}{dt} = k(T - T_0)$

where, k is a constant.

17. Green House Effect

It is defined as a process of having a high temperature in the green house although it receives fewer radiations than the outside. It occurs due to the high concentration of carbon dioxide and vapour content. The glass walls are also included under it. They allow the short wave radiations to enter the house.