Chapter -11

Thermal properties of Matter

Temperature and Heat

Temperature

Temperature is a relative measure, or indication of hotness or Coldness. A hot cooker is said to have a high temperature, and ice Cube to have a lower temperature. An Object at a higher temperature is said to be hotter than the one at a lower temperature.

The SI unit of temperature is kelvin (K), where degree celsius (°C) is a commonly used unit of temperature.

Heat

When you put a cold spoon into a cup of hot coffee, the spoon warms up and the coffee cools down as they were trying to equalise the temperature. Energy transfer that takes place solely because of a temperature difference is called heat flow or heat transfer and energy transferred in this way is called heat. The SI unit of heat energy transferred is expressed in Joule (J)

Measurement of Temperature

A physical property that changes with temperature is called a thermometric property. When a thermometer is put in contact with a hot body, the mercury expands, increasing the length of the mercury column.

(i) Celsius Scale

It defines ice-point temperature as 0°C and the steam point temperature as 100°C. The space between 0°C and 100°C marks is equally divided into 100 intervals.

(ii) Fahrenheit Scale

It defines the ice-point temperature as 32°F and the steam point temperature as 212°F. The space between 32°F and 212°F is divided into 180 equal intervals.

(iii) Kelvin Scale

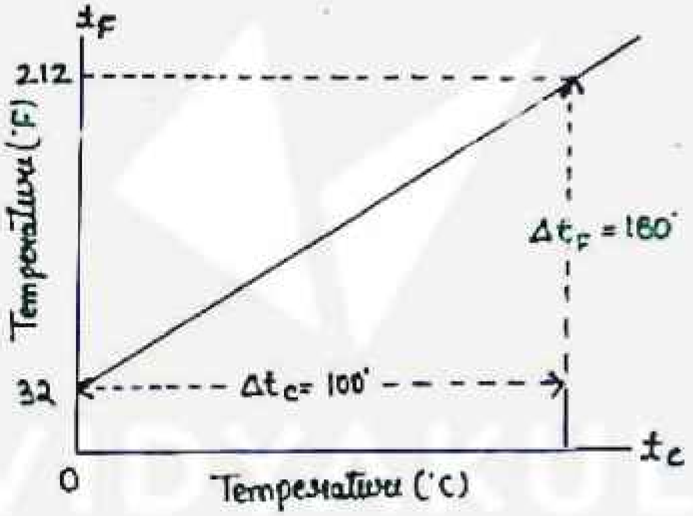
Kelvin Scale is a scale of measuring of temperature, the melting point of ice is taken as 273k and the boiling point of water as 373k the space between these two points is divided into 100 equal intervals.

(iv) Relation between Different Scales of Temperatures

To Convert a temperature from one scale to the Other, We must take into account the fact that zero temperatures of the two scales are not the same.

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

Note - The normal temperature of the human body measured on the Celsius scale is 37°C which is 98.6°F.



If t_c and t_F are temperature values of a body on celsius temperature scale and Fahrenheit temperature scale respectively, then the relationship between Fahrenheit and Celsius temperature is given by

$$\frac{t_c - 0}{100} = \frac{t_F - 32}{180}$$

Ideal Gas Equation and Absolute Temperature

(i) Ideal Gas Equation

An equation which follows the Law of Boyal, Law of Charls and Law of Avogadro is called ideal gas equation.

At Constant temperature,

$$V \propto \frac{1}{P} \quad \text{---- (From Boyal's Law)}$$

At Constant pressure,

$$V \propto T \quad \text{---- (From Charl's Law)}$$

At Constant T and P,

$$V \propto n \quad \text{---- (From Avogadro's Law)}$$

By Combing all above equation, we get

$$V \propto \frac{Tn}{P}$$

$$V = \frac{nRT}{P}$$

$$\boxed{PV = nRT}$$

Where, n = Number of moles of gas

R = Universal gas Constant ($R = 8.31 \ J mol^{-1} K^{-1}$)

P = Pressure of gas

V = Volume of gas

(ii) Absolute Temperature

The absolute minimum temperature is equal to -273.15°C. This is also known as absolute zero. Absolute zero is the foundation of the kelvin temperature scale or absolute scale temperature.

Thermal Expansion

The increase of size of a body due to the increase in the temperature is called thermal Expansion. Three types of expansions can take place in solid viz. linear, superficial and volume expansion.

(i) Linear Expansion

The expansion in length is called linear expansion and the fractional change in length, $\frac{\Delta L}{L}$ is given by

$$\boxed{\frac{\Delta L}{L} = \alpha \, \Delta T}$$

where, α = Coefficient of linear expansion

The unit of α is per degree Celsius ($°C^{-1}$). in the CGS and per kelvin (K^{-1}) in the SI System.

(ii) Superficial or Area Expansion

The increase in surface area of the solid on heating is called superficial expansion. The Fractional Change in area, $\frac{\Delta A}{A}$ is given by

$$\boxed{\frac{\Delta A}{A} = \beta \Delta T}$$

where, β = Coefficient of area expansion

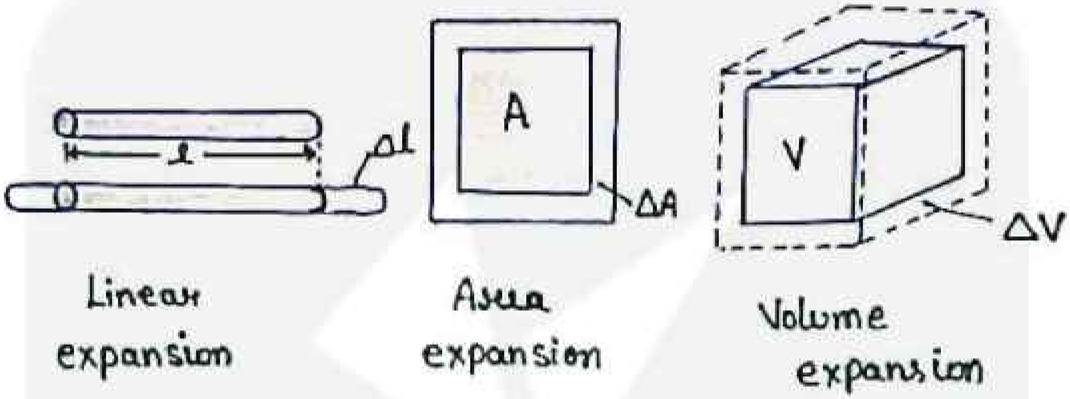
Unit of β is $°C^{-1}$ or K^{-1}.

(iii) Volume expansion

The expansion in Volume is called Volume expension and the fractional Change in area, $\frac{\Delta V}{V}$ is given by

$$\frac{\Delta V}{V} = \gamma \Delta T$$

where, γ = Coefficient of Volume expansion



Relation between Linear (α), Area (β) and Volume (γ) Expansion –

$$\alpha : \beta : \gamma = 1 : 2 : 3$$

$$\frac{\alpha}{\beta} = \frac{1}{2} \quad \text{---} \; [\beta = 2\alpha]$$

$$\frac{\alpha}{\gamma} = \frac{1}{3} \quad \text{---} \; [\gamma = 3\alpha]$$

$$\alpha = \frac{\beta}{2} = \frac{\gamma}{3}$$

Thermal Stress

When a rod is held between two fixed. Supports and its temperature is increased, the fixed supports do not allow the rod to expand, which results in a stress which is called Thermal Stress.

Thermal Stress in the rod is given by

$$\frac{F}{A} = \text{Thermal Stress} = Y \alpha \Delta t$$

where Y = Young's modulus for the material of rod,

A = Area cross-section of the rod

α = Coefficient of linear expansion

F = Developed force in the rod

$$F = \frac{YA\Delta l}{l}$$

Thermal Capacity

The thermal Capacity of a body is the quantity of heat required to raise the temperature of the whole of the body through a unit degree. It is measured in calorie per °C or joule per k.

If Q be the amount of heat needed to produce a change in temperature (Δt) of the Substance, then thermal Capacity of the Substance is given by

$$S = \frac{Q}{\Delta t}$$

Dimensional formula of heat Capacity is $[ML^2T^{-2}K^{-1}]$.

Specific Heat Capacity

The specific heat capacity (also referred to as specific heat) of a substance is the amount of heat required to raise the temperature of a unit mass of substance through 1°C. It is measured in Cal g^{-1} $(°C)^{-1}$ or J kg^{-1} K^{-1}.

The specific heat capacity of a substance is given by

$$S = \frac{1}{m} \frac{Q}{\Delta t}$$

where, m = mass of substance

Q = heat required to change its temperature Δt.

⇒ Molar specific heat capacity of a substance is defined as the amount of heat required raise the temperature of 1 mole of the Substance by 1°C.

It is given by

$$C = \frac{1}{\mu}\frac{Q}{\Delta t}$$

where μ = number of moles of a Substance

The unit of molar specific heat Capacity is $J\ mole^{-1}K^{-1}$. in SI System and $Cal\ mol^{-1}\ {}^{\circ}C^{-1}$ in CGS System.

The dimensional formula of molar Specific heat Capacity is $[ML^2T^{-2}K^{-1}mole^{-1}]$.

Calorimetry

Calorimetry is concerned with the measurement of heat, the basic apparatus for this purpose being Called the Calorimeter. When two bodies at different temperatures are 'mixed', heat 'flows' from the body at a higher temperature to the one at a lower temperature, until a common 'equilibrium' temperature is reached. Assuming this 'Heat exchange' to be confined to the two bodies alone (i.e, neglecting any heat loss to the surroundings) we have, from the law of energy conservation.

Heat gained by one body	=	heat lost by the other

This simple statement based on the law of conservation of energy is called the principle of Calorimetry.

Change of State

Depending on temperature and Pressure, all matter can exist in a solid, liquid or gaseous state. These states or forms of matter are also called the phases of matter.

The change of state from solid to liquid is called melting and from liquid to solid is called fusion. It is observed that the temperature remains constant until the entire amount of the solid substance melts. That is, both the solid and the liquid states of the substance coexist in thermal equilibrium during the change of states from solid to liquid.

The temperature at which the solid and the liquid states of the substance is in thermal equilibrium with each other is called its melting point.

The change of state from liquid to vapour (or gas) is called vaporisation. It is observed that the temperature remains constant until the entire amount of the liquid is converted into vapour.

The temperature at which the liquid and the vapour states of the substances coexist is called its boiling point. The changes from solid state to vapour state without passing through the liquid state is called sublimation and the substance is said to sublime.

Latent Heat

Latent heat is defined as the heat or energy that is absorbed or released during a phase change of a substance. It could either be from a gas to a liquid or liquid to solid and vice versa. Latent heat is related to a heat property called enthalpy. It is denoted by L and its SI unit is J/kg.

$$L = \frac{Q}{m}$$

There are two types of latent Heat.

(i) Latent Heat of melting

It is a amount of heat which is required to change of phase from Solid to liquid for unit mass at constant temperature.

Ex - Latent heat of melting of ice is 3.33×10^5 J/kg.

(ii) Latent Heat of Vaporization

It is a amount of heat which is required to change of phase from liquid to vapour for unit mass at Constant temperature.

Ex - Latent heat of vaporization of water is 22.6×10^5 J/kg.

Heat Transfer

There are three mechanisms of heat transfer which name is given as - Conduction, Convection and radiation. Conduction occurs within a body or between two bodies in contant. Convection depends on motion of mass from one region of space to another. Radiation is heat transfer by electromagnetic radiation, such as sunshine, with no need for matter to be present in the space between bodies.

(i) Conduction -

According to maxwell, Conduction is the flow of Heat through an unequally heated body from places of higher temperature to those of lower temperature.

Rate of heat transfer is given by

$$H = \frac{Q}{t} = \frac{KA(T_1 - T_2)}{l}$$

where, K = Thermal Conductivity

A = area of cross-section

(ii) Convection

Convection is a mode of heat transfer by actual motion of matter. It is possible only in fluids. Convection can be natural or forced. In natural convection, gravity plays an important part. When a fluid is heated from below, the hot part expands and therefore, becomes less dense. Because of buoyancy, it rises and the upper colder part replaces it. This again get heated, rises up and is replaced by the relatively colder part of the fluid. This process goes on.

In force convection, material is forced to move by a pump or by some other physical means. The common examples of force convection systems are forced - air heating systems in home.

(iii) Radiation

Radiation is the transfer of heat by electro-magnetic waves such as visible light, infra-red and ultraviolet rays. Everyone has felt the warmth of the Sun's radiation and intense heat from a charcoal grill or the glowing coals in a fire place. Most of the heat from these bodies reaches you not by conduction or convection in the intervening air but by radiation. This heat transfer would occur even if there were nothing but vacuum between you and the source of heat.

Thermal Resistance

The Thermal Resistance of a body is a measure of its opposition to the flow of heat through it. It is defined as

$$\text{Thermal resistance} = \frac{\text{temperature difference at the two ends}}{\text{rate of flow of heat through it}}$$

$$\text{Thermal Resistance} = \frac{\text{length or thickness of the material}}{\text{thermal Conductivity} \times \text{area}} = \frac{l}{KA}$$

Newton's Law of Cooling

Newton's Law of Cooling States that the rate of loss of heat of a body is directly proportional to the difference in temperature of the body and the surroundings, provided the difference in temperature is small, not more than 40°C.

$$\frac{dT}{dt} = -k(T - T_s)$$

-ve sign implies that as time passes, temperature T decreases.

When an object at temperature T_1 is placed in a surrounding of temperature T_2 the net energy radiated per second is,

$$P = eA\sigma(T_1^4 - T_2^4)$$