



UNIT 9

THERMAL PROPERTIES OF MATTER

HEAT

Heat is the transfer of energy across the boundary of a system due to the temperature difference between the system and its surrounding.

Heat is a macroscopic scalar quantity.

UNITS OF HEAT

- i) The S.I. unit of heat is **Joule** which is denoted by J.
- ii) Calorie (cal) is a old unit of heat **calorie** (cal) which is define as *the amount of energy transfer necessary to raise the temperature of 1g of water from 14.5 °C to 15.5 °C*
- iii) The unit of heat energy in the British system is the **British thermal unit (Btu)**, which is defined as *the amount of energy transfer required to raise the temperature of 1 lb of water from 63° F to 64° F*

TEMPERATURE

The degree of hotness or coldness of a substance is termed as its temperature.

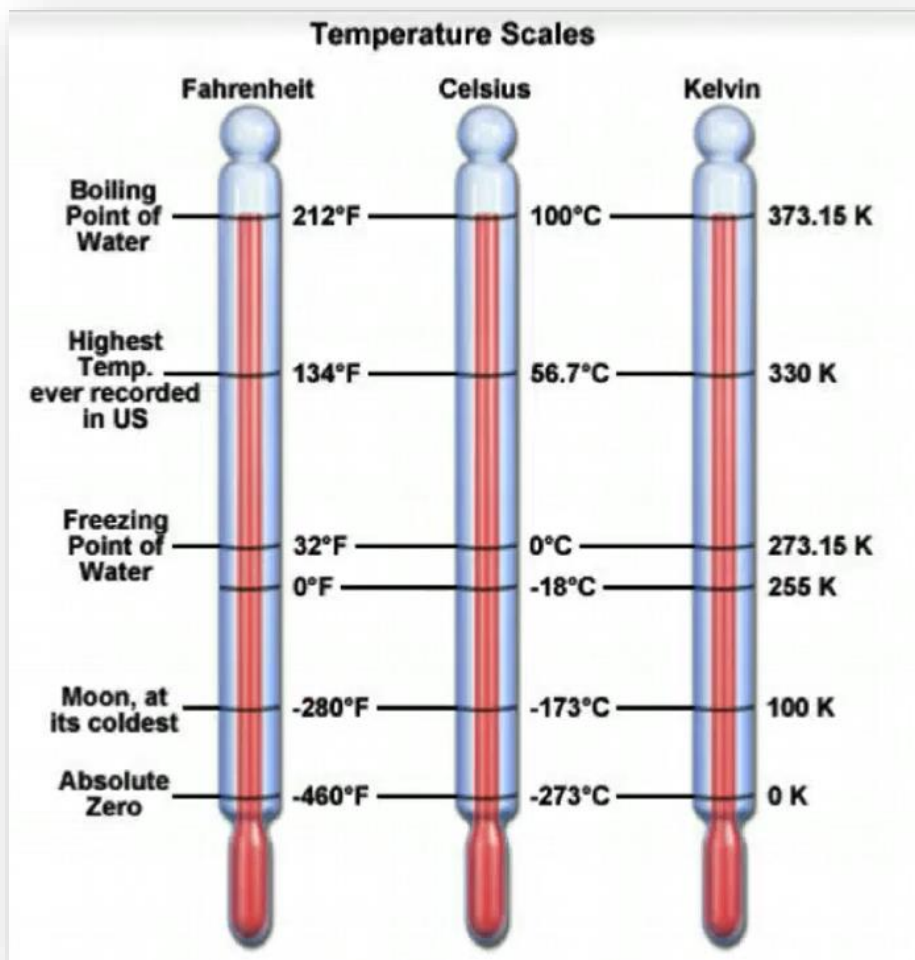
OR

Temperature measures the average translational kinetic energy of the molecules of the body.

SCALES OF TEMPERATURE

A temperature scale is used to measure the temperature quantitatively. To measure temperature quantitatively, we must put some numbers on the capillary tube, for constructing a scale of temperature, it is necessary to choose reference points that are fixed. That is the value of the fixed points. The melting point of ice and boiling point of water at standard pressure (76cm of Hg) are the two fixed points and the difference between these two points is divided in different ways, called scales of graduation. There are three scales of temperature

- (i) Centigrade or Celsius scale
- (ii) Fahrenheit scale
- (iii) Kelvin or absolute scale are commonly used these days



FAHRENHEIT SCALE

Daniel Gabriel developed the Fahrenheit scale in 1744 when he was inventing alcohol and mercury thermometers.

In the Fahrenheit scale, the freezing temperature of the water is 32⁰F, the lower point. The boiling temperature of the water is taken as 212⁰F and is fixed as the upper point. The division of the Fahrenheit scale takes place into 180 equal parts. Each part represents 1⁰F.

KELVIN SCALE

Lord Kelvin developed the Kelvin scale in 1848. The derivation of the Kelvin scale is from the Celsius scale only. Kelvin scale does not use degrees and its writing form is as Kelvin or K.

In this scale, the melting point of ice is 273K and the boiling point of water is 373K of water. The temperature is given in units called Kelvin instead of degrees. The lowest temperature is -273°C.

CONVERSION RELATIONSHIP

conversion between Celsius temperature and Kelvin temperature

We can convert the Celsius scale in to Kelvin scale. Simply by adding 273 to the Celsius temperature.

$$T_k = [T_c + 273] \text{ K} \text{-----(1)}$$

conversion between degree Celsius and degree Fahrenheit

To convert the Celsius scale in to Fahrenheit scale, we use the following relations.

$$T_F = \left[\frac{9}{5} \times T_c + 32 \right] ^\circ F \text{ -----(2)}$$

conversion between degree Fahrenheit and degree Celsius

To convert the Fahrenheit scale in to Celsius scale, we use the following relations

$$T_c = \left[\frac{5}{9} (T_F - 32) \right] ^\circ C \text{ -----(3)}$$

Heat Capacity

The **heat capacity**, C, of a body is defined as the amount of thermal energy required to raise the temperature of the body by 1 k or 1 °C.

$$C = \frac{\Delta Q}{\Delta T}$$

UNIT

The SI unit of heat capacity is J K⁻¹ or J °C⁻¹

SPECIFIC HEAT CAPACITY

The **specific capacity**, c, of a material is defined as the amount of thermal energy required to raise the temperature of a unit mass of the material by 1 K or 1 °C.

$$c = \frac{\Delta Q}{m \Delta T}$$

UNIT

The SI unit of specific heat is Jkg⁻¹k⁻¹ or J kg⁻¹ °C⁻¹

EFFECTS DUE TO LARGE SPECIFIC HEAT OF WATER

We know that water has a large specific heat, due to this quality it plays an important role in everyday life.

- The large amount of water in oceans and lakes help to maintain the temperature ranges in their surroundings.
- Water with coolant is used to reduce the temperature of engine through radiator of vehicle.
- Water also help to maintain our body temperature.

HEAT OF FUSION

The heat absorbed by a unit mass of a solid at its melting point in order to convert solid into liquid without change of temperature is called “heat of fusion”.

FORMULA

$$L_f = \frac{\Delta Q}{m}$$

Where ΔQ is the energy transferred and m is the mass of the substance.

UNIT

The SI unit for specific latent heat of fusion is **J kg⁻¹**

KEY POINT

The latent heat of fusion of water (ice) is commonly defined as **{334 kJ/kg}**, representing the energy needed to convert 1 kg of ice into water at a constant temperature of 0 °C. This energy breaks intermolecular bonds without raising the temperature.

HEAT OF VAPORIZATION

The amount of heat energy required to change the state of a substance from liquid to vapor form, without changing its temperature is called “heat of vaporization”.

FORMULA

$$L_v = \frac{\Delta Q}{m}$$

Where ΔQ is the energy transferred and m is the mass of the substance.

UNIT

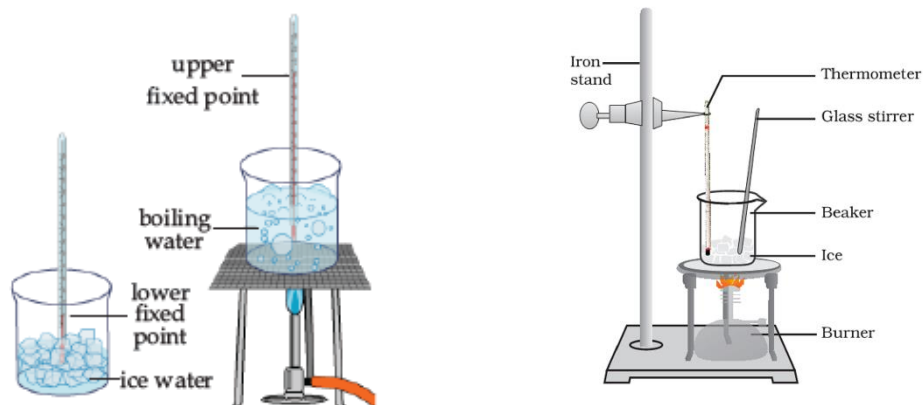
The SI unit for specific latent heat of vaporization is **J kg⁻¹**

KEY POINT

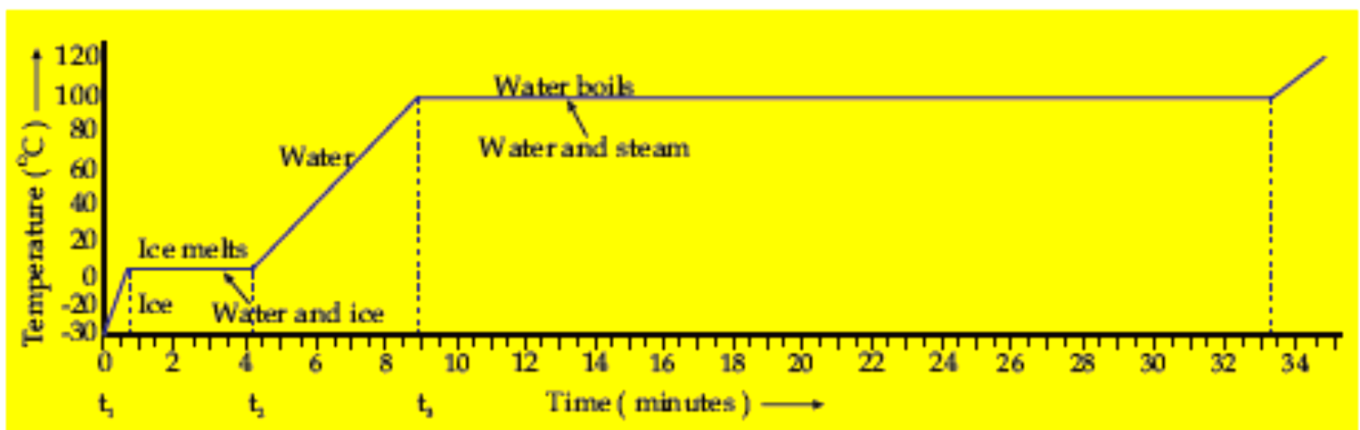
The specific latent heat of vaporization of water is approximately **2260 kJ/kg**. This is the energy required at standard atmospheric pressure to convert 1 kg of water at 100 °C into steam at the same temperature.

EXPERIMENT LATENT HEAT OF FUSSION

Take a container and place it on a stand as shown in Fig . Put small pieces of ice in the container. Suspend a thermometer in the container to measure the temperature. Take a stop watch to measure accurate time at different stages. Now place the container on the burner. The ice will start melting after absorbing heat. The temperature will remain same up to 0 °C until all the ice melts. Note the time t_1 and t_2 , which the ice takes to melt completely into water at 0 °C. Supply heat continuously to water at 0 °C, again note the time, its temperature will start to increase. Note the time, which water in container takes to reach its boiling point at 100 °C from 0 °C.



TEMPERATURE-TIME GRAPH



EVAPORATION

The process in which the water changes from liquid to gas or vapor form is known as “evaporation”.

EVAPORATION CAUSES COOLING

When evaporation occurs, the molecules of water with greater Kinetic energy escape from its surface. So the molecules of water with lower Kinetic energy are left behind. This results in a decrease in the temperature of water. Hence, evaporation causes cooling.

EXAMPLE

1 If little amount of methylated spirit is taken on our hand it evaporates rapidly and our hand feel instantly cold. To change spirit from liquid to vapor it requires latent heat which is obtained from our hand thus our hand losses heat and we feel cool.



2 You feel cold when come out directly under a heavy wind after taking bath. This is due to the reason that water molecules with greater Kinetic energy escape from your skin surface, while the molecules with lower Kinetic energy are left behind. This lowers the temperature of water at your skin and you feel cold



FACTORS WHICH INFLUENCING SURFACE EVAPORATION

- a. Temperature: With the increase in temperature the rate of evaporation also increases.
- b. Wind Speed: Rate of evaporation also increases with the increase in wind speed.
- c. Surface area of liquid: Rate of evaporation increases with the increase in surface area of liquid.
- d. Humidity: The rate of evaporation decreases with increase in humidity.
- e. Nature of liquid: Nature of liquid also effect the rate of evaporation. Liquid with lower boiling point have grater vapor pressure and evaporate more rapidly.
- f. Solute Concentration: Salty water evaporates more slowly than pure water.

DIFFERENCE BETWEEN BOILING POINT AND EVAPORATION

Evaporation	Boiling
1· It takes place without supply having external heat source.	1· It only takes place without on supply external heat source.
2· It occurs at any temperature below boiling point.	2· It occurs only at certain temperature called "Boiling point".
3· It causes cooling.	3· It do not causes cooling.
4· It is relatively slow.	4· It is relatively fast.
5· It takes place only at the liquid surface.	5· It takes place throughout the liquid.
6· No formation of bubbles.	6· Bubbles are formed.

THERMAL EXPANSION

The expansion of substance on heating is called thermal expansion.

- 1 **Railway tracks:** Gaps are left between rails so they can expand in hot weather without bending.



- 2 **Electric wires:** Power lines sag in summer (expand) and become tighter in winter (contract).



- 3 **Bridges use expansion joints** to allow metal and concrete to expand and contract with temperature changes.



Thermometers

Mercury or alcohol expands when heated and rises in the tube.



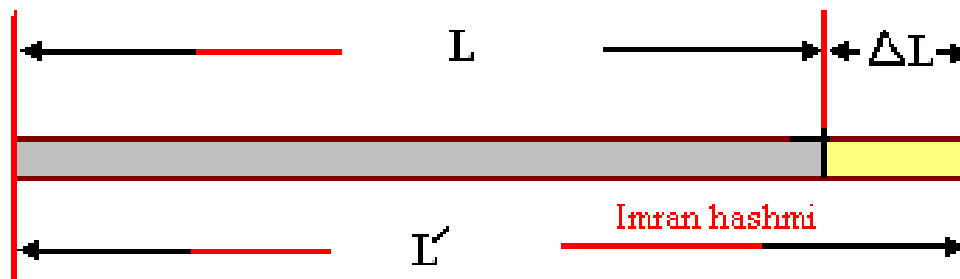
LINEAR EXPANSION

DEFINITION

Expansion in length of solids in one dimension on heating is called linear expansion.

MATHEMATICAL EXPRESSION

Consider a metal rod having original length L at temperature T_1 . Let us heat this metal rod to temperature T_2 . The rod will expand and its new length will become L' .



It has been experimentally found that the change in length of a metal rod, on heating, is directly proportional to the original length and the change in temperature of the solid.

$$\Delta L \propto L \Delta T$$

$$\Delta L = \alpha L \Delta T \text{ ----- (1)}$$

where “alpha” (α) is a constant known as coefficient of linear expansion of the solid rod and its value depends on the nature of a solid substance.

CO-EFFICIENT OF LINEAR EXPANSION

Consider equation (1) : $\Delta L = \alpha L \Delta T$

$$\text{Or } \alpha = \frac{\Delta L}{L \Delta T}$$

We are now in position to define the co-efficient of linear expansion ‘ α ’ as follows : “**the co-efficient of linear expansion of a solids is the increase in length per unit length of the solid when its temperature is raised by 1 Kelvin**”

UNIT OF “ α ”:

Its SI unit is per Kelvin

VOLUME EXPANSION

DEFINITION

Expansion in volume of solid, liquid or gases on heating is called volume or cubical expansion.

MATHEMATICAL EXPRESSION

Consider, V = initial volume of a body
 V' = final volume after heating
 ΔT = Change in temperature

It is found experimentally that, the change in volume ‘ ΔV ’ is directly proportional to its initial volume and the change in temperature.

$$\Delta V \propto V \Delta T$$

$$\Delta V = \beta V \Delta T \text{ ----- (1)}$$

CO-EFFICIENT OF VOLUME EXPANSION

Consider equation (1) : $\Delta V = \beta V \Delta T$

$$\text{Or } \beta = \frac{\Delta V}{V \Delta T}$$

We can now define the co-efficient of volume expansion ‘ β ’ as follows: **The co-efficient of volume expansion of solids is the increase in volume per unit volume of the solid when its temperature is raised by 1K.**

UNIT OF ‘ β ’

Its SI unit is per Kelvin.

RELATION BETWEEN LINEAR AND VOLUME EXPANSION

The relation between **linear expansion** and **volume expansion** for solids is

Coefficient of volume expansion = three times Coefficient of linear expansion

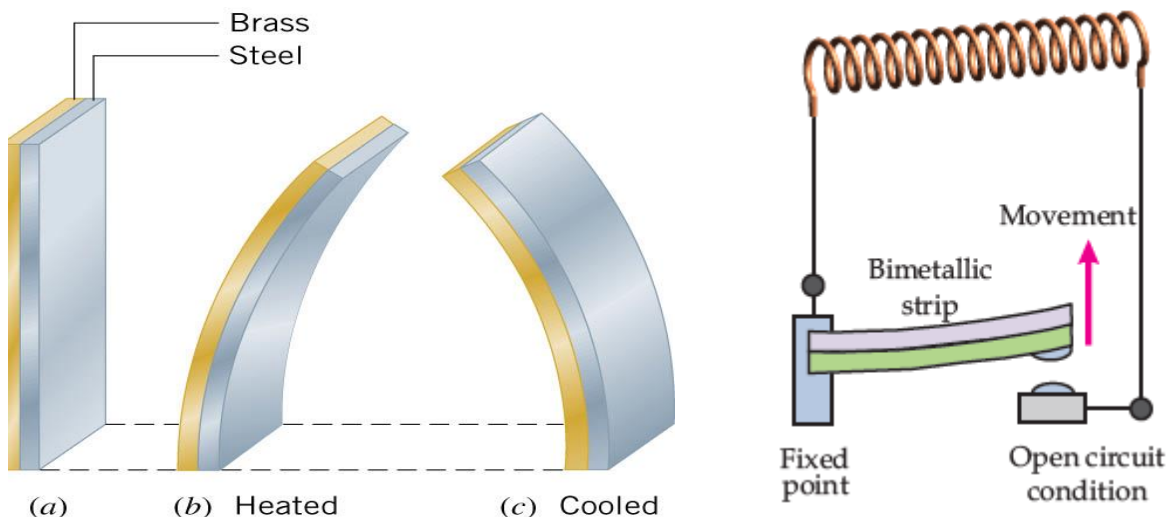
$$\beta = 3\alpha$$

APPLICATION AND CONSEQUENCES OF THERMAL EXPANSION

Thermal expansion of solids is useful in some situations of daily life and in some situations it creates problems:

BIMETALLIC THERMOSTAT

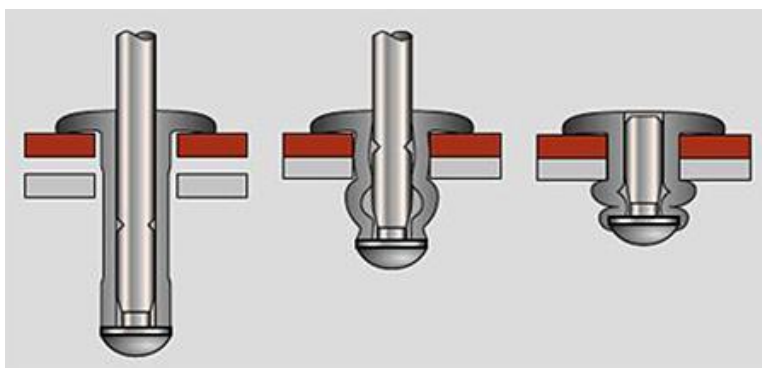
Bimetallic strip is used as an electric contact breaker in electrical heating circuits.



It is consisting of two thin strips of dissimilar metals bonded together. As the temperature of the strip increases, the two metals expand by different amount and the strip bends and contact with screw ‘S’ is broken. Due to this the current flowing through the heating coil stops. When temperature falls, the strip contracts and contact is restored.

RIVETS

Rivets are used in shipbuilding and other industries to join metal plates. A red-hot rivet is passed through holes in two metal plates and hammered until ends are rounded. The rivet contracts on cooling and pulls the two plates tightly together.



A metal rim can be fixed on a wooden wheel of a bull cart. The diameter of metal rim is set little bit smaller than the diameter of wooden wheel. The diameter of metal rim increases on heating and can easily be put over the wooden wheel. It contracts on cooling and holds wooden wheel tightly.



CAR RADIATOR COOLANT

Engine coolant is used in car radiator in place of pure water because water has greater volume expansion it can expand enough to damage the engine or radiator



REAL AND APPARENT EXPANSION OF LIQUIDS

Consider a flask, filled with water up to level “a”. The flask is placed on a burner, as shown below in; Fig

Heat starts to flow through the flask to water. So, the flask expands first. Due to expansion of flask, the level of water falls from point “a”, level L_1 to point “b”, level L_2 . So, when water get heated, it starts to expand from a point “b” beyond its original level. Thus expansion of water appear from level “ L_1 ” point “a” to level “ L_3 ” point “c” is called “apparent expansion of water”. But in real sense, the water on heating has expanded from level “ L_2 ” point “b” to level 2 “ L_3 ” point “c” which is the “real expansion of water”. Real expansion = L_2 to L_3 i.e from point “b” to “c”, as shown in ; Fig

