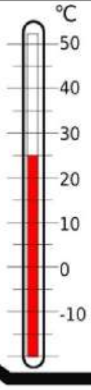

UNIT 8

THERMAL PROPERTIES OF MATTER

LONG QUESTIONS

8.2 THERMOMETER

Q.1 What is thermometer? Explain its different types.

Ans: "The instrument which is used to measure the temperature is called a thermometer"

Thermometric Substance

Some substances have property that changes with temperature. Substance that show change with temperature can be used as thermometric material. Common thermometers are generally made using some suitable liquid as thermometric material.

Properties of Thermometric Properties

A thermometric liquid should have the following properties:

- It should be visible
- It should have uniform thermal expansion
- It should have a low freezing point
- It should have high boiling point
- It should not wet glass
- It should be a good conductor of electricity
- It should have small specific heat capacity

Liquid – In – glass Thermometer

A liquid – in – glass thermometer has a bulb with a long capillary tube of uniform and fine bore. A suitable liquid is filled in the bulb. When the bulb contacts a hot object, the liquid in it expands and rises in the tube. The glass stem of a thermometer is thick and acts as a cylindrical lens. This makes it easy to see the liquid level in the glass tube.

Mercury Liquid – in – Glass Thermometer

Mercury freezes at -39 ^{o}C and boils at 357 ^{o}C. It has all the thermometric properties listed above. Thus mercury is one of the most suitable thermometric materials. Mercury – in – glass thermometers are widely used in laboratories, clinics and houses to measure temperatures in range from -10 ^{o}C to 150 ^{o}C.

Reference points

A thermometer has a scale on its stem. This scale has two fixed points.

Lower Fixed Point

The lower fixed point is marked to show the position of liquid in the thermometer when it is placed in ice.

Upper Fixed Point

The upper fixed point is marked to show the position of liquid in the thermometer when it is placed in stem at standard pressure above boiling water.

Scales of Temperature

The distance between two reference points is divided in different divisions. A scale is marked on the thermometer. The temperature of the body in contact with the thermometer can be read on that scale.

Types of Temperature Scale

There are three types of temperature scale.

(i) Celsius scale or centigrade scale
(ii) Fahrenheit scale
(iii) Kelvin scale

Fahrenheit and centigrade or Celsius scales are used to measure temperatures in ordinary life while Kelvin scale is in practice for scientific purposes.

Celsius scale

On Celsius scale, for water the interval between lower and upper fixed point is divided into 100 equal divisions. The lower fixed point is marked as 0 ^{o}C and the upper fixed point is marked as 100 ^{o}C.

Fahrenheit scale

On Fahrenheit scale, the interval between lower and upper fixed points is divided into 180 equal divisions. The lower fixed point is marked as 32 ^{o}F and the upper fixed point is marked as 212 ^{o}F.

Kelvin scale

In SI units, the unit of temperature is Kelvin (K) and its scale is called Kelvin scale of temperature. The interval between the lower and upper fixed points is divided into 100 equal divisions. Thus a change in 1^{o}C is equal to a change of 1 K. the lower fixed point on the scale corresponds to 273 K and the upper fixed point is referred as 373 K. The zero on this scale is called the absolute zero and is equal to – 273 ^{o}C.

Q.2 What is specific heat? Explain with examples and derive its mathematical formula.

Ans: "Specific heat of a substance is the amount of heat that is required to raise the temperature of 1 kg mass of that substance through 1K".

Explanation

Generally, when a body is heated, its temperature increases. Increase in the temperature of a body is found to be proportional to the amount of heat absorbed by it.

It has also been observed that the quantity of heat ΔQ required to raise the temperature ΔT of a body is proportional to the mass m of the body.

Thus $\quad \Delta Q \propto m \Delta T$

or $\quad \Delta Q = c\, m\, \Delta T$

Here ΔQ is the amount of heat absorbed by the body and c is the constant of proportionality called the specific heat capacity or simply specific heat.

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

Unit

In SI units, mass m is measured in kilogram (kg), heat ΔQ is measured in joule (J) and temperature increases. ΔT is taken in Kelvin (K). So, SI unit of specific heat $Jkg^{-1}K^{-1}$.

Q.3 Explain the importance of large specific heat capacity of water.

Ans: Specific heat of water is 4200 $Jkg^{-1}K^{-1}$ and of dry soil is about 810 $Jkg^{-1}K^{-1}$. As a result the temperature of soil would increase five times more than the same mass of water by the same amount of heat.

Water has a large specific heat capacity. For this reason, it is very useful in storing and carrying thermal energy due to its high specific heat capacity.

Examples

(i) The temperature of land rises and falls more rapidly than that of the sea. Hence, the temperature variations from summer to winter are much smaller at places near the sea than land far away from the sea. So climate of the regions near sea shore, like Karachi, remains moderate.

(ii) The cooling system of the automobiles uses water to carry large amount of heat is produced by its engine due to which its temperature goes on increasing. The engine would cease unless it is not cooled down. Water circulating around the engine maintains the temperature. Water absorbs unwanted thermal energy of the engine and dissipates heat through its radiator.

(iii) In central heating systems hot water is used to carry thermal energy through pipes from boiler to radiators. Theses radiators are fixed inside the house at suitable places.

Heat Capacity

Q.4 Define heat capacity. Derive its mathematical formula and write down an activity to explain it.

Ans: Heat capacity of a body is the quantity of thermal energy absorbed by it for one Kelvin (1K) increases in its temperature.

Mathematical Form

Thus, if the temperature of a body increases through ΔT on adding ΔQ amount of heat, then its heat capacity will be $\Delta Q/\Delta T$. putting the value of ΔQ, we get

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

Heat capacity = mc

The above equation shows that heat capacity of a body is equal to the product of its mass of the body and its specific heat capacity.

Example

Heat capacity of 5 kg of water is (5 kg x 4200 $Jkg^{-1}K^{-1}$) 21000 Jkg^{-1}. That is 5 kg of water needs 21000 joules of heat for every 1 K rise in its temperature. Thus, larger is the quantity of a substance, larger will be its heat capacity.

8.4 CHANGE OF STATE

Q.5 Explain with an activity the change of state.

Matter can be changed from one state to another. For such a change to occur, thermal energy is added to or from a substance.

Activity

Take a beaker and place it over a stand. Put small pieces of ice in the beaker and suspend a thermometer in the beaker to measure the temperature of ice.

Now place a burner under the beaker. The ice will start melting. The temperature of the mixture containing ice and water will not increase above 0 °C until all the ice melts and we get water at 0° C is further heated, its temperature will begin to increase above 0° C as shown in figure.

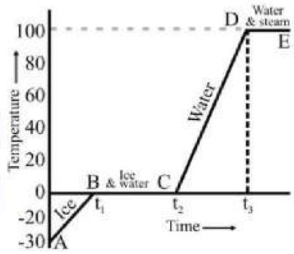

Figure 8.9: A graph of temperature and time showing change of state of ice into water and steam.

Part AB: On this portion of the curve, the temperature of ice increases from -30 °C to 0 °C.

Part BC: when the temperature of ice reaches 0 °C, the ice water mixture remains at this temperature until all the ice melts.

Part CD: The temperature of the substance gradually increases from 0 °C to 100 °C. the amount of energy so added is used up in increasing the temperature of water.

Part DE: At 100 °C water begins to boil and changes into steam. The temperature remains 100 °C until all the water changes into steam.

8.5 LATENT HEAT OF FUSION

Q.6 Define latent heat of fusion and write down its mathematical formula.

Ans: "Heat energy required to change unit mass of a substance from solid to liquid state at its melting point without change in the temperature is called its latent heat of fusion".

Mathematical Formula

It is denoted by H_f.

$$H_f = \frac{\Delta Q_f}{m}$$

Or $\Delta Q_f = m\,H_f$

Latent Heat of Fusion of Ice

Ice changes at 0^o C into water. Latent heat of fusion of ice is 3.36×10^5 Jkg^{-1}. That is; 3.36×10^5 joules heat is required to melt 1 kg of ice into water 0^o C.

Experiment 8.1

Get a beaker, set it over a stand. Put small pieces of ice in it after hanging thermometer to note the temperature. Place a heat source under it and let the ice to melt. You will observe that temperature will not rise more than 0^0C until complete ice melts into water with a time gap.

The continued heat will rise temperature to 100^0C without repeat in time gap. Drawing graph, you can calculate the latent heat of fusion of ice with the data as given:

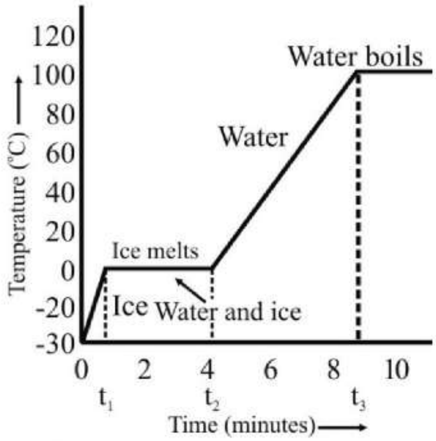

Figure 8.11: Temperature-time graph as ice changes into water that boils as heating continues.

Suppose the mass of ice =m

Measuring the time from the graph

Time taken by water to melt completely at 0^o C = $t_f = t_2 - t_1$ =3.6 minutes

Time taken by water to heat from 0^oC to 100^o C = $t_o = t_3 - t_2$ = 4.6 minutes

Specific heat of water $c = 4200\ JKg^{-1}\ K^{-1}$

Increase in the temperature of water $\Delta T = 100^o$ C

Heat required by water from 0^o C to 100^o C = ΔQ = ?

As we know that $\Delta Q = m\,c\,\Delta T$

$= m \times 4200 \times 100$

$= m \times 4.2 \times 10^3 \times 10^2$

$= 4.2 \times 10^5 \times m$ JKg^{-1}

To raise the temperature of the water from 0^o C to 100^o C, ΔQ is given to water. So the heat absorption rate of water in beaker can be given by

Rate of absorbing heat $= \Delta Q/t_o$

Since heat absorption in time $t_f = \Delta Q_f = (\Delta Q \times t_f)/t_o$

$= \Delta Q \times (t_f/t_o)$

As we know that $\Delta Q_f = m \times H_f$

$m \times H_f = 4.2 \times 10^5 \times m \times (t_f/t_o)$

$H_f = 4.2 \times 10^5 \times (t_f/t_o)$

Putting the values of t_f and t_o which can be found though graph

$H_f = 4.2 \times 10^5 \times (3.6/4.6)\ JKg^{-1}$

$H_f = 3.29 \times 10^5\ JKg^{-1}$

The latent heat of fusion of ice (H_f) found for above experiment is $3.29 \times 10^5\ JKg^{-1}$ however actual value is $3.36 \times 10^5\ JKg^{-1}$.

8.6 LATENT HEAT OF VAPORIZATION

Q.7 Define latent heat of vaporization. Write its mathematical formula.

Ans: "The quantity of heat that changes unit mass of a liquid completely into gas at its boiling point without any change in its temperature is called its latent heat of vaporization"

Explanation

When heat is given to a liquid at its boiling point, its temperature remains constant. The heat energy given to liquid at its boiling point is used up in changing its state from liquid to gas without any increase in its temperature.

Mathematical Form

It is denoted by H_v

$$H_v = \frac{\Delta Q_v}{m}$$

OR $$\Delta Q_v = m H_v$$

Latent Heat of Vaporization of Water

When water is heated, it boils at 100 °C under standard pressure. Its temperature remains 100°C until it is changed into steam. Its latent heat of vaporization is 2.26 x 106 Jkg-1. That is; one kilogram of water requires 2.26×10^6 joule heat to change it completely into gas (steam) at its boiling point.

Experiment 8.2

Water in the breaker takes to change completely into steam at its boiling point 100°C

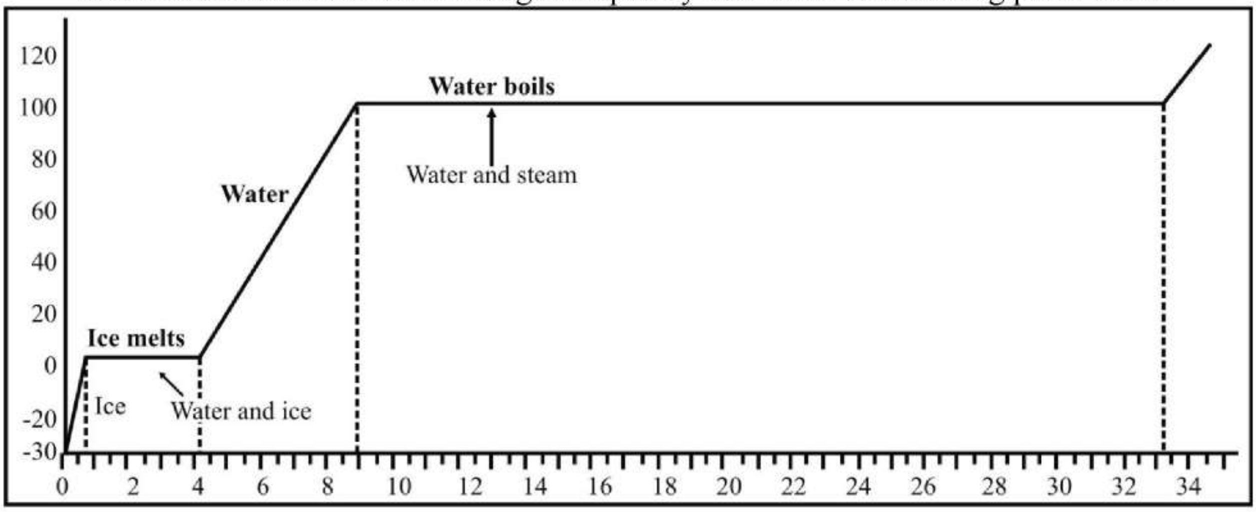

Figure: 8.12: Temperature-time graph as ice changes into water and water into steam on heating

Now take the boiling water of last experiment and heat till all water changes into steam. The time taken by boiled water to vaporize into steam is shown in graph. From graph, you can calculate the latent heat of vaporization of boiled water with the data as given:

Suppose: The mass of ice = m

Measuring the time from the graph

Time taken by water to heat from 0^o C to 100^o C = $t_o = t_3 - t_2 = 4.6$ minutes

Time taken by water to get changed into steam = $t_v = t_4 - t_3 = 24.4$ minutes

Specific heat of water $c = 4200\ JKg^{-1}\ K^{-1}$

Increase in the temperature of water $\Delta T = 100^o$ C

Heat required by water from 0^o C to 100^o C $= \Delta Q = m\, c\, \Delta T$

$$= m \times 4200 \times 100$$
$$= m \times 4.2 \times 10^3 \times 10^2$$
$$= 4.2 \times 10^5 \times m \quad JKg^{-1}$$

To raise the temperature of the water from 0^o C to 100^o C, ΔQ is given to water. So the heat absorption rate of water in beaker can be given by

Rate of absorbing heat $= \Delta Q/t_o$

Since heat absorption in time $t_v = \Delta Q_v = (\Delta Q \times t_v)/t_o$

$$= \Delta Q \times \left(\frac{t_v}{t_o}\right)$$

As we know that $\Delta Q_v = m \times H_v$

$$m \times H_v = 4.2 \times 10^5 \times m \times (t_v/t_o)$$
$$H_v = 4.2 \times 10^5 \times (t_v/t_o)$$

Putting the values of t_v and t_o which can be found though graph

$$H_f = 4.2 \times 10^5 \times (24.4/4.6)\ JKg^{-1}$$
$$H_f = 2.23 \times 10^6\ JKg^{-1}$$

The latent heat of vaporization of boiled water (H_v) found for above experiment is $2.23 \times 10^6\ JKg^{-1}$ however actual value is $2.26 \times 10^6\ JKg^{-1}$.

8.7 THE EVAPORATION

Q.8 Define evaporation. On what factor speed of evaporation depend? Explain.
(LHR 2016)

Ans: "Evaporation is the changing of a liquid into vapors (gaseous state) from the surface of the liquid without heating it".

Explanation

Take some water in a dish. The water in the dish will disappear after some time. It is because the molecules of water are in constant motion and possesses kinetic energy. Fast moving molecules escape out from the surface of water and goes into atmosphere.

Comparison of Boiling and Evaporation

Unlike boiling, evaporation takes place at all temperatures but only from the surface of a liquid. At boiling point, a liquid is changing into vapors not only from the surface but also within the liquid. These vapors are comes out of the boiling liquid as bubbles which breakdown on reaching the surface.

Example

Evaporation plays an important role in our daily life. We cloths dry up rapidly when spread.

Cooling Effect Produced by Evaporation

During evaporation fast moving molecules escape out from the surface of the liquid. Molecules that have lower kinetic energies are left behind. This lowers the average kinetic energy of the liquid molecules and the temperature of the liquid. Since temperature of a substance depends on the average kinetic energy of its molecules. Evaporation of perspiration helps to cool our bodies.

Dependence Factors

Evaporation takes place at all temperatures from the surface of a liquid. The rate of evaporation is affected by various factors.

Temperature

Why wet clothes dry up more quickly in summer than in winter? At higher temperature, more molecules of a liquid are moving with high velocities. Thus, more molecules escape from its surface. Thus, evaporation is faster at high temperature that at low temperature.

Surface Area

Why water evaporates faster when spread over large area? Large is the surface area of a liquid, greater number of molecules has the chance to escape from its surface.

Wind

Wind blowing over the surface of a liquid sweeps the liquid molecules that have just escaped out. This increases the chance for more liquid molecules to escape out.

Nature of the Liquid

Evaporation depends on the nature of the liquid. If we take spirit and water on our palm. As evaporation rate of spirit is greater than water, so we feel cooling effect due to evaporation of spirit.

8.8 THERMAL EXPANSION

Q.9 What is thermal expansion? Explain on the basis of kinetic molecular theory.
(LHR 2014)

Ans: Most of the substances solids, liquids and gases expand on heating and contract on cooling. Their thermal expansion and contractions are usually small and are not noticeable. However these expansions and contractions are important in our daily life.

Explanation on the basis of Kinetic Molecular Theory

The kinetic energy of the molecules of an object depends on its temperature. The molecules of a solid vibrate with large amplitude at high temperature than at low temperature. Thus, on heating, the amplitude of vibration of the atoms or molecules of an object increases. They push one another farther away as the amplitude of vibration increases. Thermal expansion results an increase in length, breadth and thickness of a substance.

Linear Thermal Expansion in Solids

Q.10 What is linear Expansion? On what factor it depend? Derive its mathematical formula.

Ans: "If a thin rod is heated, there is a prominent increase in its length as compared to its cross-sectional area. The expansion along length or in one dimension is called linear expansion".

Dependence

If we heat a metal rod the length of which is much larger than its thickness, then the increase in length depends on the following three factors:

(i) Length of thin rod.

(ii) Change in temperature.

(iii) Nature of material of the rod.

Mathematical form

Solids expand on heating and their expansion is nearly uniform over a wide range of temperature. Consider a metal rod of length L_o at certain temperature T_o. Let its length on heating to a temperature T becomes L. Thus

Increase in length of the rod = $\Delta L = L - L_o$

Increase in temperature = $\Delta T = T - T_o$

It is found that change in length ΔL of a solid is directly proportional to its original length L_o, and the change in temperature ΔT. that is;

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

OR $$\Delta L = \alpha L_o \Delta T$$

OR $$L - L_o = \alpha L_o \Delta T$$

$$L = L_o (1 + \alpha \Delta T)$$

Coefficient of Linear Expansion

$$\alpha = \frac{\Delta L}{L_o \Delta T}$$

Where α is the proportionality constant called co-efficient of linear expansion which depends on the nature of the material of the rod and it can be defined as:

"The fractional increase in its length per Kelvin rise in temperature which has unit K^{-1}"

OR

"If a rod of one meter length is heated through a temperature difference of 1K then the change in the length of the rod is called the co-efficient of linear expansion which has unit K^{-1}".

Volume Thermal Expansion

Q.11 What is volume expansion? On what factors it depend? Derive its mathematical formula.

Ans: "Heating a block causes an increase in length, breadth and thickness, i.e., volume of the block increases that is known as volume expansion".

Volume of a solid also changes with the change in temperature and is called volume thermal expansion or cubical thermal expansion.

Dependence

If we heat a block then increase in volume of the block depends on the following three factors:

(i) Original volume of block.

(ii) Change in temperature.

(iii) Nature of material of the block.

Mathematical form

Consider a solid of initial volume V_o at certain temperature T_o. On heating the solid to a temperature T, let its volume becomes V, then

Increase in volume of a solid = $\Delta V = V - V_o$

And Change in temperature = $\Delta T = T - T_o$

Like linear expansion, the change in volume ΔV is found to be proportional to its original volume V_o and change in temperature ΔT. Thus

$$V - V_o \ \alpha \ V_o$$

And
$$V - V_o \ \alpha \ \Delta T$$

$$V - V_o \ \alpha \ V_o \Delta T$$

$$V - V_o = \beta V_o \Delta T$$

$$V = V_o + \beta V_o \Delta T$$

$$V = V_o (1 + \beta \Delta T)$$

Coefficient of Volume Expansion

Where β is the proportionality constant and is called the co-efficient of volume expansion.

$$\beta = \frac{\Delta V}{V_o \Delta T}$$

Thus, we can define the temperature coefficient of volume expansion as:

"The fractional change in its volume per Kelvin change in temperature".

OR

"If a block of one meter cube volume is heated through a temperature difference of 1K then the change in the volume of the block is called the co-efficient of linear expansion".

Its unit is also K^{-1}, but as compared to the co-efficient of linear expansion, it is three times greater.

$$\beta = 3\alpha$$

Consequences of Thermal Expansion

Q.12 Write down the consequences of thermal expansion.

Ans: The expansions of solids many damage bridges, railway tracks and roads as they are constantly subjected to temperature changes.

- Prevision is made during construction for expansion and contraction with temperature.
- Railway tracks buckled on a hot summer day due to expansion if gaps are not left between sections.
- Bridges made of steel girders also expands during the day and contract during night. They will bend if their ends are fixed. To allow thermal expansion, one end is fixed while the other one of the girder rests on rollers in the gap left for expansion. Overhead transmission lines are also given a certain amount of sag so that they contract in winter without snapping.

Applications of Thermal Expansion

Q.13 Write down the applications of thermal expansion.

Ans: Thermal expansion is used in our daily life. In thermometers, thermal expansion is used in temperature measurements.

- To open the cap of a bottle that is tight enough, immerse it in hot water for a minute or so. Metal cap expands and becomes loose. It would now be easy to turn it to open.
- To join steel plates tightly together, red hot rivets are forced through holes in the plates as shown in figure. The end of hot rivet is then hammered. On cooling, the rivets contracts and bring the plates tightly griped.
- Iron rims are fixed on wooden wheels of carts. Iron rims are heated. Thermal expansion allows them to slip over the wooden wheel. Water is poured on it to cool. The rim contracts and becomes tight over the wheel.

Bimetal Strip (Thermostat)

A bimetal strip consists of two thin strips of different metals such as brass and iron joined together as shown in figure. On heating the strip, brass expands more than iron. This unequal expansion causes bending of the strip as shown in figure.

Usage

Bimetal strips are used for various purposes.

- Bimetal thermometers are used to measure temperature especially in furnaces and ovens.
- Bimetal strips are also used in thermo states.
- Bimetal thermo state switch is used to control the temperature of heater coil in an electric iron.

Thermal Expansion of Liquids

Q.14 Explain the thermal expansion of liquid.

Ans: The molecules of liquids are free to move in all directions within the liquid. On heating a liquid, the average amplitude of vibration of its molecules increases. The molecules push each other and need more space to occupy. This accounts for the expansion of the liquid when heated. The thermal expansion in liquids is greater than solids due to the weak forces between their molecules. Therefore, the coefficient of volume expansion of liquids is greater than solids.

No Definite Shape of Liquids

Liquids have no definite shape of their own. A liquid always attains shape of the container in which it is poured. Therefore, when a liquid is heated, both liquid and the container undergo a change in their volume.

Activity

Take a long-necked flask. Fill it with some colored liquid up to mark A on its neck as shown in figure. Now start heating the flask from bottom. The liquid level first falls to B and then rises to C.

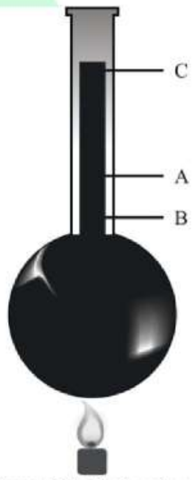

Figure 8.21: Real and apparent expansion of liquid.

Relation between expansions

We observe that there are two types of expansions appear as a result of heating a liquid in any container.

(i) Real expansion

(ii) Apparent expansion

In the given figure, real expansion is from B to C whereas A to C is apparent expansion. AB shows the expansion of the flask, whereas BC represents the real expansion of the liquid. Real expansion of the liquid is equal to the volume difference between A and C in addition to the volume expansion of the flask.

It can be seen that real expansion is comparatively greater than apparent expansion and they are related as follows:

Real expansion of liquid = Apparent expansion of liquid + Expansion of the flask

$$BC = AC + AB$$

The expansion of the volume of a liquid taking into consideration the expansion of the container also, is called the real expansion of the liquid.

Coefficients of volume expansions

The real rate of volume expansion β_r of a liquid is defined as the actual change in unit volume of a liquid for 1K (or 1 ^oC) rise in its temperature. The real rate of volume expansion β_r is always greater than the rate of volume expansion β_a by an amount equal to the rate of volume expansion of the container β_g.

Thus $\beta_r = \beta_a + \beta_g$

It should be noted that different liquids have different coefficients of volume expansion.

Coefficients of liquid expansion

In accordance with the apparent and real expansions of the liquids, their co-efficient of expansion are also measured in two ways:

(i) Coefficient of apparent expansion

(ii) Coefficient of real expansion