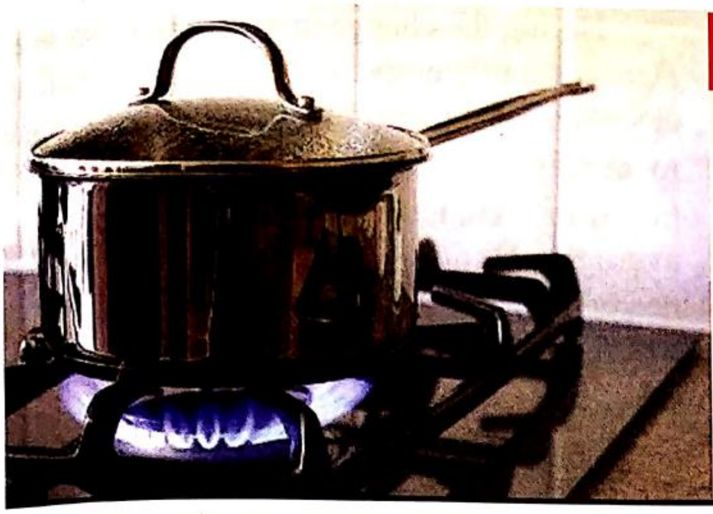


6
Heat Transfer

Theme : In both boiling and evaporation, matter changes from liquid to gas. But the two processes are quite different. When temperature of a matter increases, the particles of the matter gain energy and move with greater speed. In evaporation, the particles of the surface escape and form gas. Other particles, inside the liquid, do not have enough energy. So the process of evaporation of the liquid are at the same temperature and are involved in the process. It happens in the whole volume of the liquid. And it happens at a fixed temperature, particular to a liquid. But before change of states takes place due to supply of heat. There is another effect which is commonly observed. That is the expansion of matter. Matters in all form, except some exceptions, expand on heating. In solids, the effect is less, in liquids more, and in gases maximum. Classification of expansion into three types-linear, superficial and volume are explained with examples from daily life.

In this chapter you will learn to

- compare and contrast boiling and evaporation;
- describe thermal expansion of matter;
- describe, linear, area (superficial) and volume expansion;
- compare expansivity in solids, liquids and gases;
- construct models based on scientific process;
- observe and cite multiple physical phenomena from one experiment;

LEARNING OBJECTIVES

- Revising and revisiting previous concepts learnt by children.
- Building on children's previous learning Demonstrating points of boiling and evaporation.
- Engaging children in tasks related to boiling and evaporation.
- Explaining the difference in boiling and evaporation.
- Demonstrating linear expansion, area expansion and volume expansion through conducting simple experiments for children.
- Explaining expansion with the help of examples from daily life activities.

KNOWING CONCEPTS

- Difference between boiling and evaporation.
- Thermal expansion:
  - Linear expansion
  - Volume expansion
  - Superficial expansion
  - Compare expansivity in solids, liquid, and gases.
  - Examples and real world applications

INTRODUCTION

In the earlier classes you have read that matter is composed of tiny particles called the molecules. A molecule can exist freely in nature and it possess the properties of the matter. It is very small in size (nearly 10^{-10} m) and cannot be seen even by a microscope. The molecules are in motion as well as they have the forces of attraction amongst them. Due to motion, the molecules have the kinetic energy and due to forces of attraction, they have the potential energy. When a substance absorbs heat (or the substance is heated), the motion of its molecules becomes rapid, so their kinetic energy increases. When the substance is cooled (or it gives out heat), the motion of its molecules becomes slow and so their kinetic energy decreases. The total kinetic energy of molecules of the substance is called its internal kinetic energy and the total potential energy of molecules is called its internal potential energy. The sum of internal kinetic energy and internal potential energy is called the total internal energy or heat energy of the substance. Thus, heat is the internal energy of a substance. It is measured in the unit joule (symbol J)*.

When two bodies at different temperatures are kept in contact, heat flows from a body at high temperature to a body at low temperature. The average kinetic energy of the substance is a measure of temperature of the body. When there is a rise in average kinetic energy of molecules of a substance, its temperature increases and if there is fall in the average kinetic energy of molecules of a substance, its temperature decreases.

Imp

* Other common unit of heat is calorie (symbol cal). Where 1 cal = 4·2 J (nearly)

During the change in state of a substance, at a constant temperature, since no heat is absorbed (or rejected), there will be no change in average kinetic energy of its molecules (since temperature remains constant), but the average potential energy will increase (or decrease).

EFFECTS OF HEAT

Heat produces mainly the following three effects :

1. Change in temperature of the body,
2. Change in state of the body, and
3. Change in size of the body.

1. Change in temperature of the body :

When a body is heated, its temperature rises and when it is cooled, its temperature falls. The change in temperature of the body depends on the following two factors :

(a) Quantity of heat imparted to (or rejected from) the body : When heat is imparted (or given) to the body, its temperature rises while if heat is rejected (or taken) from the body, its temperature falls.

Reason : On heating, the molecules begin to move faster, so the average kinetic energy of molecules increases and so the temperature rises. On the other hand, on cooling, the average kinetic energy of molecules decreases, so temperature falls.

(b) Material of the body : Some materials rise to high temperature while some to a low temperature even when same quantity of heat is imparted to them.

Reason : Different materials have different specific heat capacity (*i.e.*, different amount of heat required to raise the temperature of unit mass by unit rise in temperature).

2. Change in state of the body :

Matter exists in three different states, namely solid, liquid and gas.

The process of change from one state to another at a constant temperature is called change of state.

When a solid is heated, it changes into its liquid at a fixed temperature. This process is called melting. The reverse happens when a liquid is cooled, the liquid freezes into solid at the same fixed temperature. This process is called freezing or fusion. *For example*, ice at 0°C on heating melts into water at 0°C, while water at 0°C on cooling freezes or fuses into ice at 0°C.

When a liquid is heated, it changes into its vapour (or gas) at a fixed temperature. This process is called vaporization or boiling. The reverse happens when vapour is cooled, the vapour condenses into liquid at the same fixed temperature. This process is called condensation. *For example*, water at 100°C on heating vaporizes into steam at 100°C, while steam at 100°C on cooling condenses into water at 100°C.

When a solid on heating changes directly into its vapour at a fixed temperature, the process is called sublimation. *For example*, camphor on heating, changes directly from solid to vapour. These vapour on cooling change directly into solid state. This process is called solidification or deposition.

The change of state from liquid to gas at all temperatures is called evaporation. Thus, evaporation differs from boiling. Boiling is at a fixed temperature while evaporation takes place at all temperatures. *For example*, drying of clothes is due to evaporation of water. Evaporation is a slow process, while boiling is a rapid process. Fig. 6.1, shows the change in different states of matter.

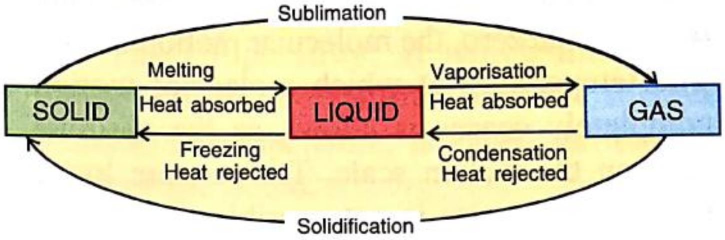


Fig. 6.1 Changes in state

The heat absorbed, (or rejected) during the change of state is called latent heat or hidden heat because it is not manifested by any change in temperature. This heat when expressed for unit mass of a substance is called specific latent heat. Since temperature does not change during the change of state, there is no change in average kinetic energy of molecules of the substance but the heat absorbed (or rejected) changes the average potential energy of the molecules of the substance.

3. Change in size of the body :

When a body is heated, it expands and upon cooling, it contracts. This change in size of the body due to heating is called thermal expansion.

Generally all solids, liquids and gases expand on heating or contract on cooling. The reason is that on heating a substance, the average inter molecular separation between the molecules of the substance increases, while on cooling it decreases.

EFFECT OF TEMPERATURE ON MOLECULAR MOTION

We have read that the molecules of each substance possess kinetic energy by virtue of their continuous motion. When the motion becomes less rapid, the temperature decreases or if the temperature decreases, the molecular speed decreases. At high temperatures, the molecules are very much agitated. This suggests that as a limit, when the temperature will become zero, the molecular motion ceases. The temperature at which molecular motion completely ceases is known as the absolute zero on the Kelvin scale. Temperature lower than absolute zero is not possible.

CHANGE OF LIQUID INTO VAPOUR STATE

A liquid changes into vapour in two ways :

1. By evaporation at all temperatures, and
2. By boiling at a fixed temperature.

1. EVAPORATION

The change of liquid into its vapour at all temperatures from its surface is called evaporation.

If you place a drop of ether on your palm, you will notice that the ether disappears within a few seconds and the palm feels cold. The process causing this phenomenon is known as evaporation. This is essentially a surface phenomenon and takes place at all temperatures. The process of evaporation can be understood in terms of the molecular motion.

EXPLANATION OF EVAPORATION ON THE BASIS OF MOLECULAR MOTIONS

It is difficult to break a solid into its small pieces, but a liquid can easily break up into small drops. We conclude, therefore, that the mutual force of attraction between the liquid molecules is much less than that in the case of a solid. The attractive force between the liquid molecules is not strong enough to keep them in fixed positions. Therefore, the liquid molecules can move throughout the liquid. The molecules of a liquid on an average have a larger speed than the molecules of a solid. The relative distance between the liquid molecules and the direction of their motion is found to be totally irregular. When a molecule, while in motion, reaches the surface of the liquid, it is pulled inside by the Cohesive force of surrounding molecules of the liquid as there are no molecules on the other side of the surface. Thus, molecules are not allowed to leave the surface and therefore a liquid has a definite volume.

On the other hand, in a gas the molecules are very much farther apart than those of a solid or liquid. There is a very small or negligible force of attraction between the gas molecules and therefore the molecules are free to move about over the entire available space. This is why a gas has neither a fixed shape nor a fixed volume.

In a liquid, molecules while in motion collide with each other. Some molecules which gain energy reach to the surface of liquid while others which lose energy remain inside the liquid. Thus, the molecules on the surface of liquid have higher kinetic energy than those inside the liquid. During evaporation, the molecules on the surface which have sufficient kinetic energy to do work against the force of attraction on them due to other molecules inside the liquid, escape out from the surface in space. These escaping molecules form the vapour of the liquid. The process continues till all the liquid evaporates. The rate of evaporation depends on temperature of liquid, wind, surface area and the presence of humidity.

Effect of temperatures on the rate of evaporation : The rate of evaporation increases with the increase in temperature of liquid. The reason is that the energy of the molecules increases with increase in temperature. So more and more molecules come to the surface of liquid, hence the rate of evaporation will increase with increase of temperature.

Effect of blowing of air on the rate of evaporation : When air is blown above the surface of liquid, the rate of evaporation increases. The reason is that blowing air takes away with it the molecules of liquid escaping out of the surface. To take their place, other molecules escape out from the surface of liquid.

Effect of increase in area of surface on the rate of evaporation : On increasing the area of surface exposed to air, the rate of evaporation increases. The reason being that on increasing the area of surface, number of molecules escaping out from the surface increases.

Effect of presence of humidity : In presence of humidity, the rate of evaporation becomes slow because vapour molecules do not find space to escape.

Cooling produced during evaporation: When a liquid evaporates, it produces cooling in its surroundings.

Reason : In the process of evaporation, a liquid changes to vapour and for this purpose some heat is needed. If there is no external supply of heat, the liquid (e.g. ether) will draw the necessary heat from its surroundings (e.g. palm of your hand) and therefore it (palm) gets cooled.

2. BOILING

The change from the liquid state to the gaseous (or vapour) state, on heating at a constant temperature, is called boiling.

The temperature, at which the liquid changes into the vapour without further increase in temperature, is called the boiling point of the liquid.

The boiling of a liquid can be demonstrated by the following activity.

ACTIVITY 1

Take a beaker. Pour some water in the beaker. Place the beaker on a wire guaze placed over the tripod stand. Clamp a thermometer in a vertical stand and insert it in the beaker as shown in Fig. 6.2. Heat the beaker over the flame of a burner and record the temperature of water after every minute.

You will notice that temperature of water rises continuously till the water starts boiling at 100°C. Once the water starts boiling, its temperature does not rise any further, although the heat is still being supplied. Now the bubbles formed throughout the water are seen. At this temperature, water begins to boil and changes into steam. Thus, the boiling point of water is 100°C.

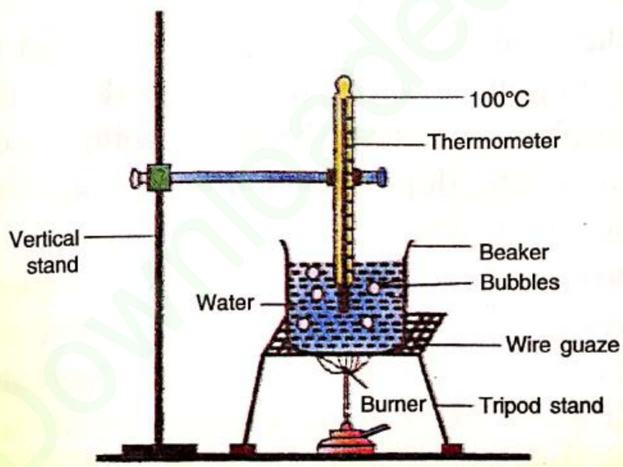


Fig. 6.2 Boiling of water

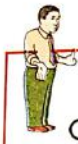
EXPLANATION OF BOILING BY MOLECUAR MOTION

When a certain liquid is heated, there is rapid formation of vapour from all parts of the liquid as indicated by visible bubbles. Heating of the liquid increases the average kinetic energy of the liquid molecules when the molecules acquire sufficient kinetic energy to do work against the force of attraction of other molecules.

These molecules now start leaving the liquid, not only at the surface but also near the walls of the containing vessel. This is shown by the presence of bubbles on the walls of the vessel. The bubbles grow in size with further evaporation and move to the surface in quick succession. This causes agitation in whole of the liquid and this is called boiling. When the boiling starts, the temperature of the liquid does not increase any further. This temperature is known as the boiling point of the liquid.

Effect of pressure on the boiling point : The boiling point of a liquid increases with an increase in pressure and it decreases with decrease in pressure. The reason is that at the boiling point, the pressure exerted by the vapour of liquid is equal to the atmospheric pressure. Thus, the boiling point of a liquid depends on the surrounding atmospheric pressure. With the increase of atmospheric pressure, boiling point of a liquid increases to increase the vapour pressure and make it equal to the atmospheric pressure and with the decrease in atmospheric pressure, it decreases.

This is why at mountains where the atmospheric pressure is low, water boils at a temperature below 100°C and it becomes difficult to cook the vegetables. On the other hand, in a pressure cooker by keeping the water vapours inside it, the surrounding pressure is increased, then water inside it boils at a temperature nearly 125°C, so the vegetables get readily cooked inside it.



Do You Know ?

One kg of water at 100°C absorbs $2{\cdot}26 \times 10^6$ J (or $5{\cdot}4 \times 10^5$ cal) of heat to convert into steam at 100°C.

DIFFERENCE BETWEEN EVAPORATION AND BOILING

In both processes evaporation and boiling, a liquid changes its state to the vapour or gaseous state. But they differ in the following respects :

1. Evaporation takes place at all temperatures while boiling takes place at a fixed temperature called the boiling point of liquid.
2. Evaporation occurs only from the surface of liquid (*i.e.*, it is a surface phenomenon) while boiling takes place throughout the mass of liquid at the same instant.
3. In evaporation, some molecules near the surface of liquid acquire sufficient kinetic energy by collisions with other liquid molecules to overcome the attractive forces of the other molecules. Thus, absorbing heat from the surroundings, they escape out in space. On the other hand, in boiling at a fixed temperature, the average kinetic energy of the liquid molecules become sufficient to overcome

the forces of attraction of other molecules and they start leaving the liquid throughout the mass of liquid. As a result, bubbles are formed. These bubbles move to the surface and boiling of liquid takes place.

4. In evaporation, heat is absorbed by the molecules at the surface of liquid from its surroundings so as to change to vapour state, while in boiling, heat is supplied externally at a fixed temperature.
5. Evaporation is a slow process while boiling is a rapid process.

THERMAL EXPANSION

It has been experimentally observed that when a substance (solid, liquid or gas) is heated, it expands and when it is cooled, it contracts. We will now consider the thermal expansion in solids, liquids and gases separately.

Do You Know?

Exceptions of thermal expansions are :

1. Water from 0°C to 4°C.
2. Silver iodide from 80°C to 141°C.
3. Silica below – 80°C.

They contract on heating and expand on cooling in the given range of temperature.

THERMAL EXPANSION IN SOLIDS

A solid has a definite shape. When a solid is heated, it expands in all directions. Hence the length, area and volume all increase on heating a solid. The increase in length of a solid is called linear expansion. The increase in area is called superficial expansion and increase in volume is called cubical expansion.

Explanation of thermal expansion of solids on the basis of molecular motion

On heating a solid, the average kinetic energy of molecules of the solid increases. They start vibrating about their mean positions with a large amplitude. The result is that their mean positions change such that the inter-molecular separation between the molecules increases, thus the solid expands equally in all directions.

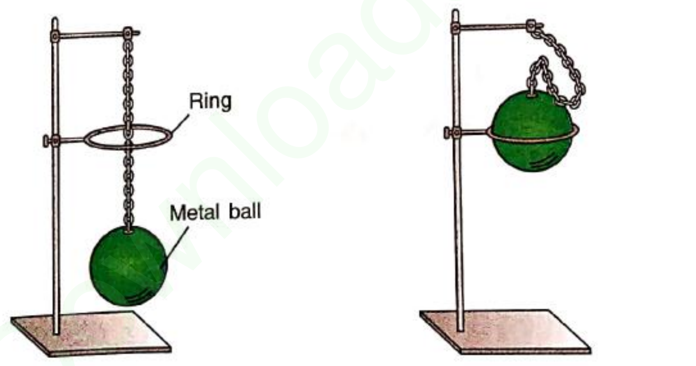
Demonstration of thermal expansion of solids

The thermal expansion in solids can be demonstrated by the following experiments.

Experiment (1) :

(i) Take a ball and ring set-up. This is shown in [Fig. 6.3(a)]. It consists of a metal ball and a ring. The metal ball just slips through the ring when both are at the room temperature.

(ii) Now heat the ball on a burner, and place it over the ring. You will notice that the ball does not pass through the ring [Fig. 6.3(b)]. The reason is that on heating, the ball expands and becomes bigger in diameter than the ring.



(a) Before heating, the ball passes through the ring

(b) After heating, the ball does not pass through the ring

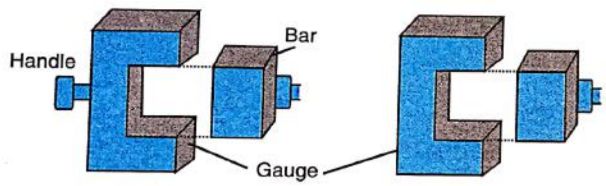
Fig. 6.3 Ball and ring set-up to show thermal expansion of a solid

(iii) Now allow the ball to cool by itself and after some time again place it over the ring. You will notice that the ball now passes through the ring. This is because on cooling, the ball contracts.

Experiment (2) :

(i) Take a bar and gauge set-up as shown in [Fig. 6.4(a)]. It consists of a metal bar and a metal gauge attached with a handle. The bar just fits into the gauge when both are at the room temperature.

(ii) Now heat the bar and try to fit it into the gauge. You will find that it does not fit into the gauge now [Fig. 6.4(b)]. This is because the bar expands on heating and becomes longer than the gap provided in the gauge.



(a) Before heating, the bar fits into the gauge

(b) after heating, the bar does not fit into the gauge

Fig. 6.4 Bar and gauge set-up to show thermal expansion in solids

(iii) Now allow the bar to cool by itself. You will find that the bar contracts on cooling and again fits into the gauge.

LINEAR EXPANSION

When a solid in form of a rod (or a wire) is heated, only the linear expansion (*i.e.*, increase in length) is effective. The increase in length of a metal rod on heating depends on the following three factors :

(i) Original length of the rod,

(ii) Increase in temperature, and

(iii) Material of the rod.

(i) Dependence on the original length of the rod : If we heat two rods of the same metal – one short and the other long, to the same temperature, we will find that the long rod expands more than the short rod. Thus, longer the rod, greater is the increase in its length.

(ii) Dependence on the increase in temperature : If we heat two identical rods (of the same metal and of the same length), one at a higher temperature than the other, we find that the rod heated to the higher temperature expands more than the rod heated to the lesser temperature. Thus, more the increase in temperature of rod, greater is the increase in its length.

(iii) Dependence on the material of the rod : If we heat two rods of same length, but one of copper and the other of iron at the same temperature, we find that the copper rod expands more than the iron rod. The increase in length of copper rod is nearly 3/2 times the increase in length of the iron rod. Thus, the increase in length of a rod depends on the material of the rod.

Do You Know ?

(I) A bimetallic strip which consists of two rods of same lengths but of different materials (say, one of iron and other of copper) rivetted together, is commonly used in a thermostat. A thermostat is a device used to control temperature by closing and opening the circuit. Thermostat is used in electrical gadgets like refrigerator, electric iron, oven, geysers, etc.

(2) The increase in length of a rod on heating does not depend whether it is hollow or solid. If we heat two rods of the same metal and of the same length, but one hollow and the other solid, to the same rise in temperature, we find that both the rods expand to the same extent.

If L_0 is the length of a rod at 0°C and its length at t °C is L_t, the increase in length is given as

$$L_t - L_0 = L_0 \alpha t$$

where α is called the coefficient of linear expansion which depends on the material of rod *i.e.*, α is different for different substances. Its unit is per °C.

The value of coefficient of linear expansion of some metals is given in the following table.

Coefficient of linear expansion of some solids

Substance	Coefficient of linear expansion ($\times 10^{-6}$ per °C)
Aluminium	24
Brass	19
Copper	17
Steel	13
Iron	12
Invar	0·9

Note : 1. Invar is an alloy which almost does not expand on heating. This is why the pendulum of a clock is made up of invar.

2. Pyrex glass also expands negligibly on heating.

Linear exparsion of solids can be demonstrated by the following activities.

ACTIVITY 2

To show linear expansion.

Take a metal rod and set up an apparatus as shown in Fig. 6.5. Fix one end of the rod and keep the other end free but it touches a pointer. Now heat the rod. You will see that the pointer starts moving up with the expansion of the metal rod. The metal rod elongates along the free end which pushes the pointer upward.

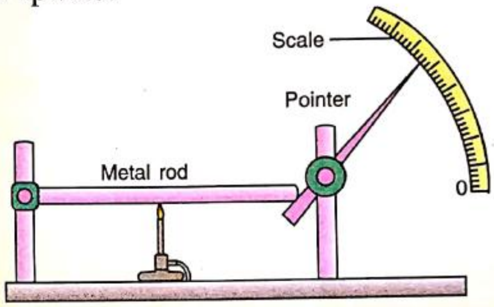


Fig. 6.5 A metal rod expands on heating

ACTIVITY 3

To show bending of a bimetallic strip

Take a composite bar (a bimetallic strip) as shown in Fig. 6.6(a). The bar is made of brass and iron of equal length and rivetted together. Heat the bar and observe. You will notice that the bar bends.

The reason is that brass expands more than iron on heating. The coefficient of linear expansion of brass is about 1·5 times that of iron. Thus, when the composite bar is heated, it acquires a curved shape as shown in the Fig. 6.6(b).

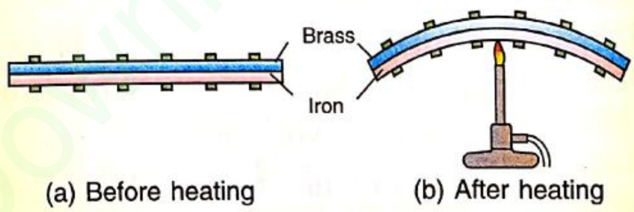


Fig. 6.6 Different metals on heating expand by different length.

Superficial expansion of solids

When a metal plate is heated, its length and breadth, both increase. This increases the area of the plate.

Experimentally it is observed that the increase in area of the plate depends on :

(i) **The initial area of the plate :** Larger the initial area of plate, more is the increase in its area on heating.

(ii) **The increase in temperature :** More is the rise in temperature, more will be the increase in area of plate.

(iii) **Material of the plate :** A brass plate expands more than an iron plate of same dimensions for the same rise in temperature.

If A_0 is the area of plate at 0°C and A_t the area of plate at t°C, the increase in area is given as

$$A_t - A_0 = A_0\beta t$$

where β is the coefficient of superficial expansion which is different for different solids/materials.

Cubical expansions of solids

When a solid is heated, it expands in all directions *i.e.*, its length, breadth and thickness all increase. Thus, the volume of the solid too increases.

Experimentally it is observed that the increase in volume of a solid depends on :

(i) **The initial volume of solid :** More is the initial volume of solid, more is the increase in its volume.

(ii) **The rise in temperature :** More is the rise in temperature, more is the increase in its volume.

(iii) **The material of the solid :** A brass ball increases in volume more than an iron ball of same radius for the same rise in temperature.

If V_0 is the volume of a solid at 0°C and V_t the volume at t°C, then increase in volume is given as :

$$V_t - V_0 = V_0\gamma t$$

where γ is called the coefficient of cubical expansion of solid. It is different for different materials.

Relationship between α, β and γ :

The three coefficients α, β and γ are related as $\beta = 2\alpha$ and $\gamma = 3\alpha$

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

Some Applications of Thermal Expansion of Solids in Daily Life

1. **Construction of a bridge :** In construction of a bridge, steel girders are used. One end A of the girder is fixed in concrete, but the other end B is not fixed into concrete (or pillar). It is supported on rollers as shown in Fig. 6.7 so that if there is any rise (or fall) in temperature during summer (or winter), girder may expand (or contract) without affecting the pillar and bridge.

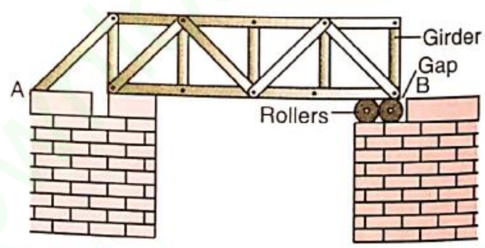


Fig. 6.7 In a bridge one end of a girder is kept on rollers for expansion or contraction

2. **Railway tracks :** The rails of railway tracks are made up of steel. While

laying the railway tracks on wooden or concrete planks, a small gap is left between the successive lengths of rail as shown in Fig. 6.8. The reason is that in summer due to considerable rise in atmospheric temperature, each rail tends to increase in its length, so a gap is left between the two rails, otherwise the rail will bend sideways.

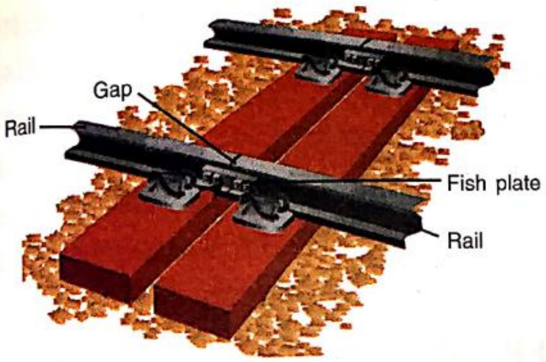


Fig. 6.8 Gap between the two rails for expansion in summer

3. **Riveting :** For joining two steel plates, they are placed one above the other and holes are drilled through them. The rivets (small steel rods) are heated red hot and then they are inserted in holes of the plates [Fig. 6.9(a)]. On heating, the rivets become soft, so their ends are easily hammered as heads. [Fig. 6.9(b)]. Now the rivets are allowed to cool [Fig. 6.9(c)]. On cooling, they contract but they can not regain their original size as they have been hammered so they bring the plates closer and firmly grip them together making the joints water-proof (or steam-proof). Such riveting is used in joining steel girders, boiler plates, etc.

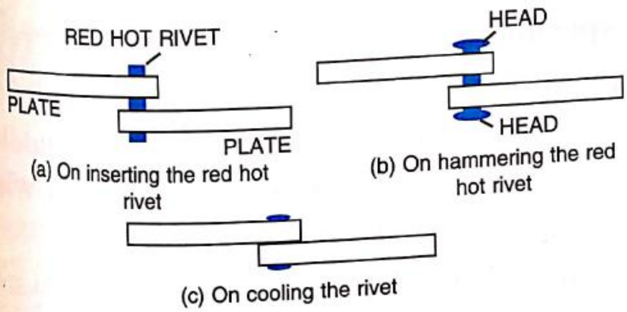


Fig. 6.9 Riveting

4. **Electric cables and telephone wires :** The electric cable in an overhead power transmission line and the telephone wires between two poles may break in winter due to contraction and may sag in summer due to expansion. Therefore, while putting up the wires between two poles, care is taken that in summer, they are kept slightly loose so that they may not break in winter due to contraction and while laying them in winter, they are kept tight so that they may not sag too much in summer due to expansion (Fig. 6.10).

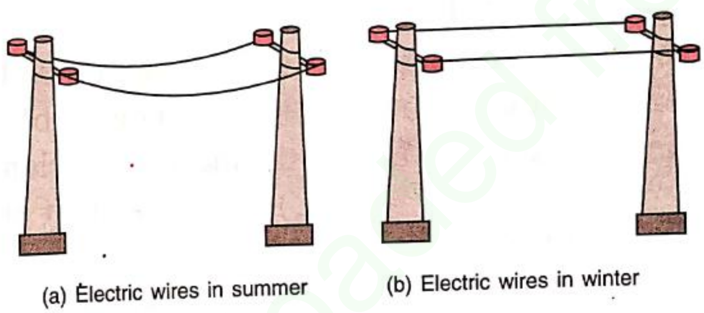


Fig. 6.10 In summer electric wires are kept loose while in winter they are kept tight

5. **Fitting the steel rim on a horse cart wheel :** The wooden wheel of a horse cart is fitted with a steel rim to make it strong and smooth. To ensure a tight fit of steel rim over the wooden wheel, the rim is made slightly smaller in diameter than the wooden wheel. Then to fit the

rim, it is first heated uniformly along its circumference till its diameter becomes slightly more than that of the wooden wheel. The rim is then slipped over the wooden wheel before allowing to cool. On cooling, the rim contracts and makes a tight fit over the wooden wheel as shown in Fig. 6.11.

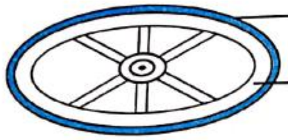


Fig. 6.11 Steel rim fitted over the wooden wheel

6. **Glassware used in kitchen :** The glassware used in kitchen are generally made up of pyrex glass. The reason is that the pyrex glass has a very low coefficient of cubical expansion, so the glassware on being heated, do not expand much and therefore they do not crack.

7. **Pendulum of a clock is made of invar :** Invar is an alloy of iron and nickel, and it has a negligibly small coefficient of linear expansion ($= 9 \times 10^{-7}$ per °C). The pendulum of invar make the clock neither to lose time in summer due to expansion, nor to gain time in winter because of contraction.

8. **Loosening a glass stopper or a metal screw cap :** A glass stopper on a bottle is loosened by warming the neck of the bottle. The reason is that on warming the neck of the bottle, the neck expands and the glass stopper in it gets space to loosen.

If there is a metal screw cap on the neck of a glass bottle, the screw cap is heated. On heating, the screw cap expands and it gets loosened.

9. **Cracking of thick glass tumbler :** When a hot liquid is poured into a thick glass tumbler, it cracks. The reason is that glass is a poor conductor of heat. When hot liquid is poured into a tumbler, the inner surface of tumbler becomes hot, while its outer surface remains at the room temperature. Therefore, the inner surface of tumbler expands, while its outer surface does not expand. This unequal expansion cracks the tumbler.

THERMAL EXPANSION IN LIQUIDS

Like solids, liquids also usually expand on heating. Liquids expand much more than the solids when heated. Liquids do not have a definite shape, but they have a definite volume, therefore the liquids have only cubical expansion.

Exception : Water contracts on heating it from 0°C to 4°C and then beyond 4°C on further heating, it expands. This is called anomalous behavior of water.

The cubical expansion of a liquid on being heated can be demonstrated by the following simple experiment.

Experiment :

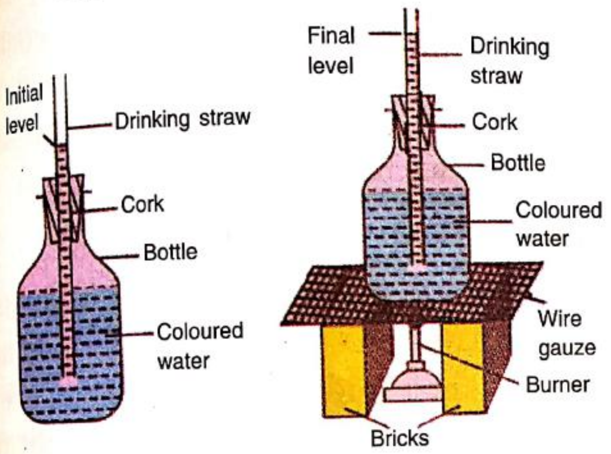
(i) Take an empty bottle with a tight fitting cork having a hole drilled in its middle, a drinking straw, two bricks, a wire guaze and a burner.

(ii) Fill the bottle completely with water and add few drops of ink in it to make it coloured for easy contrast.

(iii) Fix the cork in the mouth of the bottle and pass the drinking straw through the cork. Put some molten wax around the hole so as to avoid the leakage of water.

(iv) Pour some more water into the drinking straw so that water level in the straw can be seen. Mark the water level in the straw as shown in Fig. 6.12(a).

(v) Place the bottle on the wire gauze kept over the two bricks as shown in Fig. 6.12(b). Heat the bottle using a burner.



(a) Before heating (b) After heating

Fig. 6.12 Thermal expansion of liquid

(vi) Look at the level of water in the straw.

You will notice that as the water is heated more and more, the level of water in the drinking straw rises. This shows that water expands on heating.

Do You Know ?

When a liquid contained in a vessel is heated, first the vessel will get the heat so it will expand due to which the level of liquid will fall. Thereafter when heat reaches the liquid, it will expand, so the level of liquid will rise. Since liquids expand more than the solids, the liquid level rises above its initial level. Thus, the real expansion of liquid is more than the observed expansion.

Explanation of thermal expansion of liquid by molecular motion

In a liquid, the molecules are free to move anywhere within the liquid. When a liquid is heated, the average kinetic energy of its molecules increases. As a result, the molecules begin to move more vigorously thereby increasing the inter-molecular separation. Thus, the liquid expands on heating.

Factors affecting the cubical expansion of a liquid

The cubical expansion of a liquid depends on the following three factors :

(i) Original volume of the liquid :

Larger the volume of liquid taken, more is the increase in its volume, on heating.

(ii) Rise in temperature :

Greater the rise in temperature of a liquid, more is the increase in its volume.

(iii) Nature of liquid :

Equal volumes of different liquids when heated to the same temperature, undergo different increase in their volumes.

If V_0 is the volume of liquid at 0°C and V_t the volume of liquid at t°C, then increase in volume of liquid is given as

$$V_t - V_0 = V_0 \gamma t$$

where γ is the coefficient of cubical expansion of liquid.

Different liquids have different cubical expansion

Experimentally it is observed that equal volumes of different liquids when heated to the same temperature, expand by different amounts. This can be easily demonstrated by the following activity.

ACTIVITY 4

Take four identical glass bottles each fitted with a narrow glass tube through a cork at its mouth. Fill them up to the same level with different liquids say water, kerosene, alcohol and benzene. Place them in a common water bath containing boiling water as shown in Fig. 6.13.

After some time, you will notice that different liquids rise to different levels. Benzene expands the most, then alcohol and kerosene, water expands the least.

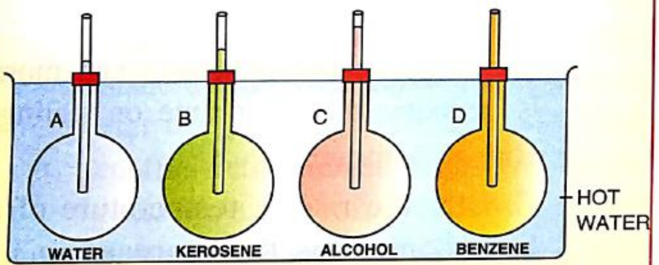


Fig. 6.13 Expansion of different liquids

The table given below gives the coefficient of cubical expansion of some common liquids.

Coefficient of cubical expansion of some liquids

Liquid	Coefficient of cubical expansion γ ($\times 10^{-4}$ per °C)
Mercury	1·8
Water (above 15°C)	3·7
Paraffin oil	9·0
Turpentine	10·5
Alcohol	11·0
Benzene	11·8

Application of thermal expansion of liquids in daily life

Thermal expansion of liquids is used in the working of a mercury thermometer. We have read that a mercury thermometer consists of a capillary tube with one end closed and a cylindrical bulb at the other end. The bulb is filled with mercury. Mercury is a shiny liquid, so its level can be seen easily in the capillary tube. When the bulb of the thermometer is kept in contact with a hot body, mercury expands. The level of mercury rises in the capillary tube. The tube is graduated to read the temperature. For each degree rise in temperature, mercury expands by the same volume, so the calibration of thermometer becomes easier.

THERMAL EXPANSION IN GASES

Gases also expand when they are heated. Gases expand much more than liquids and solids. Like liquids, gases do not have a definite shape, so they also have only the cubical expansion.

Thermal expansion of gases can be demonstrated by the following simple activity.

ACTIVITY 5

(i) Take an empty bottle. Actually, the empty bottle contains air. Attach a rubber balloon to

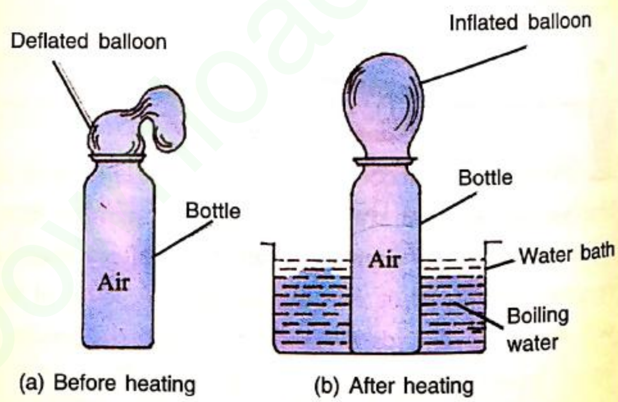


Fig. 6.14 Thermal expansion of air

its neck as shown in Fig. 6.14(a). Initially, the balloon is deflated.

(ii) Place the bottle in a water bath containing boiling water which heats the air contained in the bottle. After some time you will notice that the balloon gets inflated as shown in Fig.6.14(b). This shows that on heating, the air enclosed in the bottle expands and fills the balloon, hence the balloon gets inflated. Thus air expands on heating.

Do You Know ?

A gas is heated by keeping either its volume or pressure constant. In both cases, the expansion is same (*i.e.*, increase in pressure when volume is kept constant or increase in volume when pressure is kept constant, are same).

Explanation of thermal expansion in gases by the molecular motion

In a gas, molecules have more inter-molecular spacing amongst them. On heating, the average kinetic energy of molecules of gas increases and they begin to move violently in all space available to them for motion. As a result, the inter-molecular separation further increases, so they expand.

VARIATION OF DENSITY WITH TEMPERATURE

When a substance is heated, its volume increases while its mass remains same, therefore, the density of substance (being the ratio of mass to its volume), decreases with the increase in temperature.

In case of solids, when temperature increases, increase in volume is very small and therefore, the decrease in density is not appreciable. But in case of liquids and gases, as temperature increases, volume increases by an appreciable amount and therefore decrease in their density is quite considerable.

Exception : Water contracts on heating from 0°C to 4°C, so the density of water increases on heating it from 0°C to 4°C. On further heating above 4°C, the density of water decreases. Thus, water has maximum density (= 1000 kg m^{-3}) at 4°C.

Do You Know ?

If an iron washer shown in Fig. 6.15 is heated, its mass will remain unchanged, its internal diameter will increase, its external diameter will increase, its thickness will increase, its volume will increase but its density will decrease.

Fig. 6.15

RECAPITULATION

- Matter is the substance which occupies space and has mass.
- The three states of matter are (i) solid, (ii) liquid and (iii) gas.
- Matter is composed of large number of molecules.
- A molecule is the smallest particle which can exist freely in nature by itself and it retains the properties of the substance.

- In a liquid, the molecules are not rigid, the inter-molecular spacing is more than that in solids, the inter-molecular forces are weak and the molecules are free to move within the boundary of the liquid, so the liquid has a definite volume, but it does not have a definite shape.
- In gases, the molecules are not rigid, the inter-molecular spacing is more than that in solids and liquids, the inter-molecular forces are the weakest, thus molecules are free to move anywhere in space. So a gas has neither a definite volume nor a definite shape.
- In evaporation, a liquid changes into vapour or gas at all temperatures.
- Evaporation is a surface phenomenon that occurs at all temperatures.
- In evaporation, some molecules near the surface of liquid acquire sufficient kinetic energy by collisions with the other molecules, to reach the surface. These molecules absorb heat from the surroundings to escape out in space.
- In boiling at a fixed temperature, by absorbing heat from an external source, all molecules throughout the liquid acquire sufficient kinetic energy to overcome the force of attraction of other molecules, so they escape out from the liquid in form of vapour.
- When a solid, liquid or gas is heated, it expands.
- The expansion of a substance when heated is called thermal expansion.
- A solid on being heated expands in length, area as well as in volume. Thus, a solid undergoes linear expansion, superficial expansion and cubical expansion.
- The increase in length of a solid in form of a rod, on heating, depends on : (i) its original length, (ii) the rise in temperature, and (iii) the material of the rod. Longer the rod, greater is the increase in its length. More the rise in temperature of rod, more is the increase in its length. Equal lengths of rods of different materials expand by different lengths, when heated to the same temperature.
- The increase in length is given as $L_t - L_0 = L_0 \alpha t$
- The increase in area of a plate is given as $A_t - A_0 = A_0 \beta t$
- The increase in volume of a solid is given as $V_t - V_0 = V_0 \gamma t$
- The coefficients of linear expansion α, superficial expansion β and cubical expansion γ are related as
  $$\alpha : \beta : \gamma = 1 : 2 : 3.$$
- According to molecular motion, the molecules of a solid on heating start vibrating about their mean positions with greater amplitude. This changes the mean positions of the molecules so as to increase the inter-molecular spacing and so the solid expands on heating.
- Some solids such as invar, pyrex glass, quartz have negligible expansion on heating.
- Liquids expand more than solids when heated.
- Liquids have only cubical expansion.
- The increase in volume of a liquid is given as $V_t - V_0 = \gamma V_0 t$ where γ is the coefficient of cubical expansion of liquid.
- Different liquids of same volume expand by different amounts when heated to the same rise in temperature e.g. benzene expands much more than water.
- Water contracts on heating from 0°C to 4°C and then it expands on further heating above 4°C.
- Thermal expansion of liquids is used in the working of a mercury thermometer.
- Gases expand much more than solids and liquids, when heated. They also have only cubical expansion.
- On heating, density of solids, liquids and gases decreases.
- Water has maximum density at 4°C which is equal to 1000 kg m^{-3}.

TEST YOURSELF

A. Objective Questions :

1. Write **true** or **false** for each statement :

(a) Evaporation is rapid on a wet day.

(b) Evaporation takes place only from the surface of a liquid.

(c) All molecules of a liquid take part in the process of evaporation.

(d) Temperature of a liquid rises during boiling or vaporization.

(e) All molecules of a liquid take part in boiling.

(f) Boiling is a rapid phenomenon.

(g) All solids expand by the same amount when heated to the same rise in temperature.

(h) Telephone wires are kept tight between the two poles in winter.

(i) Equal volumes of different liquids expand by different amounts when they are heated to the same rise in temperature.

(j) Solids expand the least and gases expand the most on being heated.

(k) A mercury thermometer makes use of the property of expansion of liquids on heating.

(l) Kerosene contracts on heating.

Ans: True—(b), (e), (f), (h), (i), (j), (k)
False—(a), (c), (d),(g), (l)

2. Fill in the blanks :

(a) Boiling occurs at ....

(b) Evaporation takes place at ....

(c) The molecules of liquid .... heat from surroundings in evaporation.

(d) Heat is .... during boiling.

(e) Cooling is produced in ....

(f) A longer rod expands .... than a shorter rod on being heated to the same temperature.

(g) Liquids expand .... than the solids.

(h) Gases expand .... than the liquids.

(i) Alcohol expands .... than water.

(j) Iron expands .... than copper.

Ans: (a) a fixed temperature, (b) all temperatures, (c) absorb (d) absorbed, (e) evaporation, (f) more, (g) more, (h) more (i) more (j) less

3. Match the following :

Column A	Column B
(a) Blowing air increases	(i) increase in inter-molecular separation
(b) Increase in pressure increases	(ii) pendulum of a clock
(c) Thermal expansion	(iii) cooking utensils
(d) Invar	(iv) boiling point
(e) Pyrex glass	(v) evaporation

Ans: (a)–(v), (b)–(iv), (c)–(i), (d)–(ii), (e)–(iii)

4. Select the correct alternative :

(a) In evaporation :

(i) all molecules of liquid begin to escape out

(ii) only the molecules at the surface escape out

(iii) the temperature of liquid rises by absorbing heat from surroundings.

(iv) the molecules get attracted within the liquid.

(b) The rate of evaporation of a liquid increases when :

(i) temperature of liquid falls

(ii) liquid is poured in a vessel of less surface area

(iii) air is blown above the surface of liquid

(iv) humidity increases.

(c) During boiling or vaporization :

(i) all molecules take part

(ii) temperature rises

(iii) no heat is absorbed

(iv) the average kinetic energy of molecules increases.

(d) The boiling point of a liquid is increased by:

(i) increasing the volume of liquid

(ii) increasing the pressure on liquid

(iii) adding ice to the liquid

(iv) decreasing pressure on liquid.

(e) Two rods A and B of the same metal, but of length 1 m and 2 m respectively, are heated from 0°C to 100°C. Then :

(i) both the rods A and B elongate the same

(ii) the rod A elongates more than the rod B

(iii) the rod B elongates more than the rod A

(iv) the rod A elongates, but the rod B contracts.

(f) Two rods A and B of the same metal, same length, but one solid and the other hollow, are heated to the same rise in temperature. Then :

(i) the solid rod A expands more than the hollow rod B

(ii) the hollow rod B expands more than the solid rod A

(iii) the hollow rod B contracts, but the solid rod A expands

(iv) both the rods A and B expand the same.

(g) A given volume of alcohol and the same volume of water are heated from the room temperature to the same temperature then :

(i) alcohol contracts, but water expands

(ii) water contracts, but alcohol expands

(iii) water expands more than alcohol

(iv) alcohol expands more than water.

(h) The increase in length of a metal rod depends on :

(i) the initial length of the rod only

(ii) the rise in temperature only

(iii) the material of rod only

(iv) all the above three factors.

(i) The correct statement is :

(i) Iron rims are cooled before they are placed on the cart wheels.

(ii) A glass stopper gets tightened on warming the neck of the bottle.

(iii) Telephone wires sag in winter, but become tight in summer.

(iv) A little space is left between two rails on a railway track.

Ans.: (a)–(ii), (b)–(iii), (c)–(i), (d)–(ii), (e)–(iii), (f)–(iv), (g)–(iv), (h)–(iv), (i)–(iv)

B. Short/Long Answer Questions :

1. What is matter ? What is it composed of ?
2. Name the three states of matter and distinguish them on the basis of their (i) volume, and (ii) shape
3. Distinguish between liquid and vapour (or gas) states of matter on the basis of following factors :
   (a) Arrangement of molecules
   (b) Inter-molecular separation
   (c) Inter-molecular force, and
   (d) Kinetic energy of molecules
4. What is evaporation ? Explain it on the basis of molecular motion.
5. Do all the molecules of a liquid take part in evaporation ? If not, explain your answer.
6. No heat is supplied to a liquid during evaporation. How does then the liquid change into its vapour ?
7. Comment on the statement 'evaporation is a surface phenomenon'.
8. Why is cooling produced when a liquid evaporates ?
9. Give reason for the increase in rate of evaporation of a liquid when
   (a) air is blown above the liquid
   (b) surface area of liquid is increased
   (c) temperature of liquid is increased.

10. What is boiling ? Explain it on the basis of molecular motion.

11. Why does bubbles appear when a liquid is heated ?

12. What is the change in average kinetic energy of molecules of a liquid during boiling at its boiling point ?

13. How is the heat energy supplied to a liquid used during boiling at a fixed temperature ?

14. Name two ways of changing liquid state to the vapour state and distinguish them.

15. What do you understand by thermal expansion of a substance ?

16. Give *two* examples of the substances which expand on heating.

17. Describe an experiment to demonstrate the thermal expansion in solids.

18. State three factors on which depend the linear expansion of a metal rod on heating.

19. Two iron rods – one 10 m long and the other 5 m long, are heated to the same rise in temperature. Which will expand more ?

20. Two identical rods of copper are heated to different temperatures – one by 5°C and the other by 10°C. Which rod will expand more ?

21. One rod of copper and another identical rod of iron are heated to the same rise in temperature. Which rod will expand more ? Give reason.

22. Two identical rods – one hollow and the other solid, are heated to the same rise in temperature. Which will expand more ?

23. In the ball and ring experiment, if the ball after heating is left to cool on the ring for some time, the ball again passes through the ring. Explain the reason.

24. Explain the following :
    (a) The telephone wires break in winter.
    (b) Iron rims are heated before they are fixed on the wooden wheels.
    (c) The gaps are left between the successive rails on a railway track.
    (d) A glass stopper stuck in the neck of a bottle can be removed by pouring hot water on the neck of the bottle.
    (e) A cement floor is laid in small pieces with gaps in between.

25. Why is one end of a steel girder in a bridge kept on rollers instead of fixing it in pillar ?

26. A metal plate is heated. State three factors on which the increase in its area will depend.

27. A cubical metal solid block is heated. How will its volume change ?

28. Describe an experiment to show that liquids expand on heating.

29. State one application of thermal expansion of liquids.

30. Describe an experiment to show that air expands on heating.

31. An empty glass bottle is fitted with a narrow tube at its mouth. The open end of the tube is kept in a beaker containing water. When the bottle is heated, bubbles of air are seen escaping into water. Explain the reason.

32. Which of the following will expand more, when heated to the same temperature : (a) solid (b) liquid and (c) gas ?

33. Describe an experiment to show that same volume of different liquids heated to same rise in temperature expand by different amounts.

34. 100 ml of each of the following liquids is heated from 10°C to 50°C. Which will expand more : (a) water (b) benzene (c) alcohol ?

35. Water is heated from 0°C to 4°C. Will i[t] expand ?

36. What do you mean by anomalous behavior o[f] water ?

37. How does the density of a substance (solid, liqui[d] and gas) change on heating ?

38. An iron washer is heated. State the effect on i[ts] (i) mass, (ii) internal diameter, (iii) extern[al] diameter, and (iv) density.

Project Work

To prepare a model of fire alarm.

1. Take a bimetallic strip made of brass and iron, two vertical stands, a metal rod, a dry cell, an electric bell, a spirit lamp and some connecting wires.
2. Clamp one end (say, A) of the bimetallic strip AB on one vertical stand such that the metal brass that expands more is kept on the outer side as shown in Fig. 6.15.
3. Clamp the metal rod on the other vertical stand and place it such that the rod is just below the free end (say, B) of the bimetallic strip. The bimetallic strip is attached such that the end B of the strip does not touch the rod, but it is just about to touch.
4. Connect one terminal of the cell to the clamped end A of the bimetallic strip and the other terminal of the cell to the electric bell and then to the metal rod.
5. Burn the spirit lamp and place it just below the bimetallic strip. You will notice that on heating the bell rings. The reason is that on heating, the bimetallic strip expands. Since brass expands more than iron, it bends inwards and the end B comes in contact with the metal rod. This completes the circuit and the bell rings.

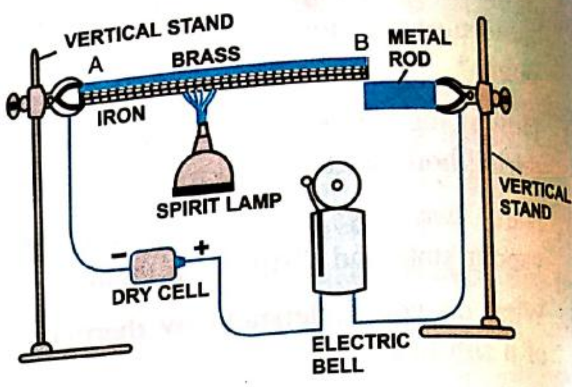


Fig. 6.15 A model of fire alarm