Heat and Its Effects

Heat: A Measurable Form of Energy

Heat is a form of energy and thus, can be converted into other forms of energy (like mechanical energy, electrical energy, etc.), and vice versa.

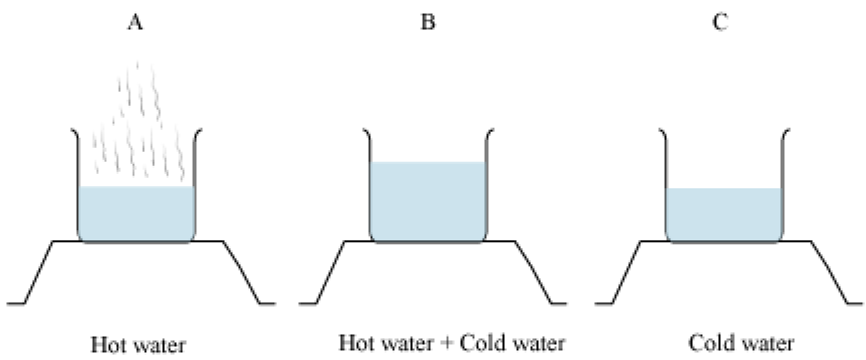
On returning from school, Ravi touched the iron gate leading to his house. He found it to be extremely hot. Later, he touched other things made of iron present inside his house and found that they were not hot. Then, he touched other substances (not made of iron) present in his house to determine whether they were hot or cold. He listed his observations as in the table given below.

Substance	**Hot/ Cold**
Tea	Hot
Coffee	Hot
Ice	Cold
Ice cream	Cold
Cooked rice	Hot
Frozen meat	Cold

Try to make a table listing some other substances that are present in your house, and classify them as hot or cold. **But how do you decide whether a substance is hot or cold? Can you always tell whether a substance is hot or cold simply by touching it?** The following activity will help you understand better.

Activity:

Take three containers and label them as **A**, **B** and **C**. Take hot water in container **A**, and cold water in container **C**. In container **B**, mix hot and cold water in equal amounts. Now, place your left hand in container **A** and right hand in container **C** for two minutes. Then, dip both your hands in container **B**.



What can you say about the water present in the three containers? Note your observations in the table given below.

Container	**Hot/Cold**
A	
B	
C	

What is your observation for container B? Is the water in container B hot or cold?

When you dip your hands in container **B**, your left hand will tell you that the water is cold, while your right hand will tell you that the water is hot. Thus, you will not be able to distinguish whether the water present in container **B** is hot or cold.

From this activity, we can conclude that we cannot decide whether a substance is hot or cold just by touching it. Thus, we need something more reliable than our sense of touch to decide whether a substance is hot or cold.

Is heat measurable?

The measure that is used for detecting the degree of hotness of a substance is called temperature. The more the temperature of a substance, the hotter it will be. **The device that is used for measuring temperature is called a thermometer.**

The scales used for measuring temperature can either be degree Celsius or degree Fahrenheit. There are two types of thermometers: **clinical thermometers and laboratory thermometers**.

How is temperature a measure of heat?

In the SI system, the unit of temperature is kelvin, whereas the unit of heat is joules. Still temperature measurement can tell us about the heat energy contained in a body.

$$Q = m \times C \times t$$

Effects of Heat

Man is dependent on various sources of heat. The sun is the major source of heat on the earth. The heat received from the sun is the reason why life flourishes on the earth.

Here are many changes that take place around us because of the effects of heat.

Let us study the effects of heat in detail.

Rise of temperature

The temperature of a body increases on heating; however, the temperature falls on removing heat from a body or by cooling it.

When we heat water and oil in separate vessels, it takes more time to for change ing the temperature of the water by 1one degree Celsius than time taken to raise the temperature of the oil by 1one degree Celsius.

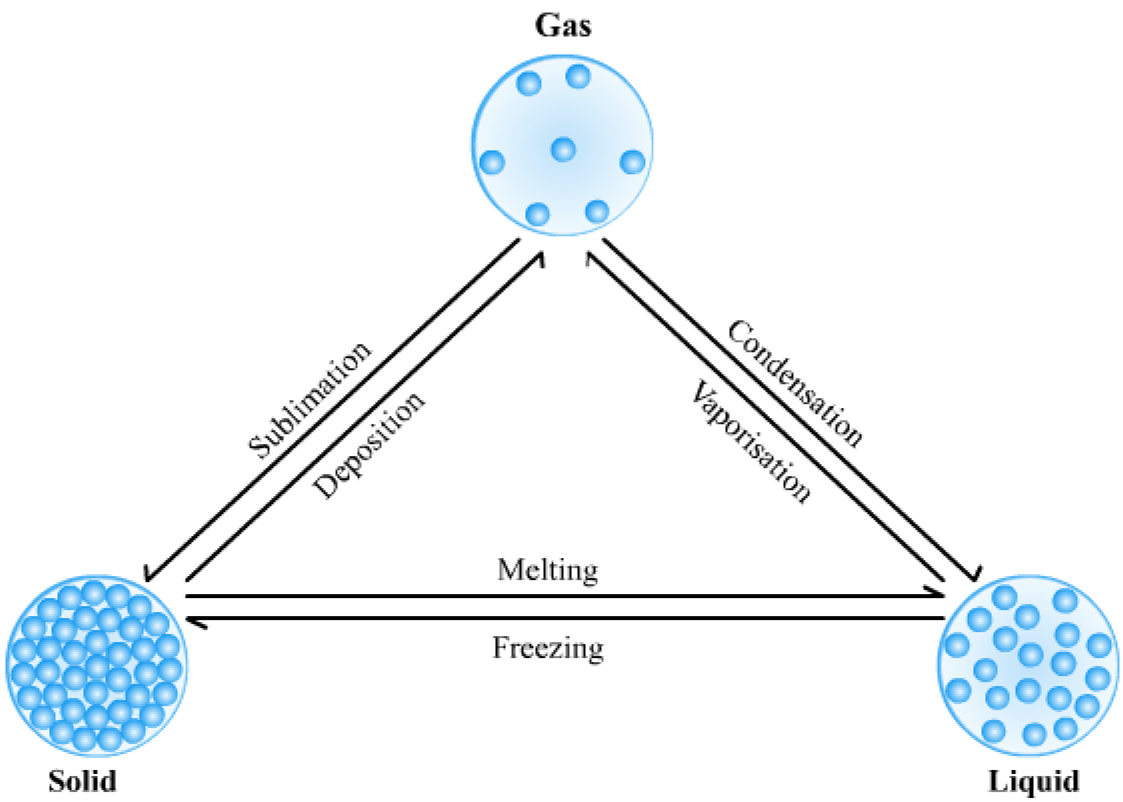
Do you know the reason behind this?

The amount of heat required to raise the temperature of a substance is dependent on the nature of the substance. Oil absorbs the heat faster than water, and this is the reason that it takes more time to increase the temperature of water by one degree Celsius.

Change in state

The addition of a sufficient amount of heat to a substance, or the removal of a sufficient amount of heat from it, can change the state of the substance. When a solid is heated up to a particular temperature, it starts melting and, after some time, changes into a liquid.

In the same way, when a liquid is heated to a certain temperature, it starts to boil and converts into a gas. On cooling, the gas is converted into its liquid state, and on further cooling, it is converted into its solid state.



For example, ice kept at room temperature absorbs heat from the surroundings and melts into water. Water, on strong heating, boils to form water vapour. If we cool the water vapour, it gets converted into water, and on cooling water, it is converted into ice.

Therefore, it can be concluded that when a substance is heated, it changes its state from solid to liquid to gas, and when it is cooled, the reverse happens.

Change in physical properties

The physical properties of substances are altered on heating. For example, iron, which is a hard metal at room temperature, becomes soft on strong heating and can be moulded into a desired shape.

The electric resistance of a conductor decreases at high temperatures. High temperature of a conductor is achieved on heating it.

Heating a magnet leads to loss of its magnetism.

Chemical changes

The application of heat can cause chemical changes to a substance. Some substances break down—for example, calcium carbonate decomposes into calcium oxide and carbon dioxide on heating. The speed of a chemical reaction may increase or decrease with heat. For example, food decays faster in summer than in winter. Reactions in which heat is released slow down if heat is added—for example, the rate of a neutralisation reaction decreases on adding heat.

Expansion
You must have observed that in winter, it is difficult to open the lid of a jar. So, to open the jar, it is heated. Why do we do this? It is because **substances expand on heating and contract on cooling.** This property is exhibited by all the states of matter (solid, liquid and gas). The amount of expansion or contraction depends on the nature of the material and the amount of heat applied.

Changes Among Various States of Matter

Change of State-An Overview

In daily life, we see different kinds of changes in the states of matter. The formation of ice cubes from water in the refrigerator is an example of a change in the state of matter from liquid to solid. When water is boiled, vapours are formed. This is an example of change in the state of matter from liquid to gas.

The following terminologies are used to describe the changes in the states of matter.

- Change from the solid state to the liquid state is called **melting**.
- Change from the liquid state to the solid state is called **freezing**.
- Change from the liquid state to the gaseous state is called **vapourisation**.
- Change from the gaseous state to the liquid state is called **condensation**.

There are two other changes between the three states of matter—sublimation and deposition.

Sublimation: It is the process in which a substance changes directly from the solid state to the gaseous state without entering into the liquid state. The changing of snow into water vapour is an example of sublimation. Some common examples of substances that sublime are dry ice, camphor, and naphthalene.

Deposition: It is the process opposite to sublimation. In this, a substance changes directly from the gaseous state to the solid state. Frost is an example of deposition.

Did You Know?

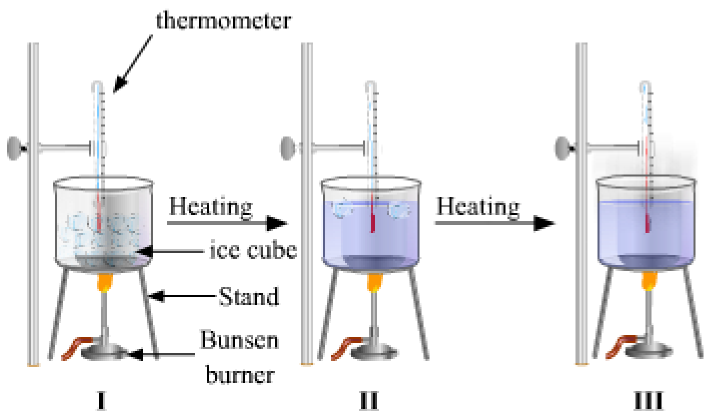
When we open the refrigerator, we see freezing fog. This is nothing but condensed water.

Air contains vapours. When we open the refrigerator, the temperature comes down. This condenses the vapours into tiny drops of water and produces freezing fog.

Temperature Affecting the Change of State

Let us perform an activity to understand the effect of temperature on the different states of matter.

Procedure: Take about 150 g of ice in a beaker and use a laboratory thermometer to note the temperature of ice. Start heating the beaker on a low flame and record the temperature when the ice starts melting. Observe the temperature when all the ice gets converted into water. Stir the water with a glass rod till it starts boiling.



Result: In the beginning, the temperature of ice is below 0°C. When ice begins melting, the temperature is recorded to be 0°C. Temperature remains constant at 0°C untill all the ice melts. The continued heating of water causes its temperature to rise.

Conclusion: It can be concluded from this activity that an increase in temperature changes a substance from its solid state to its liquid state, and further heating (i.e., further increase in temperature) changes the liquid so formed into vapour.

Temperature Affecting the Change of State

You know that matter, irrespective of its state, consists of particles. What happens to these particles of matter while it is undergoing a change in its state? For us to understand this, we need to first know that:

- The particles of matter possess kinetic energy.
- A force of attraction exists between any two particles.

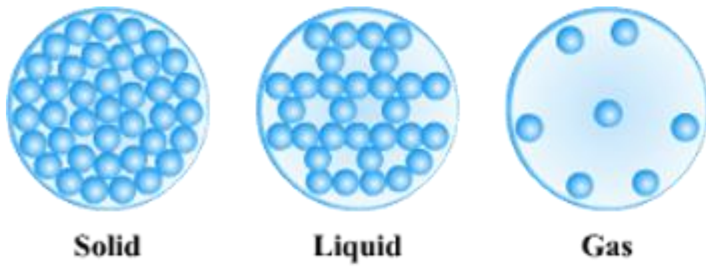
Kinetic energy of the particles of matter: A moving particle/object possesses a certain amount of energy because of its motion. This energy is called kinetic energy. The particles of matter are in constant motion. Therefore, they possess kinetic energy.

Particle-particle force of attraction: Every particle of matter attracts the particles near it. An increase in the distance between particles decreases the force of attraction between them. Conversely, a decrease in distance increases this force of attraction.

The given figure shows the kinetic energy of particles and the particle-particle force of attraction in the three states of matter.

Kinetic energy of particles: Gas > Liquid > Solid

Particle−particle force of attraction: Solid > Liquid > Gas



Temperature Affecting the Change of State

When a solid substance is heated, there is an increase in the kinetic energy of its constituent particles. As a result, the particles start vibrating with greater speed. This extra energy helps the particles to overcome the particle-particle force of attraction. Soon, they leave their positions and start moving more freely. Consequently, the substance melts into its liquid state. This is known as **melting point**. The melting point of ice is 0°C.

Liquids have a characteristic temperature at which they turn into solids. This is called **freezing point**. The freezing point of water is 0°C.

Further heating increases the kinetic energy of the liquid particles. This increases the velocity of the particles. At a certain temperature, they obtain enough energy to break free from the particle-particle force of attraction. At this point, the liquid changes into its gaseous state. This is known as **boiling point**. The boiling point of water is 100°C.

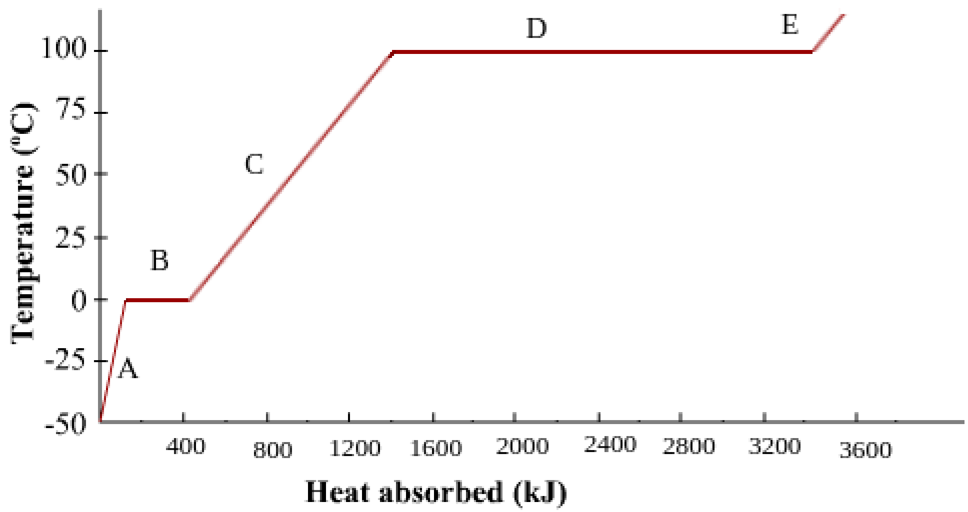
During the conversion of ice into water, the temperature remains constant until all the ice melts into water. The supplied heat is used up for changing water from its solid state to its liquid state. The heat energy is absorbed by the ice without showing any rise in temperature. This heat energy is called **latent heat**.

The amount of heat required to convert 1 kg of a solid into its liquid state without a change in temperature (i.e., at its melting point) is called **latent heat of fusion**. For ice, the latent heat of fusion is 334 kJ kg^{-1}. This implies 334 kJ of heat has to be provided to convert 1 kg of ice at 0°C into 1 kg of water at 0°C. Conversely, 334 kJ of heat is released when 1 kg of water freezes at 0°C to give 1 kg of ice at 0°C.

Know More

Latent heat of vapourization is the amount of heat required to convert 1 kg of a liquid into its vapour state without a change in temperature. For water, the latent heat of vapourization is 2260 kJ kg^{-1}. This means that 2260 kJ of heat must be provided to convert 1 kg of water at 100°C into 1 kg of vapour at 100°C. Conversely, 2260 kJ of heat is released when 1 kg of water vapour condenses at 100°C to give 1 kg of water at 100°C.

Heating curve



If the increase in temperature during heating and the absorbed heat are plotted on a graph, then the curvature which is formed is called the **heating curve**.

In the figure, 'A' represents the rise in the temperature of the substance in its solid state from −50ºC to 0°C; 'B' shows the latent heat of fusion; 'C' shows the increase in the temperature of the substance in its liquid state from 0°C to 100°C; 'D' shows the latent heat of vapourisation, and 'E' shows the increase in the temperature of the substance in its gaseous state.

Solved Examples

Easy

Example 1:

If the melting point of a solid is high, then the __________ between the particles is stronger.

Solution:

force of attraction

Medium

Example 2:

Which has more energy: solid wax at 42°C or liquid wax at 42°C?

Solution:

Liquid wax at 42°C has more energy than solid wax at the same temperature.

Hard

Example 3:

Choose the process which will absorb heat/energy from the surroundings.

A.Conversion of ice into water

B.Conversion of water vapour into snow

C.Precipitation of water vapour as rain

Solution:

The correct answer is A.

Temperature Affecting the Change of State

Measuring Temperature

Three scales are commonly used for measuring temperature, namely, the **Celsius scale**, the **Fahrenheit scale**, and the **Kelvin scale**.

The relation between the Celsius and the Kelvin scale can be expressed as C + 273 = K

The relation between the Celsius and the Fahrenheit scale can be expressed as follows:

$$\frac{C}{5} = \frac{F - 32}{9}$$

Example: 30°C can be expressed as 303 K and 86 ^{o}F.

Celsius to Kelvin: 30 + 273 = 303 K

Celsius to Fahrenheit:

$$\frac{30}{5} = \frac{F-32}{9}$$
$$\Rightarrow 6 = \frac{F-32}{9}$$
$$\Rightarrow 54 = F-32$$
$$\Rightarrow F = 86$$

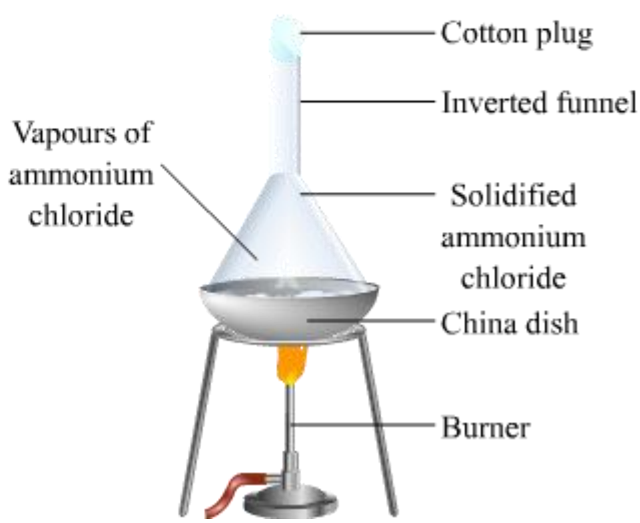
Did You Know?

Cool Facts

- The temperature zero Kelvin is known as absolute zero. Nothing can be colder than zero Kelvin.
- Dry ice is frozen carbon dioxide. Its temperature is −78.5°C. It turns directly into carbon dioxide gas without undergoing a liquid phase. Its sublimation characteristic and super-cold temperature make dry ice suitable for refrigeration. It is commonly used to export frozen materials across long distances.

Whiz Kid

Take some ammonium chloride salt in a china dish. Crush the salt and cover the dish with a funnel, as shown in the figure. Plug the stem of the funnel using some cotton. After this, start heating the dish slowly using a burner.



Result of the activity:

Upon heating, ammonium chloride will vapourise without transforming into its liquid form (**sublimation**). Later, the vapours will get cooled on the walls of the funnel and will directly convert into solid ammonium chloride (**deposition**).

Note: The same activity can be done using camphor or naphthalene.

Pressure Affecting the Change of State

We know that change in temperature affects the state of matter. Change in pressure, too, affects the state of matter. Let us see how.

We have a gas in a closed container. Say, we put some weight on the lid of the container. This increases the pressure on the container, which in turn causes the gas particles to come close to one another.

As a result, the kinetic energy of the particles reduces. Nevertheless, the particles are still quite far away from one another and, hence, are still in the gaseous state. When the pressure on the container is increased further, the gas particles come very close to one another. Gradually, the gas **liquefies**.

Did You Know?

Water boils below 100°C (at approx. 92°C) in Mussoorie.

Mussoorie is a hill station set at a height of about 2000 m above sea level. Atmospheric pressure decreases as you go up from the sea level. Decrease in pressure lowers the boiling point of water below 100°C.

Whiz Kid

Liquid crystals are believed to be an independent state of matter as their properties lie in between those of liquids and solid crystals. They exist in a specific temperature range. They behave as solids below that temperature range and as liquids above that temperature range.

Know More

Why we need to liquefy gases

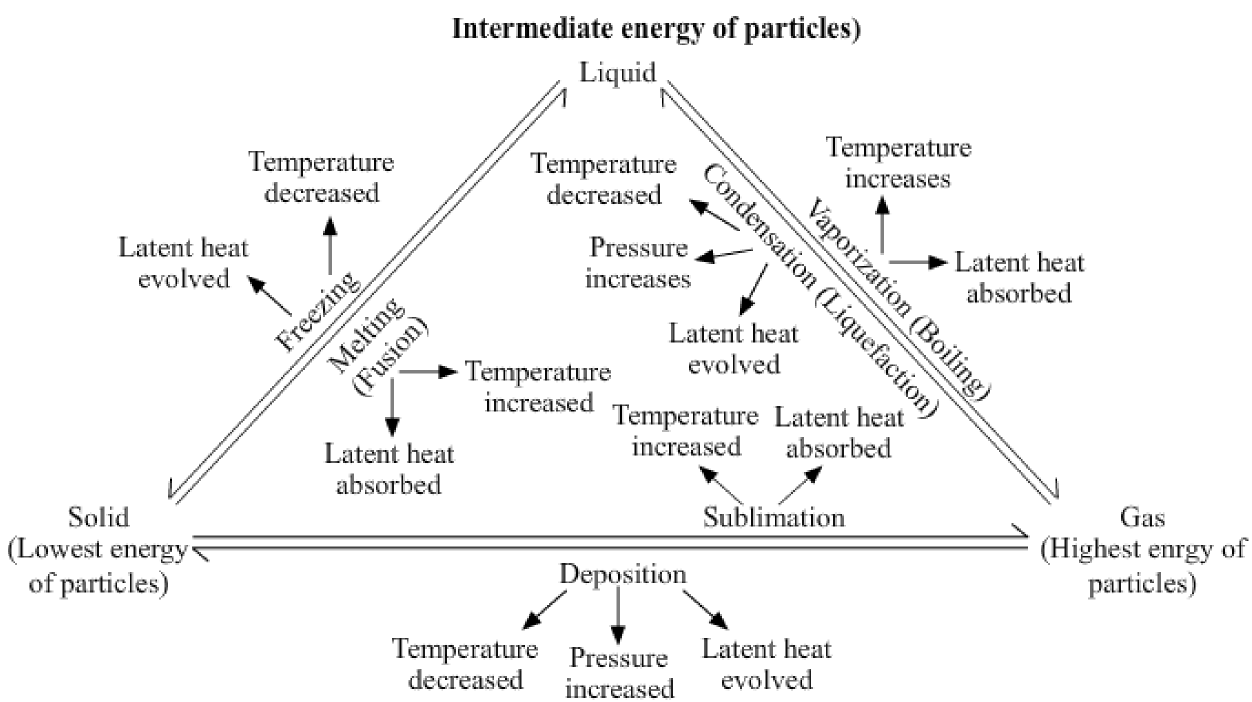
Together with low temperature, high pressure is generally used to liquefy gases.

A highly combustible gas is released during the fractional distillation of crude oil. This gas is known as petroleum gas. Petroleum gas is also trapped over the reserves of oil present beneath Earth's crust. Petroleum gas is liquefied by applying high pressure and low temperature. This is known as liquefied petroleum gas or LPG. LPG is used as a domestic fuel.

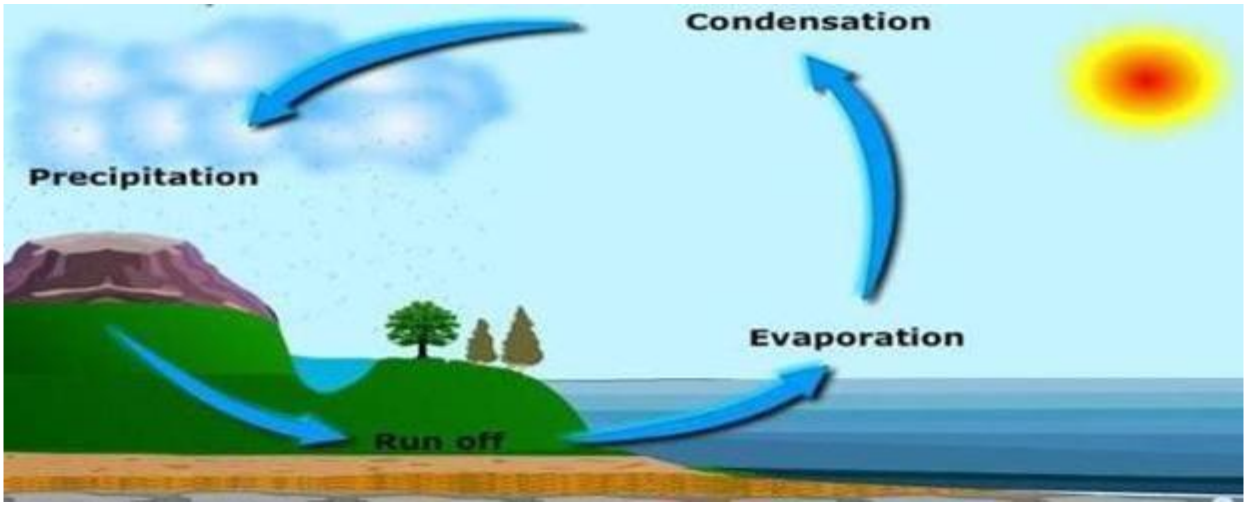
Other uses of liquefaction of gases

- Liquefaction of gases is helpful for their easy storage and transportation.
- Liquefied gases can be used in various fields; for example, in air conditioning and refrigeration systems (gases used are liquid ammonia and liquid sulphur dioxide).
- Liquid oxygen is supplied to hospitals for patients. It is also used as a rocket propellant.
- Liquid nitrogen is used in **cryosurgery**.
- Liquid chlorine is supplied to water treatment plants for purification of water.
- Liquid hydrogen in combination with liquid oxygen forms the fuel for rocket propulsion.

Inter-Conversion among Solids, Liquids, and Gases



Evaporation



The circulation of water on our planet Earth takes place in a cyclic manner. This cyclic process is known as the **water cycle**.

Evaporation is the process in which physical state of a substance changes from liquid state to gaseous at a temperature below its boiling point.

Evaporation depends on the following factors.

- Humidity
- Temperature
- Wind speed
- Surface area

Humidity

When the humidity is high during summer days, we feel more hot and sweaty than usual. Why is this so?

High humidity means that the air surrounding us is rich in water vapours and, hence, has a lesser tendency to take up more water vapours. In consequence, when we sweat, the sweat takes longer to vaporize. This is the reason why we feel particularly hot and sweaty in times of high humidity.

Temperature, Wind Speed and Surface Area

There are two conditions in which the earlier activity is carried out:

- The hot and windy condition under the running fan
- The cold and non-windy condition inside the closet

The test tube and the first china dish are placed in the hot and windy condition. In this case, the rate of evaporation of water is high because of the following factors.

- Moving air (running fan)
- High temperature

Now, between the china dish and the test tube, the surface area of the former is more than that of the latter. As a result, the rate of evaporation is higher in case of the china dish than in case of the test tube.

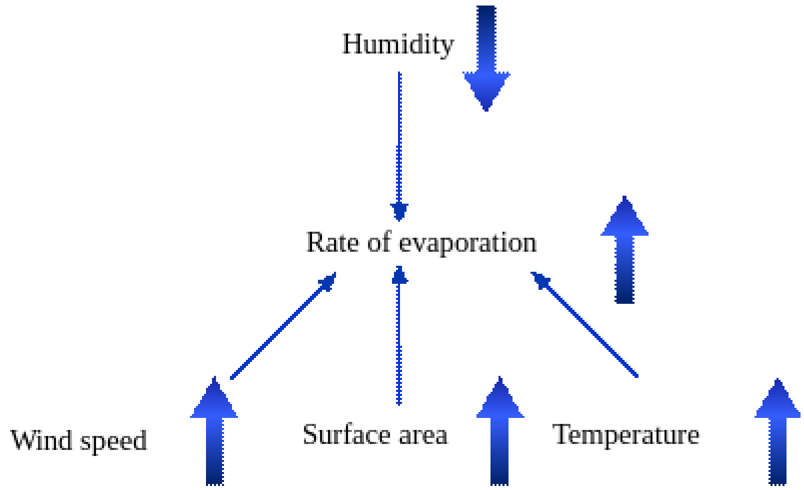
The second china dish is placed in the cold and non-windy condition. In this case, the rate of evaporation of water is low because of the following factors.

- No moving air
- Low temperature

Also, as the water evaporates, the humidity inside the closed space of the closet rises. Consequently, the rate of evaporation decreases.

So, the rate of evaporation (r. o. e.) of water with respect to each container is as follows:
r. o. e. from the first china dish > r. o. e. from the test tube > r. o. e. from the second china dish

Conclusion



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Project Ideas

Clouds in a Bottle

- Add one to two teaspoons of water in a plastic bottle and shake it well so that the water spreads across the walls of the bottle.
- Next, put a lit splinter in the bottle. This will cause the water inside to evaporate. As the water vapours rise, they will condense on the smoke particles to form clouds.
- Link this activity to atmospheric cloud formation as a result of evaporation and to the types of clouds formed depending upon the height where water vapours condense.

Solved Examples

Medium

Example 1:
The rate of evaporation in a lake will be higher on a ___________.
1. hot and dry summer day
2. hot and humid summer day

Solution:
The correct answer is A.

The rate of evaporation will be higher on a hot and dry summer day. This is because the air will not contain as much water vapour as it will on a hot and humid day.

Example 2:
Which of the following will dry faster?

1. **A cloth hanging on a wire**
2. **A cloth lying on a flat floor**

Solution:
The correct answer is A.

A cloth hanging on a wire will have more surface area exposed for evaporation as compared to a cloth lying on a flat floor.

Easy

Example 3:
We feel cold after bathing in cold water during summers. This is because of __________.

1. **condensation**
2. **evaporation**

Solution:
The correct answer is B.

The evaporation of water from the body causes the body to cool.

Did You Know?

Cetyl alcohol is sprayed as a layer on the water in the reservoirs to reduce evaporation.

Factors Affecting Evaporation

Here are a few examples showing the cooling effect of evaporation.

1. Water present in an earthen pot remains cool: An earthen pot has minute pores all across its surface. Water keeps coming out of these pores. This water absorbs heat from the pot and evaporates. Consequently, the water present inside the pot remains cool.

2. The skin becomes cool when deodorant or perfume is sprayed: Perfumes and deodorants contain alcohol—a highly volatile substance. When deodorant is applied to the skin, it absorbs heat from the area and gets evaporated. This is the reason why the skin becomes cool when sprayed with deodorant or perfume.

3. We perspire more during summers. The water molecules present in our sweat absorb heat energy from our body and change into vapours. Consequently, the body gets cooled because of this loss of heat.

4. People sprinkle water on the roof during a hot sunny day. This is done as the sprinkled water absorbs heat from the roof and changes into water vapours. The roof cools as a result of the loss of heat.

5. During summers, people prefer to wear cotton clothes: Cotton absorbs water and also allows air to pass through itself. This aspect of cotton makes it the preferred material for clothes worn during summers. Cotton clothes absorb sweat and expose it to air. As a result, the sweat evaporates and heat energy (equal to the latent heat of vaporization) is lost by the body. This cools the body.

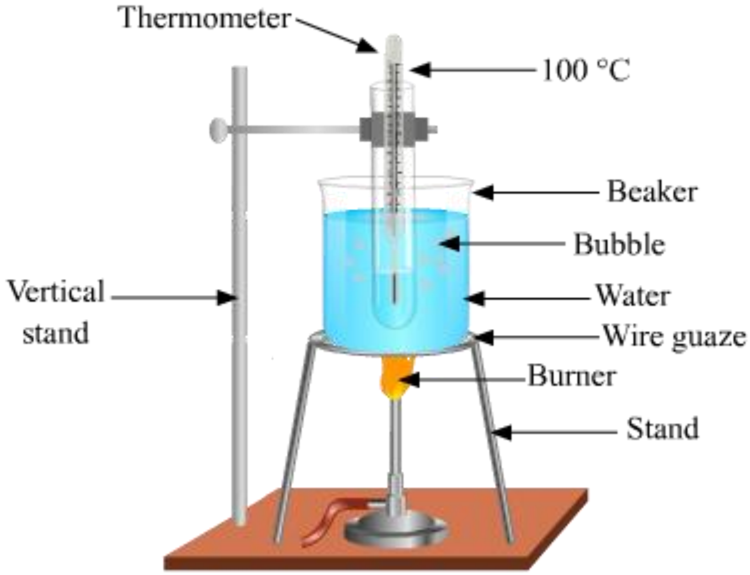
6. A desert cooler gives cool air. The water in the cooler is sprinkled onto the pads by the pump. This allows easy evaporation. The air outside the cooler is pulled in through the moist pads where it is cooled by evaporation. The cooled air is then pushed out of the cooler by the fan.

Boiling

Boiling is a phenomenon in which a liquid changes to vapour at a **constant temperature** on heating. This constant temperature at which the change from liquid state to gaseous state occurs without further increase in temperature is called the boiling point of the liquid.

Demonstration of Boiling of Liquid

A beaker filled with water is kept on a wire gauze placed over a tripod stand. A thermometer clamped on a vertical stand is inserted in the beaker as shown in the figure below. Now the beaker is heated and the temperature of water is recorded every minute.



Boiling of water

It is found that the temperature of the water increases continuously till the water starts boiling at 100 ^{o}C. Now, at this stage, though the temperature of water remains constant but still heat is continuously being supplied to it.

Due to this continuos supply of heat, bubbles starts forming throughout the water. Thus, at this stage, water begins to change into steam. Hence, it can be concluded that the boiling point of water is 100 ^oC.

Explanation of Boiling by Molecular Motion

On heating a liquid, the average kinetic energy of its molecules increases. Thus, the molecules gain sufficient kinetic energy to overcome the force of attraction of other molecules. They now begin to leave the liquid not only at the surface, but also near the walls of the beaker containing the liquid.

This can be observed by the presence of bubbles on the walls of the beaker. Now, the bubbles grow in size with continuous heating and move to the surface in quick succession. This brings agitation in whole liquid and this is known as boiling.

Effect of Pressure on Boiling Point

The boiling point of a liquid is directly related to pressure i.e. it increases with increase in pressure and decreases with decrease in pressure.

This is because the pressure exerted by the liquid at its boiling point is equal to the atmospheric pressure. Thus, if the surrounding or atmospheric pressure increases, the boiling point increases and vice versa.

- At mountains, it becomes difficult to cook food as the boiling of water occurs below 100 ^oC. The decrease in boiling point of water is because of the presence of low pressure.

Can you explain why food get readily cooked in pressure cooker?

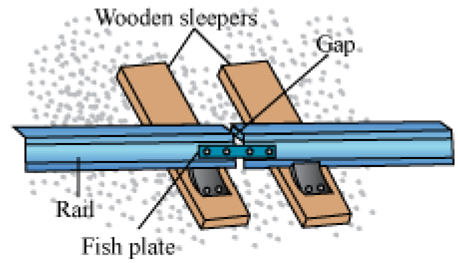
Evaporation Versus Boiling

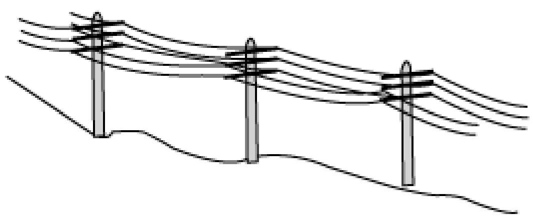
Evaporation	Boiling
It takes place at all temperatures	It takes place at fixed temperature known as boiling point of liquid
It is a surface phenomenon	It is a bulk phenomenon
It is a slow process	It is a rapid process
The surface molecules absorb heat from their surroundings	The heat absorbed by molecules is supplied externally

Thermal Expansion

Expansion of Solids

Rohit was travelling from Nasik to Mumbai. While waiting on the platform for the train to arrive, he noticed the rail track carefully. He observed that the rail tracks were joined by a metal plate and there was a small gap between the rail tracks. Can you explain the reason behind leaving a small gap between two rails at the joining?





Have you ever noticed the electric transmission wires connected to electric poles? Their lengths are always kept longer than the distance between the poles, so that they sag down. Do you know why?

The rail tracks and the electric wires are made up of metals. On heating, almost all metals expand. The expansions may be along the length, area or volume.

Now, can you answer why a gap is left between two rail tracks at the joining? During summers, the metals rail tracks expand because of heating. If the rail tracks are fitted end-to-end leaving no gap, then on expansion, the rail track would bend. To avoid this, rail tracks are joined by a fish plate, leaving some gap between the rail tracks.

The lengths of electric transmission wires are also kept longer to avoid any tension in the wires when they contract during winters.

Expansion of Gases and Liquids

Have you seen people gliding in the air in a basket tied to a balloon? This is called hot-air ballooning. How does the balloon move?

Situated just below the balloon and above the basket is a flame that heats up the air inside the balloon up to about 100ºC. This hot air expands as a result of heating.

When the air expands, its density reduces. The air inside the balloon thus becomes lighter and less dense than the air outside the balloon. This makes a hot-air balloon rise.

Thus, we know that air expands on heating.

Not only air, but **all gases expand on heating**.

Let us perform an activity to understand this principle

We know that hot air expands. How does hot air make a balloon move up?

Let us perform an activity to understand this phenomenon

Using a pump, inflate a balloon with cold air and another one with hot air. Hang them on a horizontal, wooden stick. Observe the motion of both the balloons.

You will find that the balloon filled with hot air rises more in comparison with the balloon filled with cold air. **Can you explain why this happens?**

Since air expands on heating and occupies more space, the hot-air balloon becomes lighter than the cold-air balloon.

Why does the smoke from a fire move upwards? This is because fire heats the air and causes the air to move upwards. The upward-moving air carries the smoke along with it.	

Like gases, liquids also expand on heating. Let us perform an experiment to see the expansion of liquids on heating.

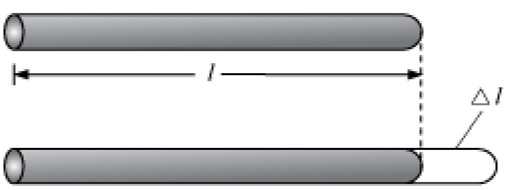
Take three similar glass bottles. Fill the bottles with three different liquids, say kerosene oil, coloured water and milk. Now, insert a straw in each bottle with the help of a cork. Mark the liquid levels in the straws. Place the bottles in a big beaker and pour hot water in the beaker. What do you observe after 10 minutes?

You will see that the liquid levels in the straws increase, and the increases are different for all the three liquids. This happens because the liquids expand on heating, and they expand at different rates on the same amount heating.

Expansion of Solids

Linear Expansion of Solids (Δl)

It is also known as expansion of length.



Linear expansion

Linear expansion ∝ Original length × Temperature change

$\Delta l \propto l\Delta T$

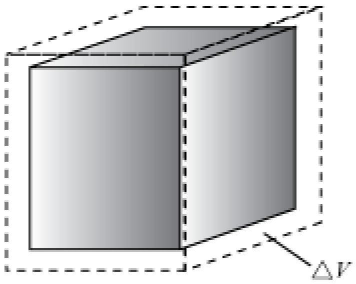
$$\frac{\Delta l}{l} = \alpha_l \Delta T$$

α_l → Coefficient of linear expansion (characteristic property of material)

Generally, metals have high α_l values.

Volume Expansion of Solids (Δ*V*)

It is also called cubical expansion. It occurs in complete volume of body.



Volume expansion

$\Delta V \propto$ Original volume × Temperature change

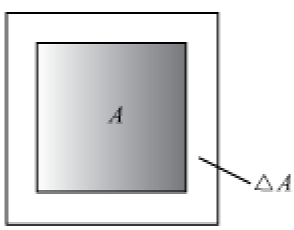
$\Delta V \propto V\Delta T$

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

$\alpha_V \rightarrow$ Coefficient of volume expansion

α_V varies with temperature. It becomes constant at high temperature.

Area Expansion of Solids (Δ*A*)



Area expansion

$\Delta A \propto$ Original area × Temperature change

$\Delta A \propto A\Delta T$

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

$\alpha_A \rightarrow$ Coefficient of area expansion

Relationship between α_l, α_A and α_V

For a solid cube of length l,

Volume, $V = l^3$

Area, $A = l^2$

$\therefore$ Change in volume, $\Delta V = (l + \Delta l)^3 - l^3$

$\simeq 3l^2\Delta l$ [In eq.$\Delta l^2$and Δl^3 have been neglected]

Since Δl is small compared to l,

$\Delta V = \dfrac{3V\Delta l}{l} = 3V\alpha_l \Delta T$

Which gives,

$\boxed{\therefore \alpha_V = 3\alpha_l}$

Change in area, $\Delta A = (l + \Delta l)^2 - l^2$

$\simeq 2l\Delta l$

$\Delta A = \dfrac{2A\Delta l}{l}$

$\Delta A = 2A\alpha_l$

$\boxed{\therefore \alpha_A = 2\alpha_l}$

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

Expansion of Liquids and Gases

Expansion of Liquids

How is expansion in fluids different from solids?

Liquids do not have linear or surface dimensions as they acquire the shape of the containing vessel.

We can only record the thermal expansion of liquids relative to the container.

Because liquids have definite volume, so we can define only the volumetric expansion coefficient for a liquid.

$V_2 = V_1(1 + \beta\Delta T)$
where, V_2 = Final volume of liquid

V_1 = Initial volume of liquid
ΔT = Change in temperature

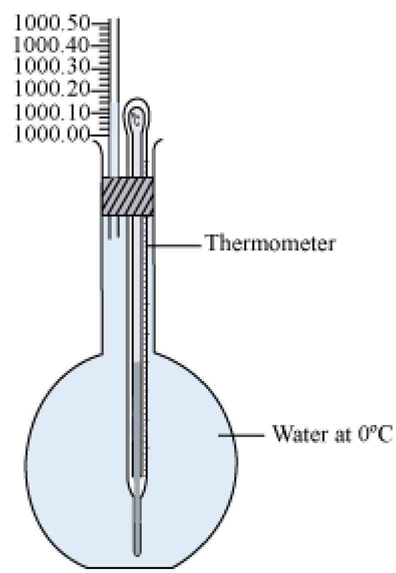
β = Volumetric expansion coefficient of liquid

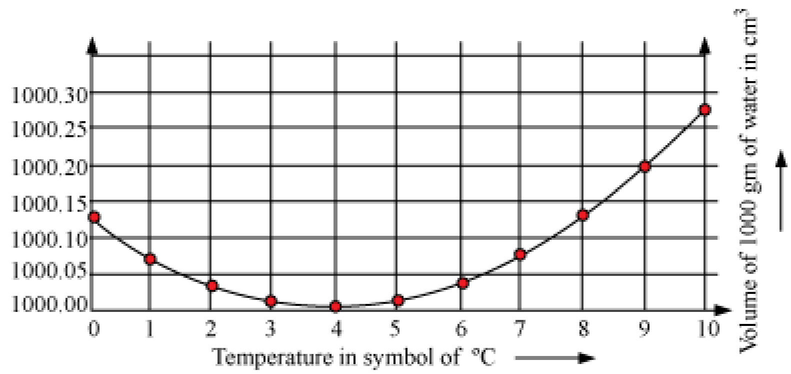
Anomalous Expansion of Water

Liquids generally expand on heating and contract on cooling whereas water shows a peculiar behaviour of expanding above and below 4°C.

Let us perform an experiment to see the peculiar behaviour of water around 4°C.

Take 1 kg of water at 0°C in a flask. Put a fine capillary tube and a sensitive thermometer into this flask. Volume of water is found to be 1000.14 cm^3. Now heat the water up to 4°C. You will observe that the volume of the water now becomes 1000 cm^3. Now, plot a volume versus temperature curve on a graph. The graph will look as follows.

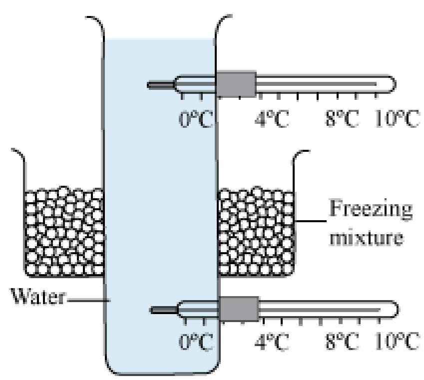




Hope's Experiment

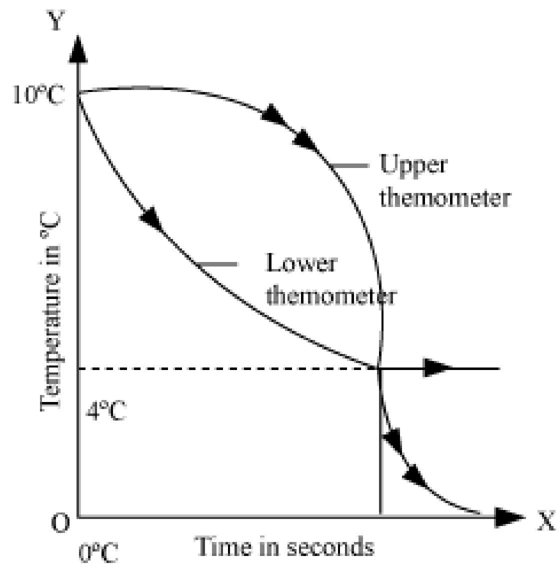
Set up

The experimental set up consists of a metal cylinder, having circular trough around its middle. It has two openings on the same side for putting two thermometers into the cylinder. The cylinder is filled with water at about 10°C and the trough contains freezing mixture of ice and salt.



Observations

- Readings of the upper thermometer do not alter whereas readings of the lower thermometer fall rapidly.
- The reading of the lower thermometer stabilises at 4°C whereas reading of upper thermometer starts falling till 0°C.
- A thin crust of ice forms at the top of water in the cylinder.



Explanation

Water around the ice region cools down to 4°C and gets heavier. As the density of water is the maximum at 4°C, the water from the middle portion settles down near the bottom of the cylinder. Thus, the temperature at the lower thermometer is found to be 4°C.

As the water from the middle portion settles down to the bottom, warm and lighter water from the bottom portion blows up to fill up the place. Therefore, convection current is set up at lower portion of the cylinder.

Because of this convection current, the temperature of the water gradually goes down to 0°C towards the upper portion of the trough. Hence, the reading of the upper thermometer gradually goes down to 0°C.

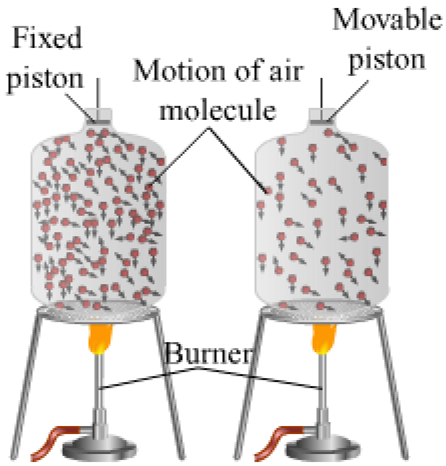
Conclusions:

1. Density of water is the maximum at 4°C.
2. Ice formed at 0°C is lighter than water at the same temperature.
3. Freezing of water will start from top to bottom, but water in lower regions will stay at 4°C.

Expansion of Gases

- Gases do not have fixed volumes and shapes and gases expands on heating.

Suppose a gas of equal volumes is kept in two vessels. The first vessel has a fixed piston and the second one has a movable piston as shown. Now, heat the two vessels for some time. We will observe that the volume of the gas in first vessel does not increase; instead its pressure increases. In the second vessel, the volume increases.



Thus, in case of gas, its expansion is measured by keeping its pressure constant. Volumetric expansion of a gas is given as

$V_2 = V_1(1 + \beta\Delta T)$

where, V_2 = Final volume of gas

V_1 = Initial volume of gas

ΔT = Change in temperature
β = Constant pressure expansion coefficient of gas

- Gases expand on heating provided its pressure is kept constant. They undergo cubical expansion on heating.

- Increase in volume of different gases for the same rise in temperature is the same.

- Density of a gases decreases appreciably with increase in temperature. This is because of the increase in the volume of the gases in appreciable amount with temperature.

- The force of attraction between the molecules of a gas is negligible. Thus on heating, the molecules' average kinetic energy increases further because of which they move violently in all the space available. Due to this, the inter-molecular separation increases further. Hence, the gas expands on heating.

Thermal Expansion and Its Applications

Expansion of Solids

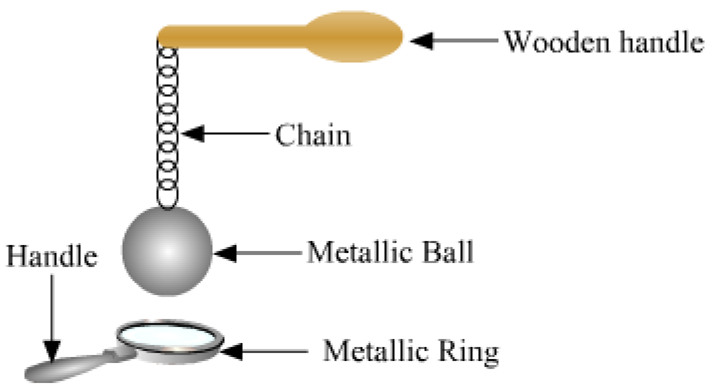
Heat not only raises the temperature of a substance, but it also has some additional effects.

Expansion of Solids on Heating

On heating, solids generally expand in all directions. Hence, it is also known as cubical expansion or volume expansion. But many a times, one of the dimensions of the solid object might be negligible as compared to others.

For example, the thickness of a plate is negligible in comparison to its surface area, or the cross section of a wire is negligible in comparison to its length.

Activity: Solids Expand on Heating



Take a ring and ball apparatus such that the metallic ball just passes through the ring, as shown in the figure. This is so because the internal diametre of the ring is same as the diametre of the metallic ball.

Now, heat the metallic ball over a burner for 5-10 minutes. Again, try to pass the ball through the ring. You will notice that the ball does not pass through the ring.

Why? This is because the metallic ball expands on heating, hence, its diameter also increases. So, the ball is unable to pass through the ring.

Now, let the ball cool and then try to pass it through the ring. What will you observe?

You will observe that the ball passes through the ring.

This activity shows that solids expand on heating and contract on cooling.

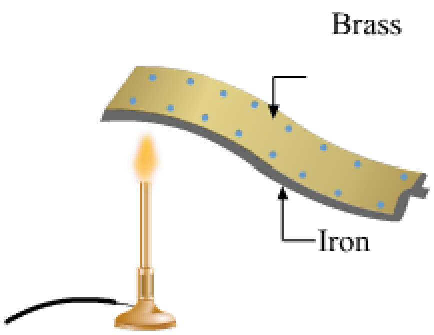
Advantages and Disadvantages of Expansion of Substances

The thermal expansion of solids has many advantages and disadvantages in our daily lives. Let us see some of them:

Advantages

1. Bimetallic strips are used as heat operated switches in circuits of some appliances such as iron box, fire alarms, microwave oven, etc.

Expansion in Bimetallic Strip



A bimetallic strip contains equal strips of brass and iron riveted together firmly on a wooden handle.

Let us heat one end of the strip using a burner. You will observe that the strip bends towards the iron strip. This bending of the strip is used in switches.

But why does the strip bend?

This is because brass expands more on heating than iron.

2. Many thermometers work on the principle of expansion of liquids.

3. Expansion of gases is useful in automobile engines.

Disadvantages

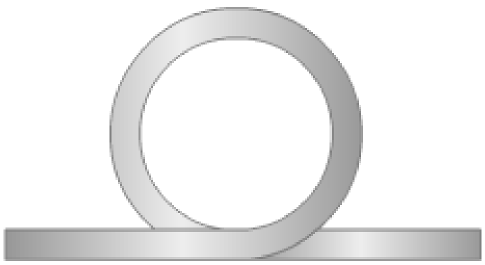
1. Breaking of a thick glass tumbler on pouring boiling water into it: When boiling water is poured into a thick glass tumbler, it cracks immediately due to the fact that glass is a poor conductor of heat. The heat from the boiling water expands the inner wall of the glass but it is not transferred to the outer wall. Thus, the outer wall fails to expand and this uneven expansion breaks the glass.

Similarly, a thick glass tumbler cracks when ice is placed in it.

The solution to this problem is that a very thin glass tumbler with low expansion capacity (like pyrex or borosilicate) should be chosen.

2. Narrow spaces are left between the small stretches of **cemented roads** so that they do not bend and cause problem to vehicles and people.

3. The **metal pipelines** used to transfer hot water or molten liquid in industries are provided with metal loops at regular intervals. This is because the expansion and contraction might bend or break the pipe. So, the expansion of pipeline causes the size of the loop to increase slightly and prevent the pipe from breakage.



Loop of metal pipe

4. The **iron tyres of cart wheels** are made a little smaller than their wooden wheels in order to prevent them from expanding in summers and loosening from the tyre.

5. Railway tracks are made up of steel, leaving small spaces in between them in order to prevent the tracks from bending and derailing the trains. The spaces get closer in summers and wider in winters and prevent the track from bending.

6. The **telegraph wires** between two poles are never strongly tightened as they sag in summers and get tighten in winters.