States of Matter

Kinetic Theory of Matter

The ***kinetic theory of matter*** is a theory that tells us about the behaviour of matter.

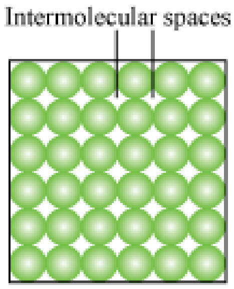
Kinetic Theory of Gases

- All matter is made up of molecules.
- All molecules of a substance are identical.
- Molecules of different substances differ in composition, shape and size.
- Molecules are in continuous motion; they don't stop for any length of time.
- Intermolecular forces depend on the distance between the molecules and the type of molecules.
- Motion of molecules is affected by the change in temperature; the higher the temperature, the more they move.

Intermolecular force is an attractive force between molecules. It depends on the distance between molecules.

- **Arrangement of molecules in Solids**
- In solids, molecules are very tightly packed because of very strong intermolecular forces between them.
- The molecules can only vibrate, but cannot move from their respective positions. This is because strong intermolecular force holds the molecules at one place. For the same reason, solids are rigid and hard.

An iron weight

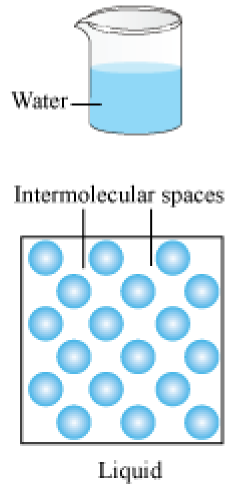


Solid

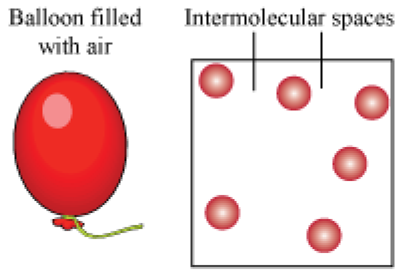
So, solids have a fixed shape and a fixed volume, and thus, cannot be compressed.

When we heat solids, they gain heat energy. This energy increases the vibrations of the molecules. Due to the increase in vibrations, the intermolecular spaces increase, which in turn leads to the expansion of solids. Thus, solids expand on heating.

- **Arrangement of molecules in Liquids**
- Molecules are slightly further apart than in solids.
- Intermolecular forces are less strong than in solids.
- Molecules can move from their positions in liquids.
- Thus, liquids flow, and take the shape of containers.
- Liquids do not have a definite shape, but they do have a definite volume.
- When we heat a liquid, its molecules vibrate. As the intermolecular forces are weaker in liquids than in solids, the molecules of the liquid also move vigorously. Thus, liquids also expand on heating, but only slightly
- As there is more space between the molecules in liquids than in solids, liquids can be compressed a little.



- **Arrangement of molecules in Gases**
- Molecules are very far apart; hence, there is hardly any attraction between the molecules.
- Intermolecular forces in gases are negligible.
- Therefore, molecules of a gas are free to move around.
- As gases are free to move around, they don't have any fixed shape and volume, they can enclose the entire space in which they are kept.
- A gas can easily be compressed.



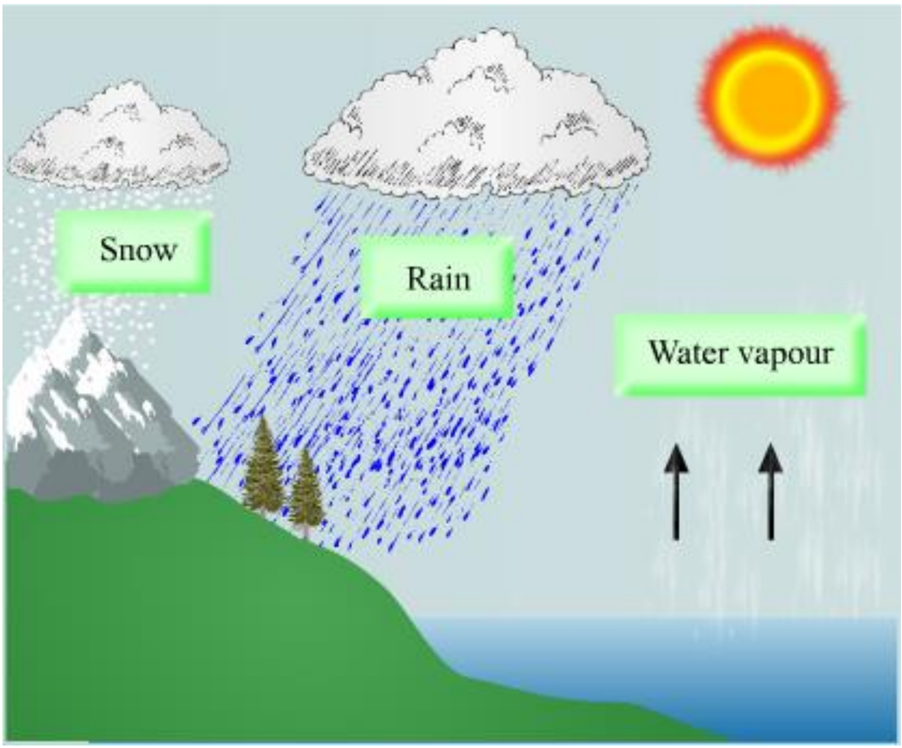
The Solid State

States of Matter-An Overview

We know that everything is made up of matter, yet things exist in different forms. What makes things look different from one another?

Matter is a broad umbrella covering different sub-categories which we know as the **states of matter**.

The view of the hills during winters is ideal for observing the three main states of matter—solid, liquid and gas. Here, you can see heavy clouds which are nothing but collections of vapourised water particles. You can also see liquid water falling from these same clouds as rain. And of course, there is the dusting of snow which is in fact solidified water.



The different states of matter are:

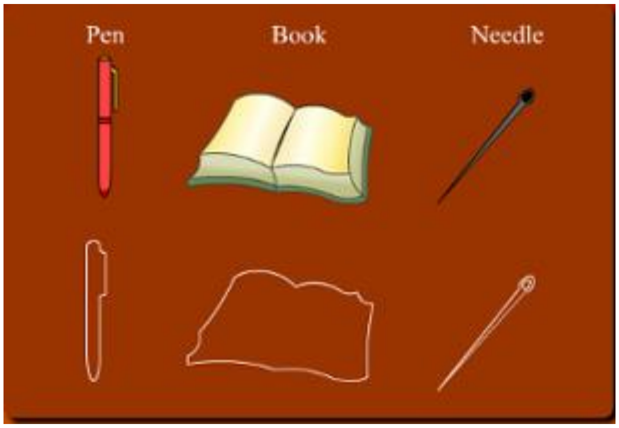
- Solid
- Liquid
- Gaseous
- Plasma
- Bose-Einstein condensate

The Solid State

Matter is said to be solid if it has a fixed **shape** and a fixed **volume**. For example, a pen. It has a fixed shape and a fixed volume; hence, it is solid. Matter that does not have a fixed shape is not solid, as is the case with water. The particles of solids have a minimum or no kinetic energy and therefore the particles do not have any movement.

The intermolecular spaces between the particles of solid are very small due to stronger attraction among the particles. Solids, therefore, cannot be compressed.

Activity Time



Procedure: Collect a pen, a book, and a needle. Trace the shapes of these materials in a notebook and compare the tracings. Also, try compressing each material.

Result: When you compare the tracings, you will observe that each material has a distinct shape and boundary. When you try compressing the materials, you will observe that each material has negligible [[mn: glossary]]compressibility[[/mn: glossary]].

Conclusions: The following conclusions can be made about a solid.

- It has a fixed shape, fixed volume, and a fixed boundary.
- There are very little **intermolecular** spaces in a solid. Hence, it has a tendency to maintain its shape. This means that it has negligible compressibility.
- It is **rigid**. It may break under force, but it is difficult to change its shape.
- It rarely **diffuses** in another solid. Example- Diffusion of chalk powder on a blackboard. This is the reason why it is difficult to clean (rub) a used blackboard that has not been cleaned for several days.

Whiz Kid

Solids have the following forms.

- **Crystalline**: Calcite (rhombic), fluorite (octahedral) and quartz (hexagonal) are crystalline solids.
- **Polycrystalline**: Metals are polycrystalline solids.
- **Amorphous**: Glass is an amorphous solid.
- **Polymeric**: Natural rubber is a polymeric solid.

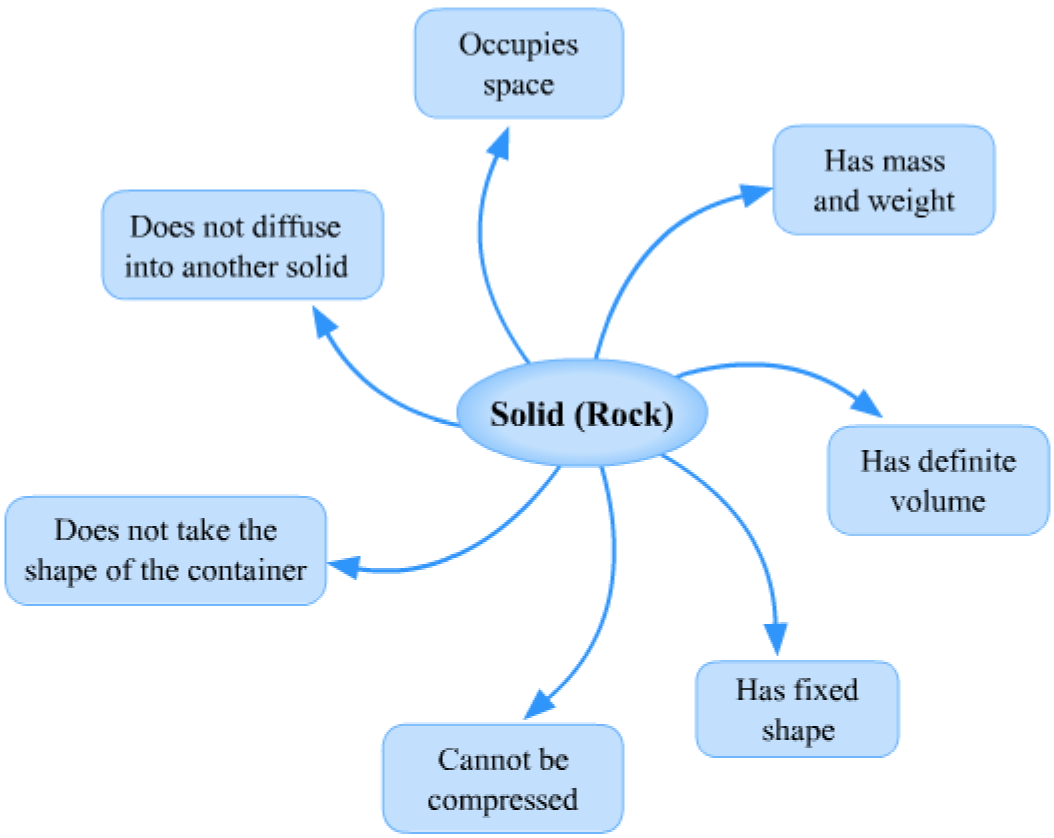
It is possible to stretch certain substances without breaking them. These substances are made up of long chains of atoms bonded together (usually carbon atoms bonded by covalent bonds). These substances are called polymeric substances. This is why the shape of rubber changes when stretched even though it is solid.

Did You Know?

Although sponge is solid, it can be bent and squeezed. Sponge has minute holes on its surface. Air is trapped in these holes. This air is expelled as we press or squeeze sponge. This makes it possible to bend and squeeze sponge.

The Solid State

The following diagram illustrates the properties of a solid.



The Liquid State

Unlike a solid, a liquid has no fixed shape. However, it does have a fixed volume. It takes the shape of the container in which it is kept. For example, water does not have a fixed shape, but its volume is fixed. When a certain volume of water is poured into a container, it takes the shape of the container, but its volume remains the same. On the other hand, a pen (which is a solid) has a fixed shape and volume. A liquid is not rigid, i.e., it flows freely. The intermolecular spaces in a liquid are greater than in case of a solid. Hence, a liquid has more compressibility than a solid. The particles of liquids have more kinetic energy than solid particles and therefore has greater speed than solid particles.

Characteristics of a liquid on the basis of the particle nature of matter

- A liquid does not have a fixed shape. It takes the shape of the container in which it is kept.
- A liquid has a fixed volume.
- It is not rigid, i.e., it flows freely.
- It has more compressibility than a solid. So, it can easily diffuse in other liquids.
- In most cases, the density of a substance in the liquid state is lesser than its density in the solid state.

Usually liquids have lower density than solids, yet ice floats in water. Can you say why?

Ice is lighter than water since a particular mass of ice occupies more space than the same mass of water. In ice, water molecules are closely packed because of the tight bonding between them. This makes ice lighter than water.

Know More

Solids, liquids and gases can diffuse in liquids. The dissolution of salt or sugar in water and the dissolution of ink in water are examples of the same. Gases such as oxygen and carbon dioxide diffuse and dissolve in water bodies. It is because of these gases that aquatic plants and animals are able to survive underwater.

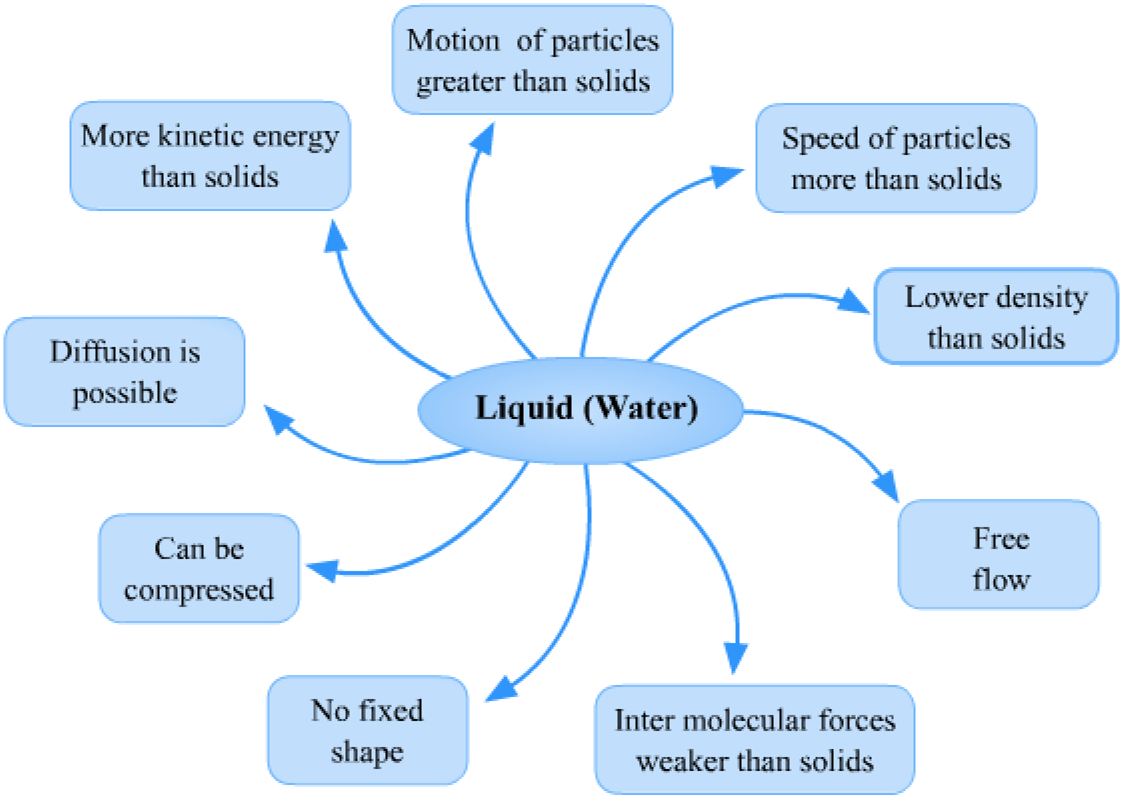
This high rate of diffusion in liquids is because of the fact that a liquid has larger intermolecular spaces.

Did You Know?

Bronze, an **alloy**, expands when its state changes from liquid to solid. This property of bronze is utilized in moulding statues.

The Liquid State

The following diagram illustrates the properties of a liquid.



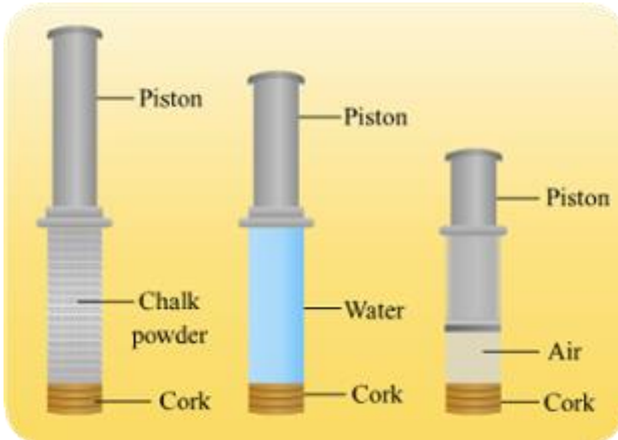
The Gaseous State

A gas neither has a fixed shape nor a fixed volume. Hence, it does not have a fixed boundary. It can flow in all directions and can be easily compressed. In a given space, the number of particles in a gas is lesser than in the case of a solid or a liquid. The constituent particles of a gas show a random motion because of the presence of large spaces between them.

Consequently, the kinetic energy of the particles in a gas is more than in the case of a solid or a liquid. Due to the large distances between the particles, the forces of attraction between them are very low or negligible.

Activity Time

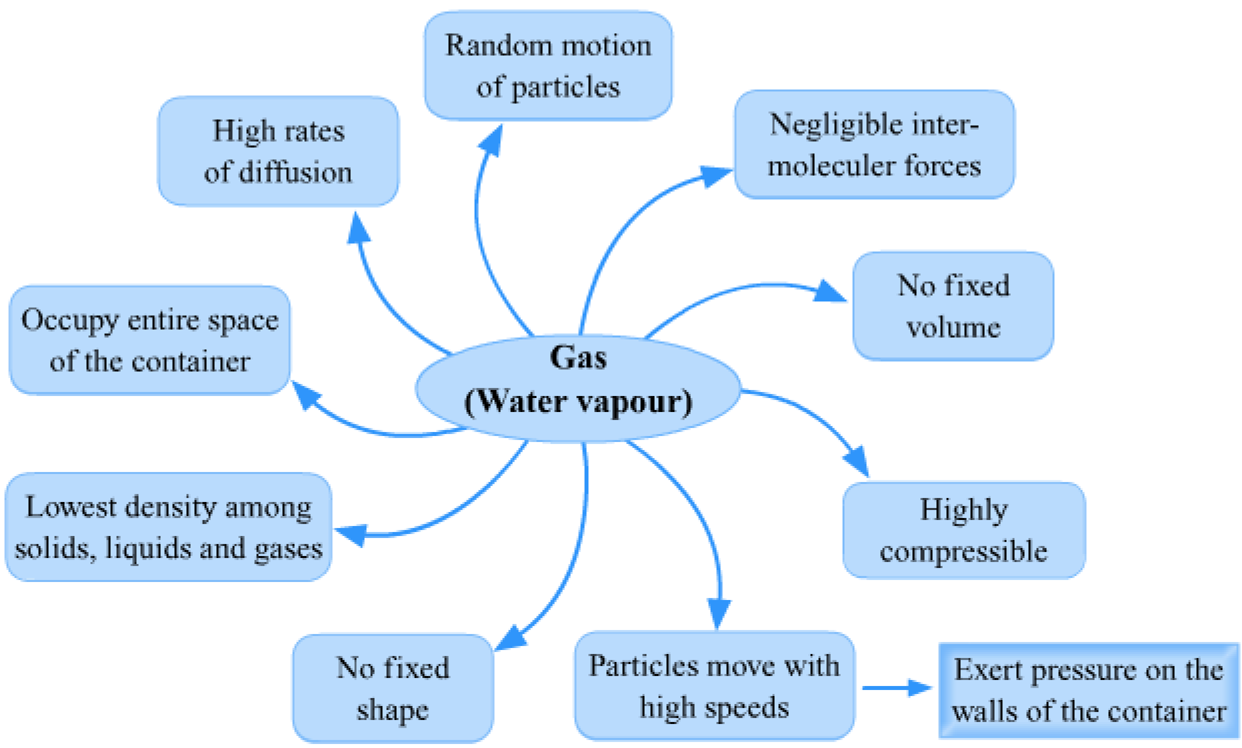
Procedure: Take three 100 mL syringes and remove their pistons. Close the nozzles of the syringes with rubber corks. Fill one syringe with chalk powder and another with water. Now, reinsert the pistons and push them.



Result: The force required to push the pistons of syringes containing chalk powder and water will be greater than that required to push the piston of the syringe containing air.

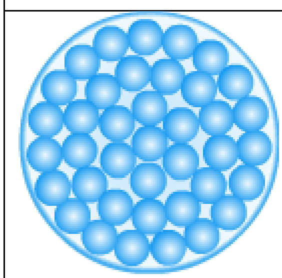
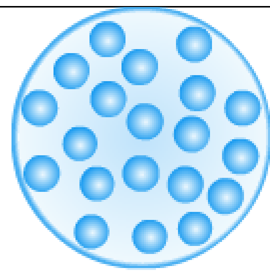
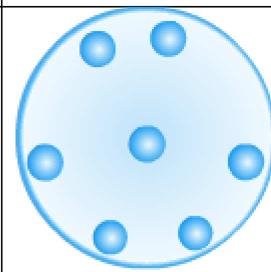
The Gaseous State

The following diagram illustrates the properties of a gas.



Differentiating between the Three States of Matter

Differentiating the Three States of Matter

Solid	Liquid	Gas
Definite shape Occupies space Definite volume Cannot be compressed Rigid Does not diffuse in other solids	No definite shape Occupies space Definite volume Slightly compressible Not rigid Can diffuse in other liquids	No definite shape Occupies space No definite volume Highly compressible Not rigid Can diffuse in other gases
 Solid	 Liquid	 Gas

Solved Examples

Easy

Example 1: **Answer the questions with a ‘Yes’ or a ‘No’ for each of the three states of matter.**

Questions	Solid	Liquid	Gas
Does it occupy space?			
Does it have a definite volume?			
Can it be compressed?			
Does it take the shape of the container enclosing it?			
Can it diffuse in a like state of matter?			

Solution:

Questions	Solid	Liquid	Gas
Does it occupy space?	Yes	Yes	Yes
Does it have a definite volume?	Yes	Yes	No
Can it be compressed?	No	Yes	Yes
Does it take the shape of the container enclosing it?	No	Yes	Yes
Can it diffuse in a like state of matter?	No	Yes	Yes

Differentiating the Three States of Matter

Solved Examples

Easy

Example 2:

Identify the state I’m in.

Object	State
Glass Welding arc Liquid helium Mercury Fog	Bose-Einstein condensate Solid Gas Plasma Liquid

Solution:

i → b; ii → d; iii → a; iv → e; v → c

Medium

Example 3:

Guess who I am.

i) The container I’m placed in does not matter. My shape does not change. I’m _______.

ii) I’m flexible and particles can move with some speed. I’m _______.

iii) I possess highest kinetic energy and my particles move with high speed. I’m _______.

iv) I’m charged and have high temperature. I’m _______.

Solution:

(i) solid

(ii) liquid

(iii) gas

(iv) plasma

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?

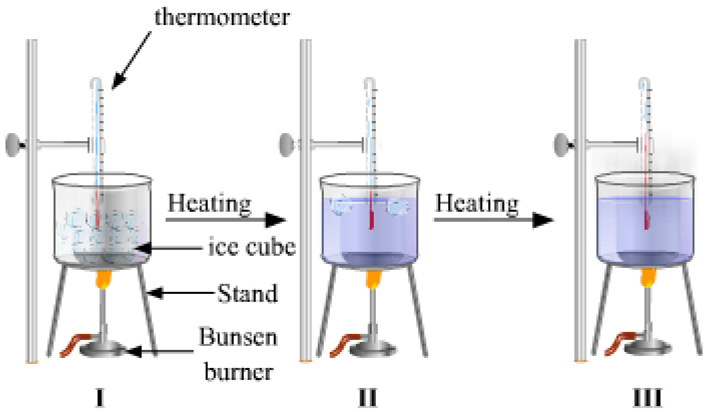
When we open the refrigerator, we see freezing fog. This is nothing but condensed water.

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

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.

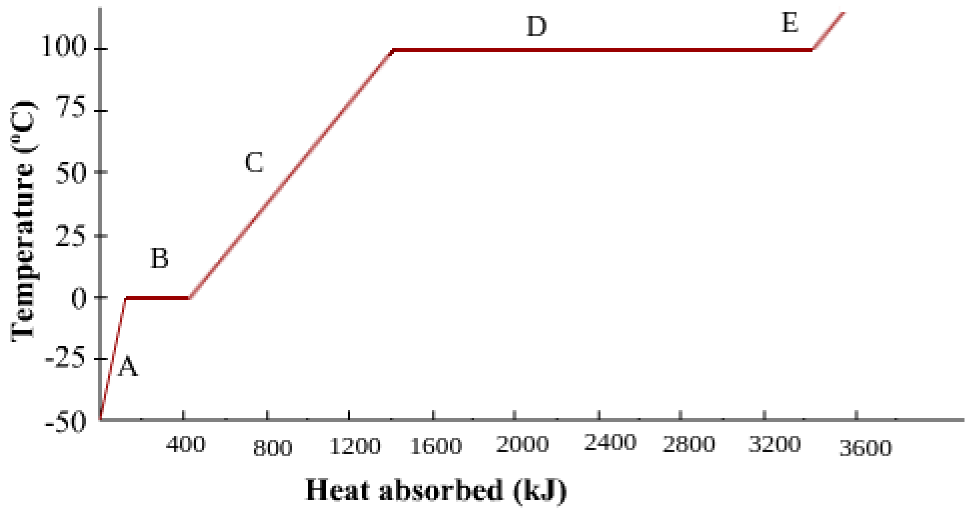
During the conversion of ice into water, the temperature remains constant until all the ice melts into water. The supplied heat is used up for changing water from its solid state to its liquid state. The heat energy is absorbed by the ice without showing any rise in temperature. This heat energy is called **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 −50°C 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.

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?

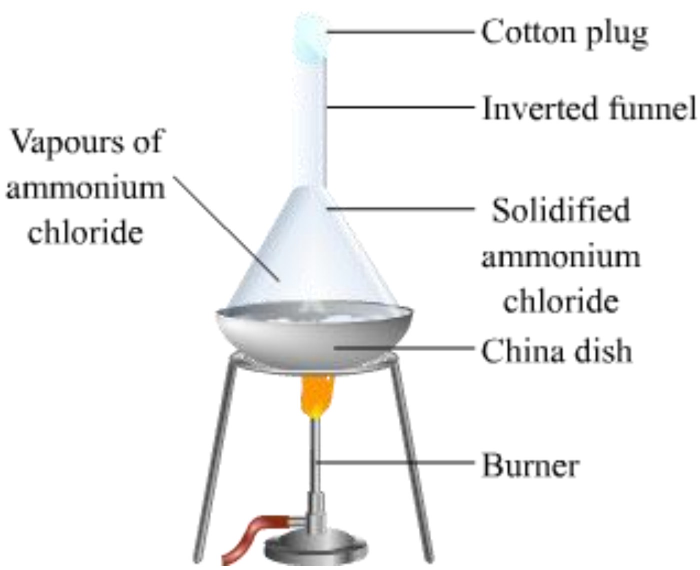
Cool Facts

- 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.

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.

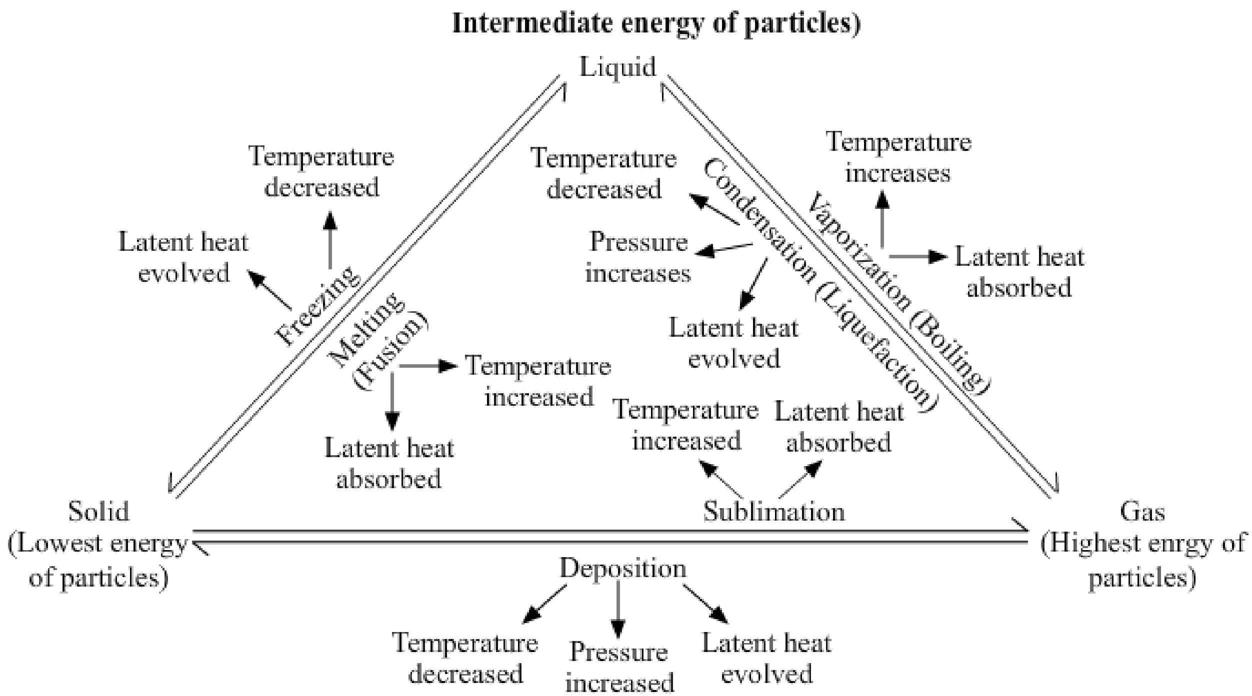
A highly combustible gas is released during the fractional distillation of crude oil. This gas is known as petroleum gas. Petroleum gas is also trapped over the reserves of oil present beneath Earth's crust. Petroleum gas is liquefied by applying high pressure and low temperature. This is known as liquefied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



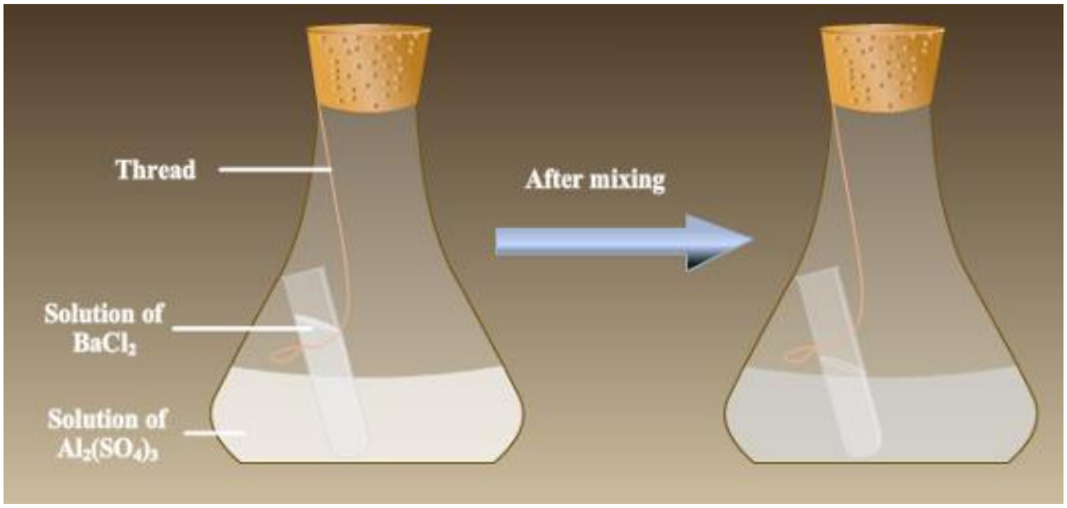
Law of Chemical Combination

Lavoisier and Proust proposed two laws that sought to explain the chemical combinations of elements. These laws are the law of conservation of mass and the law of constant proportions, respectively.

Let us first study about the law of conservation of mass.

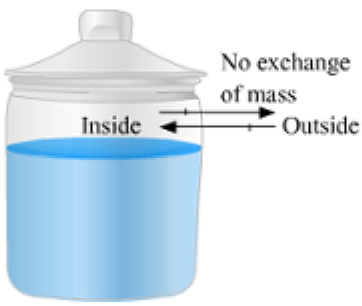
According to this law, '**mass can be neither created nor destroyed.**' In other words, for a chemical reaction taking place in a closed system, the total mass of the reactants is the same as that of the products.

For example, an unmixed solution of barium chloride and aluminium sulphate weighs the same as that of the mixed solution of the two.



Know More

Closed System



A system is said to be closed if there is no exchange of mass across the boundaries of the system and the surroundings. However, it can exchange energy with its surroundings.

Solved Examples

Medium

Example 1:

In a decomposition reaction, 100 g of mercuric oxide—when heated in a closed test tube—decomposes to produce mercury and oxygen gas. If the mass of the produced mercury is 92.6 g, then what is the mass of the produced oxygen?

Solution:

According to the law of conservation of mass:

Total mass of the reactants = Total mass of the products

It is given that:

Mass of the decomposing mercuric oxide = 100 g

Mass of the produced mercury = 92.6 g

Let the mass of the produced oxygen be x.

So, we have:

100 g = 92.6 g + x

$\Rightarrow x = (100 - 92.6)$ g

$\Rightarrow \therefore x = 7.4$ g

Laws of Chemical Combination and Dalton’s Atomic Theory

The law of conservation of mass can be explained using the first and third postulates of Dalton’s atomic theory.

The law of conservation of mass states that mass can be neither created nor destroyed. According to this law, in case of a chemical reaction taking place in a closed system, the total mass of the reactants equals that of the products.

Mass is the amount of matter in something. As per the first postulate of Dalton’s atomic theory, all matter is made up of atoms.

The third postulate of the same theory asserts that atoms can be neither created nor destroyed in a chemical reaction, i.e., the total number of atoms and their mass should remain the same before and after the reaction. This is the same as the law of conservation of mass.